TRACING OF A HYDRAULIC CHANNEL OF A FRIENDLY FISH TURBINE

G. NIÑO DEL RÍO, R. G. RAMIREZ CAMACHO, E. R. SILVA.

Instituto de Engenharia Mecânica, Universidade Federal de Itajubá-UNIFEI

Av. BPS Nº 1.303, Itajubá, MG Brasil.

ge.nino@hotmail.com, ramirez@unifei.edu.br, Edna@yahoo.com.br

ABSTRACT.

This work is based on methodologies in classical design of axial and radial rotors, applying the conservation equations of mass and angular momentum, available in the literature for the develop a preliminary channel design with the information on pressure variations and rotational velocity of rotor. After tracing the primary channel, will be possible obtain the inlet and outlet conditions that allows calculate the (viscous / turbulent) flow field using CFD tools to quantify the hydraulic power and the shaft´s Power of the rotor, in a subsequent stage of the work done in this article.

Keywords: Fish Friendly Turbine, Turbomachinery, Francis Turbine, Nq_A, Logarithmic-Spiral.

INTRODUCTION

Due to necessity and interests over the environment, that have the different nations, about natural sources preservation and the decrease on environment impact for the maintenance of a sustainable development in this matter, different governments and industries that are focused in the hydropower sector generation, have being developed researches about diverse designs for a fish friendly turbine, according with the project requirements that are dependent to the operations conditions existents like the hydraulic heads, the flow capacity among others, to without have a significative reduction on the efficiency in the power generation.
Currently there are numerous turbines operating with high, medium and low hydraulic heads with high efficiencies, many of which cause environmental damages, especially about the injuries caused to the fishes. In this sense it is important, a hydraulic turbine rotors design project, that can reach environmental criteria and standards.

1 METHODOLOGY

For the application of design methodology were had in account the environmental requirements established by (Cook et al., 1997), that are mentioned by Amaral Stephen, in an Alden report in June 2001 and the US. Environmental Protection Agency in 2000 that are mentioned in (Cooke et al 2011), and are presented below:

- 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 should be less than 550 kPa/s,
- The rate of velocity change across a shear zone should not be more than 4.5 m/s per 2.54 mm,
- Shear Stress Indicator 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.

1.2 Classical Techniques of the Radial and Axial Rotors Applied to the Fish Friendly Rotor Design.

For establishment of the dimensions for the fish friendly rotor, was applied the classical one-dimensional technique for determine the specific work, the momentum and the hydraulic power of the rotor for a specific case and operational conditions given.
The operational conditions chosen for the purpose of the generation of the hydraulic channel for a friendly fish turbine, were established, according to the physical criteria above mentioned about the design for a fish friendly turbine and the information obtained from the Final report presented by the Epry U.S. Department of Energy, about the same topic, of Alden laboratory, presented by Dixon D. and Dham R. (2011). Within the chosen parameters were:

- The head hydraulics of 10 m, a medium height water turbine project.
- The peripheral velocity at the inlet taken was u_4=12 m/s, without choking turbine consideration.
- A flow of water for turbine project were established in 28m^3/s.
- β_4 supplementary angle of the relative velocity at the inlet adopted, was 18º.

With these conditions and a low rotational speed of 90 rpm adopted, was determined the diameter at the inlet rotor D_4 =2.55m and the N_{qA}. The outcome indicated by the N_{qA} obtained (N_{qA}= 255), was the corresponding to the Francis rotor's behavior, therefore was chosen the one-dimensional design approach for radial and mixed flow turbomachines (Preliminary dimensions for a Francis turbine) at the inlet of the hydraulic channel.
For the establishment of the dimensions of the cone and the application of one dimensional approach design, were adopted the following geometrical parameters in the eq.1, eq.2 and eq.3:

$$\frac{D_4}{D_{5i}} = 6 \qquad (1)$$

$$D_{5e} = 0.85\ D_4 \qquad (2)$$

Appling these ratios were obtained the rotor dimensions for D_{5i} =0,424 m and the D_{5e}=2,16m. In the same way having in account the data supplied by Sousa and Bran (1969) in the ratio (b_o/D_{5e}) and N_{qA} previously calculated see Fig.1, was obtained the blade height at the inlet of hydraulic channel b_o=0.68 m by the eq.3.

$$\frac{b_o}{D_{5e}} \Rightarrow 0.31 \qquad (3)$$

Posteriorly D_{5e} was changed by the D_{5e} obtained from the blade tracing generation in ICEM CFD®. Having the blade height, was possible by the eq.4 to determine the meridian velocity at the inlet of the channel C_{m4}=5.15 m/s. and after all components velocities triangles at the inlet,

$$Q = C_{m4}\pi D_{4m} b_o \quad \therefore \quad C_{m4} = Q / \pi D_{4m} b_o \qquad (4)$$

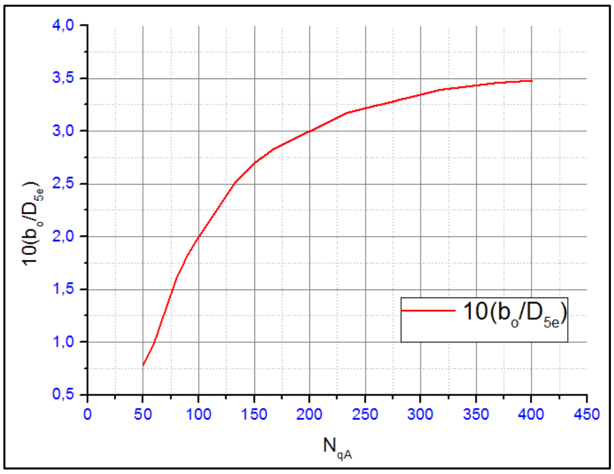

Figure 1-Elements of preliminary design of Francis rotors $10(b_o /D_{5e})$ vs. N_{qA}.
(Sousa and Bran.,1969).

The results obtained by the determination of the velocities at inlet are showed below in the eq.5, eq.6, eq.7, eq.8 and also the α_4 angle at the inlet in the eq.9 respectively. In the same way is showed the configuration of velocities triangle at the inlet in the Figure 2.

$$w_4 = \frac{c_{m4}}{sin\beta_4} \Rightarrow 16.67 m/s \tag{5}$$

$$w_{u4} = \frac{c_{m4}}{cos\beta_4} \Rightarrow 15.86 m/s \tag{6}$$

$$c_{u4} = w_{u4} + u_4 \Rightarrow 27.86 m/s \tag{7}$$

$$\alpha_4 = tan\,g^{-1}\left(\frac{c_{m4}}{c_{u4}}\right) \Rightarrow 10{,}48° \tag{8}$$

$$c_4 = \sqrt{u_4^2 + w_4^2 - 2u_4 w_4 cos\beta_4} \Rightarrow 28{,}33 m/s \tag{9}$$

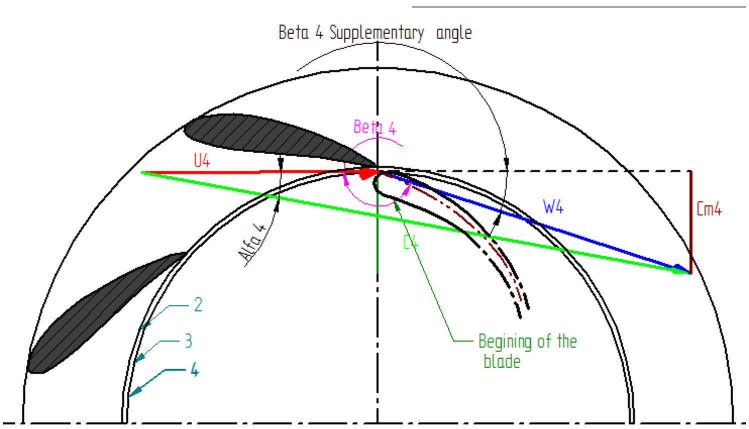

Figure 2- Schematic velocity triangles at the rotor inlet.

For matters of continuity in the development and the narrow relationship among the velocities triangle at the rotor outlet and the axial machine approach used with the application of the free vortex potential to improve the specific energy of turbine's rotor, will be commented simultaneously with the tracing of the blade's generation.

2 TRACING OF THE BLADE'S GENETATION

In the development of a tracing of a hydraulic channel for a fish friendly fish turbine, was taken in account a conical rotor form, that has a smoothed curve revolution's profile (see Fig.3), with which, allows produce a significative variation on the momentum, due to the great change of the direction of the flow throughout the rotor turbine.

For the tracing generation of the channel's tracing were used a logarithm spiral in Cartesian coordinates represented by the eq.10, in the elaboration of the rotor's hub and the blade trajectory throughout it. (See Fig. 3). Where the beta angle is the angle of the relative velocity at the rotor inlet, and theta is the rotational sweep along the helix trajectory in radians.

$$r = \left(r_4 e^{(\tan\beta)\theta} \cos\theta ; r_4 e^{(\tan\beta)\theta} \sin\theta \right) \qquad (10)$$

With respect to the coordinates in the *z* axis, were generated in base of the determination of a variable pitch obtained, derived from the multiplication of the intervals of the same height of the helix for the different radius r and a percentage rate's of increment and decrement.

The imposed design conditions were established as a radial turbo machine at inlet of the channel, and an axial turbo machine's behavior approach at the outlet. For the dimensions establishment, were used a one-dimensional approach of design for a radial and mixed flow turbomachine rotor at the inlet, and a one-dimensional approach of design for an axial flow turbomachine rotor at the outlet. With which allows produce a significative variation on the momentum, due to the great change of the direction of the flow throughout the rotor turbine.

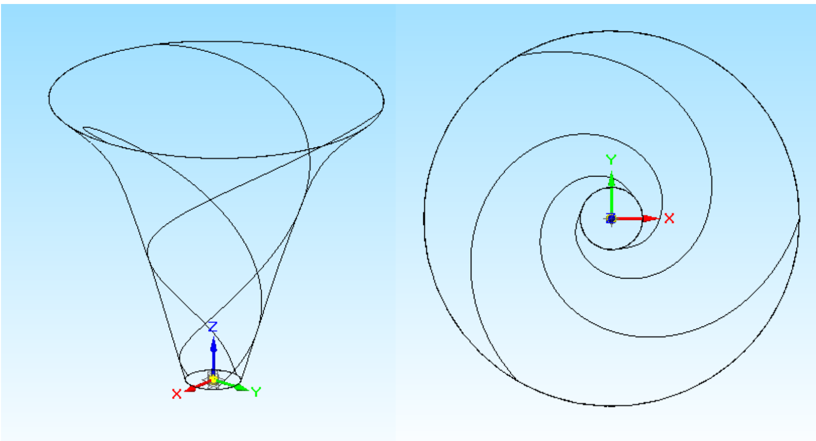

Figure 3-Rotor cone geometry elaborated with a logarithmic spiral curve.

After have been done the rotor cone geometry and the principal helices to generate the profile of the blade throughout the cone, with tools proportioned by ICEM CFD®, was done the projection of the points, that conforms the principal curves in the *z* axis, with the blade's height b_o previously established. Subsequently the projected points of the curves in the z axis were displaced with an angular increment of 9°, varying of 0° until 90° with respect z axis, doing this variation from the

first points of the curves until its last points, having as rotation points, the points that conforms the principal curves, that have been used for the rotor cone construction.
In the Fig 4, are showed the rotor geometry with its blades constructed. At the same time are showed the rest of the components (shroud, draft tube inlet, among others), that conforms the set of the turbine, that will be used in a posterior analysis in CFD. (See Fig.5).

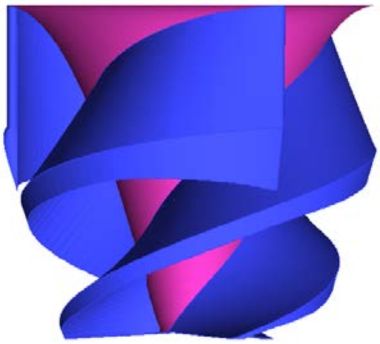

Figure 4- Rotor and blade geometry constructed

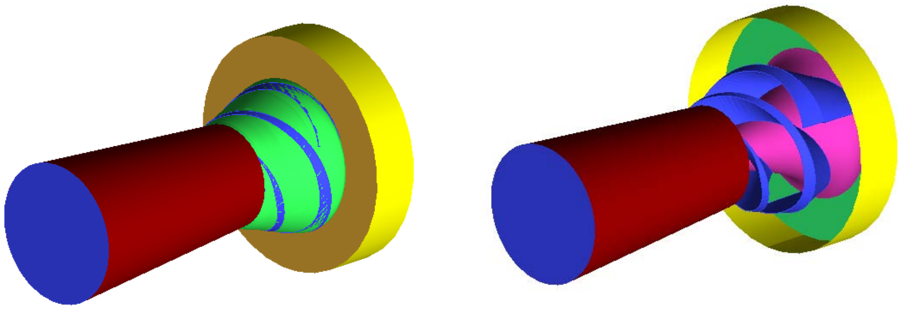

Figure 5- Components of the set of the turbine for its posterior analysis in CFD

Having the rotor geometry generated, is measured the D_{5e}, due its variation through its construction, being the new value of D_{5e}= 1.752m. Posteriorly was calculated the meridional velocity C_{m5} at the rotor outlet with the eq.11.

$$c_{m5} = \frac{4Q}{\pi\left(D_{5e}^2 - D_{i5}^2\right)} \qquad (11)$$

Due to the principal necessity to improve the specific energy in the rotor turbine, is necessary to apply two conditions: a) the free vortex potential at the trailing edge rotor, $dY_{blade} = 0$, $c_m = cte$ b) radial equilibrium $\frac{dp}{dr} = \rho \frac{c_u^2}{r}$. For doing this, the meridional velocity c_{m5} must be constant in its magnitude across all transversal outlet area.

In the Table 1 are showed the different refinement angles β_5 and $w_{5,}$ calculated to forcing the free vortex at the rotor's outlet for the different positions at the rotor. In the same way are showed the actual values of the β_5, that has the rotor geometry proposed and have to be modified by the calculated refinement angles β_5 for the free vortex generation.

Table 1: Angles and relative velocity corrected in the trailing edge

	$\beta_{5,}$ angle measured in trailing edge	β_5 angle modified in the trailing edge (dY_{blade}=0 ; rc_u=cte)	w_5, relative velocity corrected in the trailing edge	C_5=C_{m5} in m/s by application of the free vortex potential
Hub	65.25^o	80.79 ^{o}	12.50 m/s	12.34 m/s
Blade half	36.28^o	75.78 ^{o}	12.73 m/s	12.34 m/s
Blade tip	21.67^o	56.22 ^{o}	14.85 m/s	12.34 m/s

Therefore below are presented the expressions for the blade infinite specific work, blade infinite hydraulic power and the blade infinite momentum, taken in account the approach for an axial rotor at the outlet in the eq.12, eq. 13, and eq. 14,

$$Y_{blade\ \infty} = u_4 c_{u4}\ ; \quad c_{u5}=0, \tag{12}$$

$$P_{blade\infty} = \dot{m} Y_{blade\infty} \Rightarrow \rho \dot{V} Y_{blade\infty} \tag{13}$$

$$M_{blade\infty} = \frac{P_{blade\infty}}{\omega} \tag{14}$$

Values according to the classical theory for the design of hydraulic turbomachinery considering infinite number of blades, inviscid flow, it has been. $Y_{blade\infty}$=334.29J/kg; $P_{hblade\infty}$= 9.341 MW and $M_{blade\infty}$= 16.519kN m.

4. CONCLUSIONS

In base in the classical methodology for the rotors projects of hydraulic flow machines, specifically in Francis turbines, is possible to obtain a tracing for a Fish Friendly Turbine, that attends the pressure and velocity restrictions that the fishes could support (Cook et al., 1997 and Cooke et al 2011), with the objective of reduces the mortality rate among the fishes. Also, were developed a velocities analysis in the mean line between the inlet and rotor outlet. In the trailing edge was applied the free vortex potential condition with objective to maximize the angular moment quantified through the specific work.

In addition, future work will be defined after the channel geometry. It is possible to calculate the flow field using CFD (viscous and turbulent flow) tools in order to determine the hydraulic efficiency. Optimization with conflicting objectives are considered in order to minimize the rate of fish mortality and increase the power shaft

REFERENCES

1. Amaral S., 2001, Turbine Passage Survival Estimates for the Dunvegan Hydroelectric Project, Alden Research Laboratory Environmental Services. PDF. 30 Shrewsbury Street Holden, MA 01520.

2. Bran R., Souza Z., 1969, Máquinas de Fluxo Turbinas Bombas Ventiladores, Editorial ao Livro Técnico S.A. Rio de Janeiro.

3. Cooke S., Hatry C., Hasler C., Smokorowski K., 2011, Literature Review, Synthesis and Proposed Guidelines Related to the Biological Evaluation of “Fish Friendly” Very Low Head

Turbine Technology in Canada.PDF, Fish Ecology and Conservation Physiology Laboratory Department of Biology and Institute of Environmental Science Carleton University Canada and Great Lakes Laboratory for Fisheries and Aquatic Sciences Fisheries and Oceans Canada.

4. Dixon D., Dham R., 2011, “Fish Friendly” Hydropower Turbine Development and Deployment Alden Turbine Preliminary Engineering and Model Testing, Final report. Electric Power Research Institute and US. Department of Energy, California. USA.