

Blade Polymeric Material Study of a Cross-Flow Water Turbine Runner

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Although Romania has a consistent hydro energetic potential, till now is valued just approximate 30 percent of it. On the big rivers there are already installed high power hydro plants, but a lot of small and medium rivers are not valued energetically. Installing a new high power hydro plant tends to affect the zone, being necessary a lot of changes in the environment. The Cross-Flow hydraulic turbines don't need very complex hydro settlements, being very suitable for small and medium power hydro plants. Also a quite big potential in the use this type of hydraulic machines is the energy recovery in the water treatment and sewage plants. The turbine's blades surfaces enters in contact with the pressurized water jet. The water jet creates a hydrodynamic force that tends to stress the blade. Mainly the Cross-flow turbine blades are made from steel. This article presents the hydrodynamic design and the possibility of using new polymeric material Delrin ®AF for the Cross-Flow turbine runner blades, together with the stress analysis.

Keywords: polymeric material, blade design, Cross-Flow turbine runner, Von Misses analysis

The Cross-Flow water turbine [1-5] is an action type turbine, having a cylindrical runner mainly, composed from two discs and curved blades flushed in a cylindrical ring. The water enters the runner through a wicket gate, which drives it such as at entrance the attack angle is constant. The water which gets out from the nozzle, passes through the runner blades two times, giving 2/3 of the hydraulic energy at the first passing and 1/3 on the second one. In figure 1 is presented a vertical section through a Cross-Flow runner and the water flow path inside it.

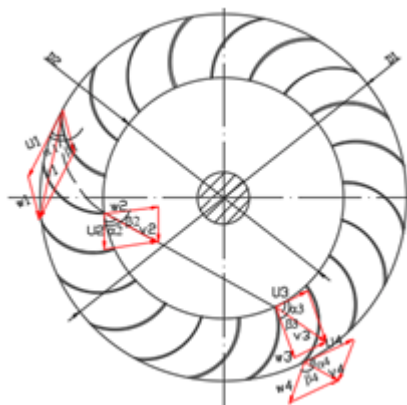


Fig.1. Vertical section through a Cross-Flow turbine runner

Generally the Cross-Flow turbine blades are circle arcs with constant width. The variable thickness blade has the advantage of a smoothly modification of the inter blade channel. The blade shape was designed using O. Popa method [6], the geometry being generated using a trigonometrical 6th grade polynomial, (fig. 2). The sharp

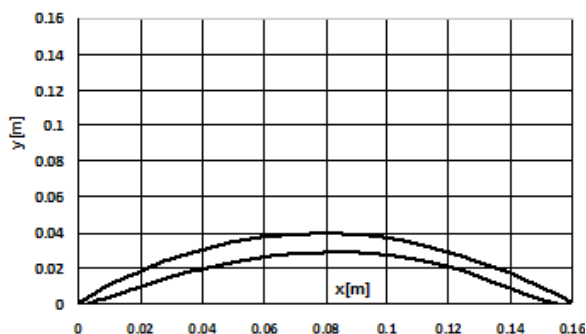


Fig.2. Cross-Flow turbine blade with variable thickness

blade edge ensures with minimal losses the stream distribution at runner inlet. Although with classic machining was quite difficult and expensive to make the shape of the blade, the new methods and materials make this possible in quite an easy manor. Usually, the Cross-Flow turbine blades are made from steel. The development of the new polymeric materials, and of the new technologies, make possible the implementation of these two in the Cross-Flow runners and blades manufacturing.

This paper presents the hydro-dynamic blade design and a study from strength of materials point of view of some suitable polymeric materials class for the turbine blades.

The Cross-Flow turbine hydrodynamic runner and blade sizing

The analysed blade is intended to be used for a Cross-Flow turbine with a head of $H=40$ m and a volumetric flow rate of $Q=1.8$ m³/s. The stereo-mechanical power of the turbine is:

$$P_s = \rho g Q H_T \eta_T \quad (1)$$

in which it is assumed an efficiency $\eta_T=0.8$, water density $\rho=1000$ kg/m³ and gravitational acceleration $g=9.8065$ m/s². The speed of rotation of the hydraulic turbine's runner is selected between the synchronization speeds with a.c. frequency 50 Hz namely:

$$n = \frac{3000}{pp} [\text{rev/min}], \quad n_s = n \frac{\sqrt{P_s [kW]}}{H_T^{5/4}} \quad (2)$$

in which $pp=\overline{1, N}$ are the pole pairs of the electric generator. The specific speeds for the Cross-Flow hydraulic turbines are $n_s=50...150$.

Runner diameter is:

$$D_1 = \frac{n_{11} \sqrt{H_T}}{n} [\text{m}], \quad n_{11} = 40 \text{ rev/min} \quad (3)$$

Absolute flow velocity at the entrance in the runner:

$$v_1 = k_{v1} \sqrt{2gH_T} [\text{m/s}] \quad (4)$$

where $k_{v1}=0.98$ depends on the nozzle hydrodynamics. Runner tangential velocity is:

$$u_1 = \frac{\pi D_1 n}{60} [\text{m/s}] \quad (5)$$

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Absolute velocity angle is:

$$\alpha_1 = \alpha \tan \sqrt{\frac{v_1^2 - 4u_1^2}{2u_1}} \quad (6)$$

Runner angles are:

$$\beta_4 = \alpha \tan(2 \tan \alpha_1) \quad (7)$$

$\beta_1 = 180^\circ - \beta_4 = 150^\circ$, $\beta_4 = 30^\circ$ also it is assumed:

$$\beta_2 = 90^\circ = \beta_3 \quad (8)$$

Inner runner diameter was obtained through an iterative procedure

$$D_2 = D_1 \sqrt{\frac{-\sin^2 \beta_4 + \sqrt{\sin^4 \beta_4 + 4 \frac{\sin^2 \beta_1}{\sin^2 \beta_2} \cos^2 \beta_4}}{2 \cos^2 \beta_4}} \quad (9)$$

The relative velocities are:

$$w_1 = -\frac{v_1 \cos \alpha_1}{2 \cos \beta_1} \quad w_2 = w_1 \frac{D_1 \sin \beta_1}{D_2 \sin \beta_2} \quad (10)$$

The literature gives different formulas for the turbine hydraulic efficiency. So it is accepted:

$$\eta_{hT} = 0.887 - \frac{D_1}{H_T} 0.717 \quad (11)$$

So we consider acceptable the estimated overall efficiency of the cross-flow hydraulic turbine $\eta_T = 0.8$. The blades number after an empirical formula: $z = 4 \times \text{INT}(10 \cdot D_1 - 1) = 24$. The transport velocity by the inner diameter of the runner:

$$u_2 = u_1 \frac{D_2}{D_1} [\text{m/s}] \quad (12)$$

The flow angle here is:

$$\alpha_2 = \alpha \tan \frac{w_2 \sin \beta_2}{u_2 - w_2 \cos \beta_2} [\text{rad}] \quad \varepsilon = 2\alpha_2 \quad (13)$$

$$v_2 = \frac{u_2 - w_2 \cos \beta_2}{\cos \alpha_2} [\text{m/s}] \quad (14)$$

Runner width

$$b_r = \frac{Q}{k \cdot k_{v1} \cdot D_1 \sqrt{2gH_T}} + 0.02 [\text{m}], \quad k=0.1 \quad (15)$$

The Cross-Flow turbine runner has the main geometric sizes $D_1 = 0.76$ m, $D_2 = 0.44$ m and the width $L = 0.884$ m. The turbine blade geometry has been generated transposing the circles network in an airfoils network, (fig. 3).

The network characteristics results from the singularization of the network, obtaining the coefficients of approximation trigonometric polynomial. The blade geometry was approximated through a 6 order trigonometric polynomial. The blade coordinates are:

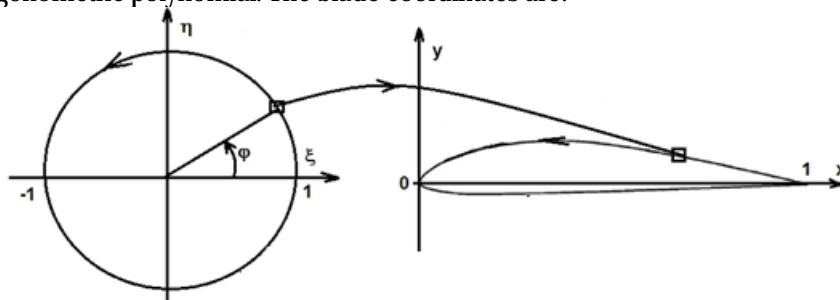


Fig. 3. Conformal mapping of the unit circle external domain into the external domain of an airfoil

n	0	1	2	3	4	5	6
a_n	0.205	-0.002476	-0.108	0.0003333	0.0045	0.002143	0.001
b_n	0	0.036	-0.002309	0.003667	0.002887	0.001224	0

Table 1

$$X = \frac{1}{2}(1 + \cos \varphi), \quad Y = \frac{a_0}{2} + \sum_{n=1}^N [a_n \cos(n\varphi) + b_n \sin(n\varphi)] \quad (16)$$

$Y = Y(\varphi)$, $\varphi \in [0, 2\pi]$. For $N=6$ coefficients, is considered

$\Delta\varphi = \frac{\pi}{6}$. In order to obtain the trigonometrical polynomial coefficients are considered 12 values for Y , $p = 0, 1, 2, \dots, (2N-1)$. With these values are calculated the coefficients of the trigonometrical polynomial:

$$a_n = \frac{1}{N} \sum_{p=0}^{2N-1} Y_p \cos\left(p \frac{n\pi}{N}\right), \quad b_n = \frac{1}{N} \sum_{p=0}^{2N-1} Y_p \sin\left(p \frac{n\pi}{N}\right) \quad (17)$$

For the studied blade, the trigonometrical polynomial coefficients are presented in table 1.

Force on blade calculation

In this case we analyzed the hardest condition, this was when the runner is completely blocked and on it acts the whole force of the water jet.

As it is known from the fluid mechanics theory the force of the jet is:

$$F_j = \rho Q \Delta v \quad (18)$$

where: $\rho = 1000$ [kg/m³] is the water density, $Q = 1.8$ [m³/s] is the volumetric flow rate, $\Delta v = 28$ [m/s] is the absolute velocity variation (we considered the most hard condition, when the velocity variation is equal with the velocity from the pipe). As we know from the geometry the jet attacks three blade channels, it means that for one blade force calculation we must consider the formula:

$$F_{jb} = \rho \frac{Q}{3} \Delta v \quad (19)$$

After calculus results that $F_{jb} = 16800$ N.

Material study

In many mechanical solutions, the thermoplastic resins are a very good alternative solution for the conventional materials [7-12]. From this material class, the acetal homo polymer present a combination of physical and mechanical properties which permits them to compete easy with metals. The acetals are formed from a group of aldehyde or ketone which reacts nucleophile with alcohol in the presence of an acid catalyst [13]. The acetal ensures a high resistance and rigidity associated with a good dimensional stability and machinability. Also it is characterized through a low friction coefficient and good wear properties, especially in wet medium. The acetal absorbs minimal humidity quantities, keeping it's properties constants in a big variety of media. The low water absorption confers an excellent dimensional stability for the parts machined with high precision. From acetals homo polymers Delrin® AF gain a large scale recognition because of it's reliability and performance in many domains of

mechanical engineering [14]. From producer datasheet Delrin®AF presents the following mechanical properties given in table 2.

Table 2
DELIN®AF MATERIAL MECHANICAL PROPERTIES [8]

Material	Modulus of elasticity, E [MPa]	Tensile strength σ_r [MPa]	Elongation at break A [%]
Delrin®AF	3200	70	15

The finite element simulation

Taking into account the blade geometry and the load resulted from hydro dynamic calculus, (fig. 4), it has been made a numerical analysis of the blade stress and strain. The material is defined elastic linear with properties similar with the acetal Delrin®AF. The blade support conditions have been established according to it's mounting solution in the runner, considering also two intermediary supports, (fig. 5).

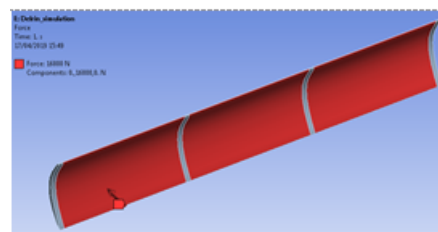


Fig. 4. The hydro dynamic force applied on blade inner surface

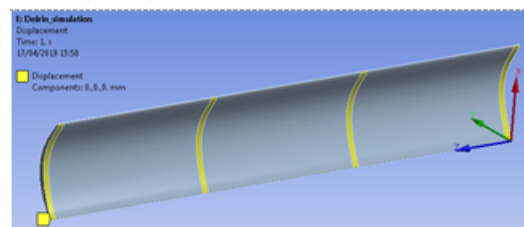


Fig. 5. Supports applied on both blade surfaces

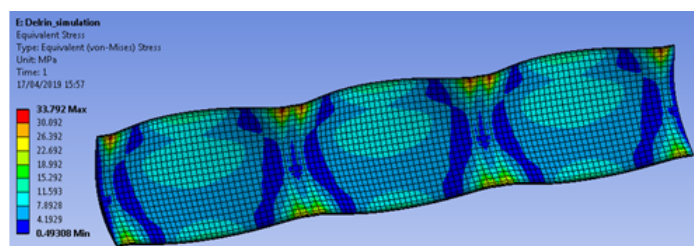


Fig. 6. The equivalent Von Mises stress distribution

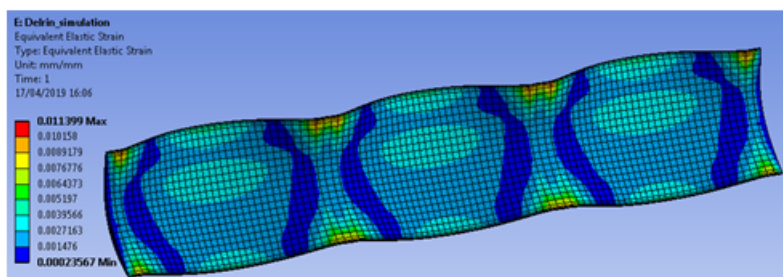


Fig. 7. The equivalent Von Mises strain field

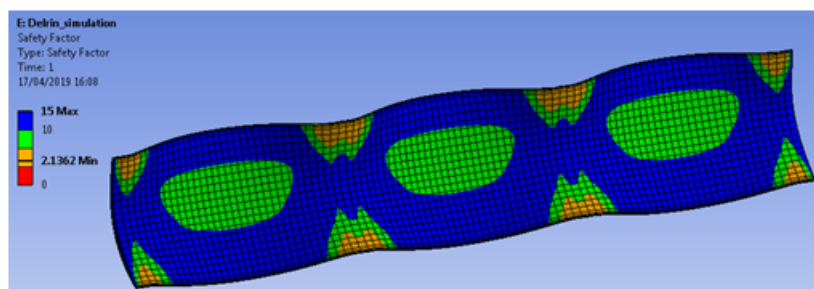


Fig. 8. The safety factor distribution

The figure 6 and 7 presents the Von-Mises equivalent stress and strain distributions for the considered loading case. As a result of blade geometry and deformation modulus can be seen stress concentrations in the blade upper part, nearby the supports. However these stress concentrations give a relatively good safety coefficient accepted in the design standards of these components, (fig. 8).

The use of thermoplastic materials in Cross-Flow hydraulic turbines blades and runners has many advantages as: good mechanical resistance, easy machining because of lower density than metals, the hydraulic machine components having a reduced weight. For the studied case the blade volume is de 0.00127652 m³. In the case in which the blade will be machined from steel, for a medium steel density of 7850 kg/m³, will give a blade mass of 10 kg. If Delrin material is used, having the density of 1420 kg/m³, the blade will have the mass of 1.812 kg, being almost 5.5 times lighter.

Conclusions

The Cross-Flow turbines with polymeric material runners, can be used as energy recovering units in water treatment plants and also in sewage plants, being suitable for relatively small heads and variable flows.

The analytical knowledge of the geometry is useful for the future analysis of the blade behavior. The O. Popa method permits the establishment of any blade design using trigonometrical polynomials.

In order to analyze the blade it is necessary to size the turbine runner, knowing mainly the geometric parameters, the sizing method is given in the presented paper.

The use of new materials in the accomplishment of Cross-Flow hydraulic turbines components, permits the utilization of these machines for energy production also with dirty waters.

From variable thickness blade analysis designed for a Cross-Flow turbine, is concluded that the thermoplastic

material Delrin, presents advantages which recommends it to be used for this turbine type runners.

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