CONSTRUCTION OF A SMALL-SCALE PROTOTYPE OF HYDROKINETIC POWER GENERATION APPLIED TO EDUCATION IN MECHANICAL ENGINEERING

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Abstract. *This work presents the fundamentals of hydrokinetic energy to undergraduates in mechanical engineering, which is a important step in the dissemination of knowledge about renewable energy in Higher Education Institutions in the Country. In this paper is discussed about the construction of a small-scale prototype of hydrokinetic turbine, whose goal is to generate electricity, disseminating the operation of this type of device to undergraduate students. This mechanism consists of a rotor, spindle, pulleys, belt and electric generator, that converts kinetic water energy into electric energy usable for activating devices called LED's (Light Emitting Diode) installed in an electrical circuit. The system is coupled to a tank in which flows pumped water that in contact with the rotor blades spins it, starting the process of energy conversion, demonstrating clearly the energy generation.*

Keywords*: hydrokinetic turbine, renewable energy, fluid mechanics*

1. INTRODUCTION

A major concern that the global society is facing is with respect to the environmental impacts of energy generation, and how to develop new technologies that demand for renewable sources will have greater participation in global energy production. Environmental problems as global warming is associated with increasing emissions of pollutants from the combustion of fossil fuels. It is therefore important to invest in developing technologies for power conversion, besides, is of fundamental importance that the engineering student is placed in this context, it is necessary that the university enter one of these energy transformations in society.

In response to this need the use of technologies such as hydrokinetic turbine is shown as an interesting means of generating energy. Such technology is renewable and nonpolluting. Its operation uses the kinetic energy of water and converts it into electrical energy by means of appropriate equipment. Also, can work in a variety of rivers, from small to large, without interrupting the natural flow of water. The feasibility of its application depends on the characteristics of studies presented by the rivers of waters such as speed, depth, continuity, presence of debris and more.

The disclosure of the existence of alternative energy with less damage to the environment appears as a key step in the use and development of new technologies, especially in the Amazon region, where many rivers with good potential hydrokinetic. Upon graduation in mechanical engineering, the dissemination of this knowledge allows students to better understand the mechanism of operation and also develop improvements to the subject matter. This disclosure is not just the graduates, the work is also presented to high school students in the region in an attempt to increase the interest of young people on the subject.

This work deals with the construction of a hydrokinetic system in a small-scale with an educational purpose to present to the graduate application of knowledge in various areas of engineering and power generation with the use of renewable natural resources and low environmental impact . The system includes a model with a hydrokinetic turbine prototype submerged in a tank containing water. Water is pumped into the tank in order to make the recycling of it, printing speed to maintain fluid and the fluid volume constant, and is flexible in its assembly and disassembly, where the student can get an idea of maintaining rotor, calculating loss of load and power generation to meet small isolated communities.

2. PROJECT OF THE HYDROKINETIC SYSTEM

2.1. PROJECT AND FUNCINES OF THE STAND

The process of awareness of the use of renewable energy can be optimized through the use of didactic and pedagogical means. To this end it is planned to construct a model which is represented in a village with the electricity supply coming from a hydrokinetic turbine.

The stand described here aims to present an application of hydrokinetic system through a small-scale prototype that uses the concepts of real installations. Through visualization of the prototype circuit and running the target audience will be able to gain a better understanding of the operation of such a mechanism of energy conversion.

The operation of the mechanism is represented by figure 1, where part of the kinetic energy supplied by the pump fluid is used by the prototype to be converted into electric power feeding circuit components present along the model and another part that remains in the fluid.

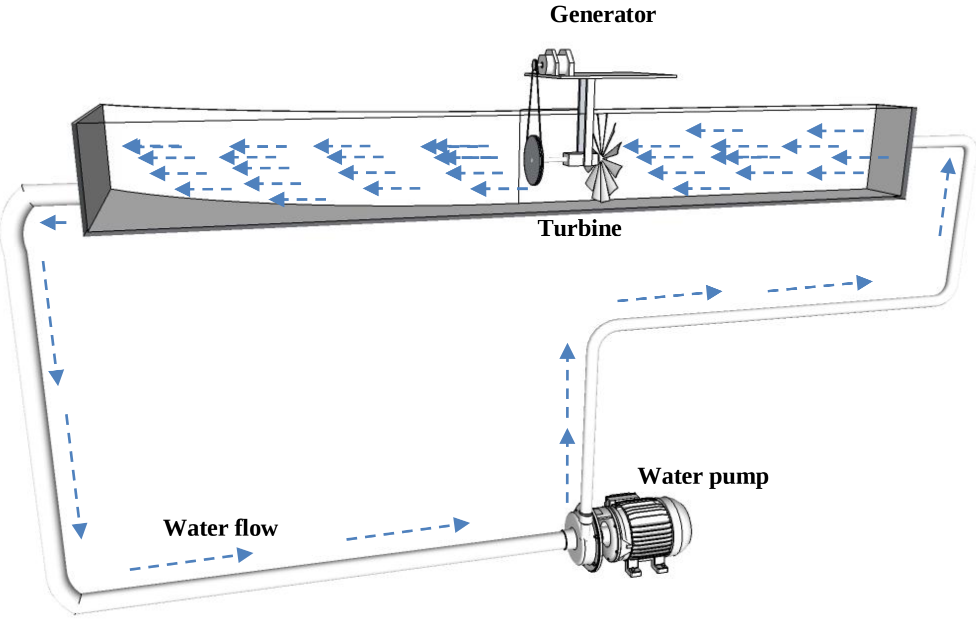

Figure 1. Illustration of the hydrokinetic system.

The construction of the stand was based on the designs shown in Figure 2 and studies related to power generation through hydrokinetic turbines. The 3D renderings show the stand, the model and prototype.

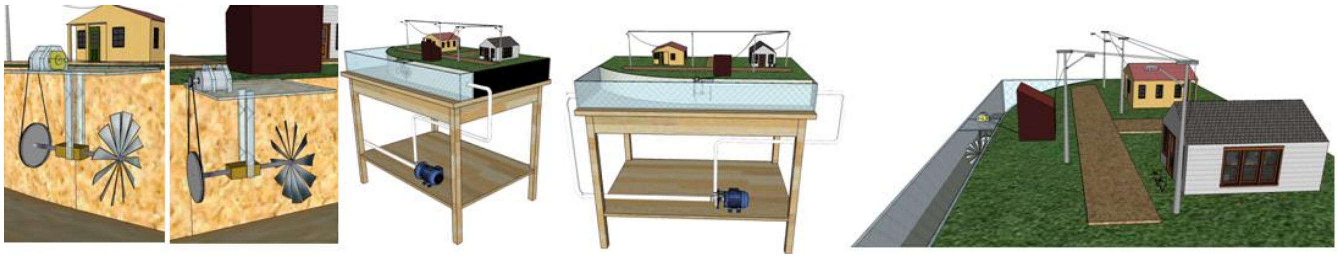

Figure 2. 3D drawings in the project fase.

The stand has the function behave the three main parts of the project: the hydraulic system, the prototype power generation and the model with the small town as shown in Figure 3. The project facilitates the understanding of important issues involved in engineering, it correlates areas like hydraulics, materials, electronics, turbomachinery, power transmission, fluid mechanics, etc..

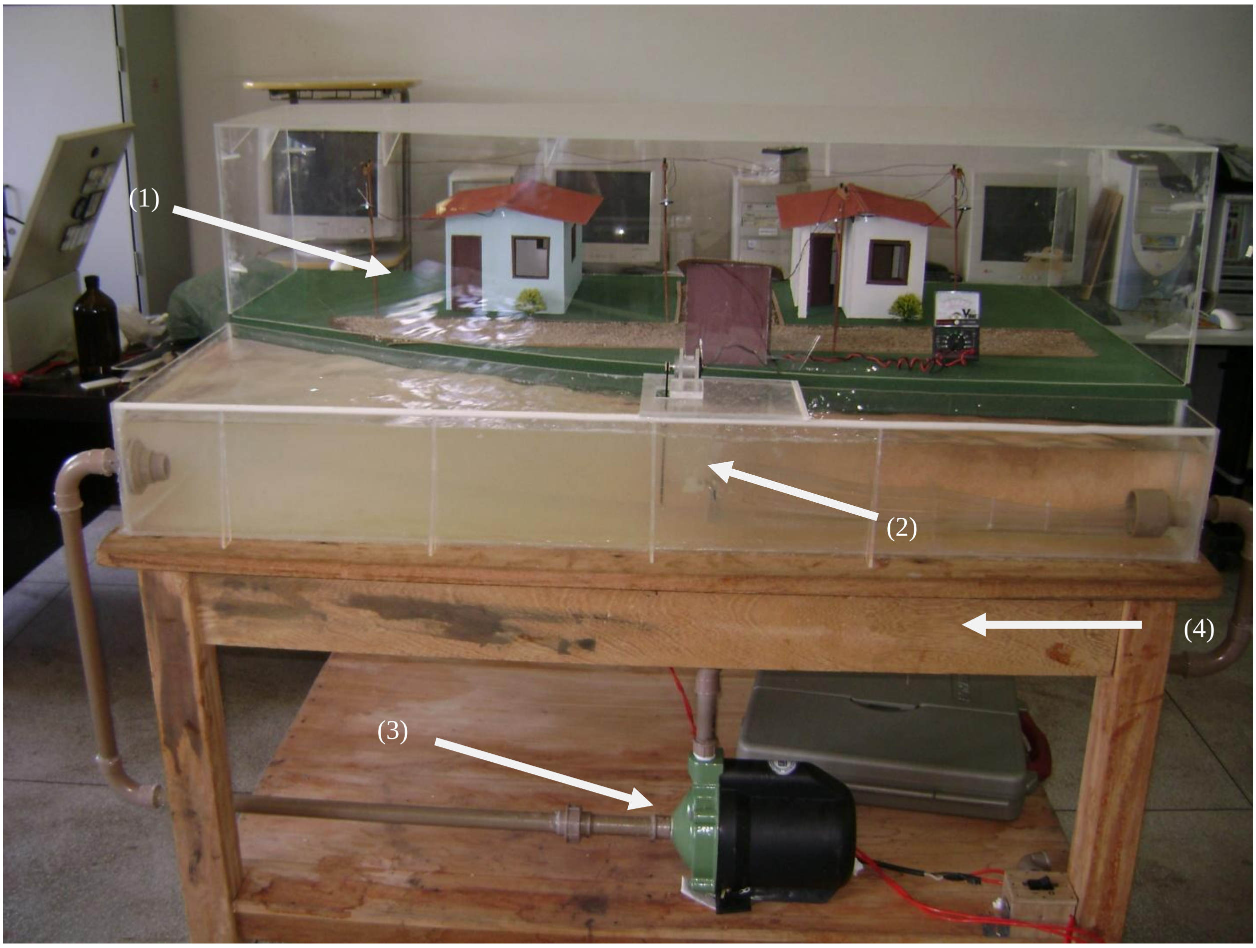

Figure 3. Maquete (1), tank (2), hydraulic system (3), stand (4)

2.2. PROJECT AND FUNCINES OF THE MODEL

The model simulates a small community geographically isolated from the vicinity of a river, where the energy supply of the local utility is not available. It is known that about 85% of small villages located within the state of Amazonas along the trough's eastern Amazon River are reasonably met by the local utility by using diesel-electric and the remaining 15% are in regions that disable this service (IBGE, 1992). This aspect shows that there is a need to develop new technologies that can serve isolated communities, and reduce the environmental impacts promoted by existing fossil fuels in many small villages in the Amazon region.

Therefore, in this paper, we describe a hydrokinetic system that simulates small-scale power generation using resources of their own rivers. In this case, the model used is supplied by the hydrokinetic system installed in the center of the tank. The images of the construction and operation of the model shown in Figure 4. The components were designed on a scale of 1:20. The electrical circuit of the city has nine white LEDs of high brightness connected in parallel to a continuous medium voltage 2.8V and current of 0.7mA DC supplied by the generator. The data are supplied by a voltage analog meter installed in the model, figure 3. The components present in the model and the electrical system are: two houses, poles, wiring, LED, meter, capacitor, a device voltage regulator to prevent overcharging.

The model helps students to understand that the hydrokinetic system is able to completely replace the traditional energy supply from distribution networks. This achievement represents a paradigm shift, since for many renewable are seen as distant realities. Household appliances such as lamps, fans, refrigerators and more are perfectly driven with this type of source.

The electrical circuit of the bench can also be used as an example of a practical application of electrical engineering concepts seen in class, showing the function of each component and their proper formulations, providing students with understanding of associated circuitry from mechanical coupling of hydrokinetic turbine.

Figure 4. Image of the construction and funcines of the model.

2.3. HYDROKINETIC SYSTEM IN SMALL-SCALE

The prototype aims to generate electricity for a small system spread throughout the model, which was built with a deliberate setup for the observation of its components and their operations is clear. Its operation is caused by passage of water in the plane of the turbine wheel, causing it to rotate, transmitting power through the belt drive system to the generator shaft connected to the electrical system.

The mechanical components in the system are: (1) aluminum rotor blades 12 to 10 cm in diameter attached to the shaft by bushings, (2) solid steel shaft with 8 cm long and 3mm diameter supported by plain bearings; (3) drive pulley diameter of 55mm (4) the driven pulley diameter of 6.85 mm, (5) belt, (6) electric generator and acrylic structures. These components are shown in Figures 5 and 6.

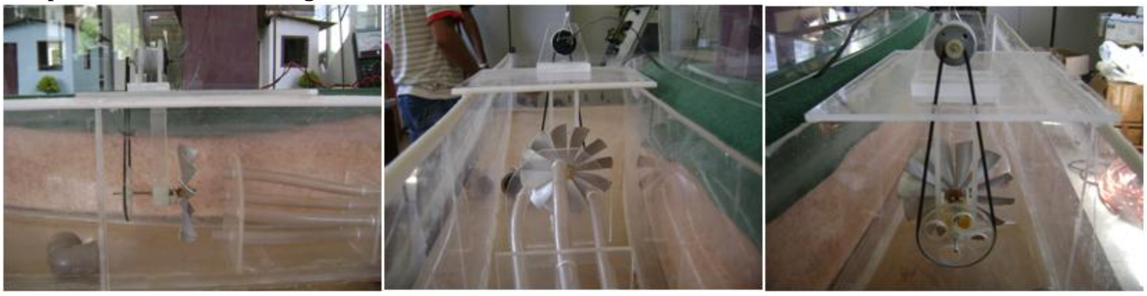

Figure 5. Prototype image.

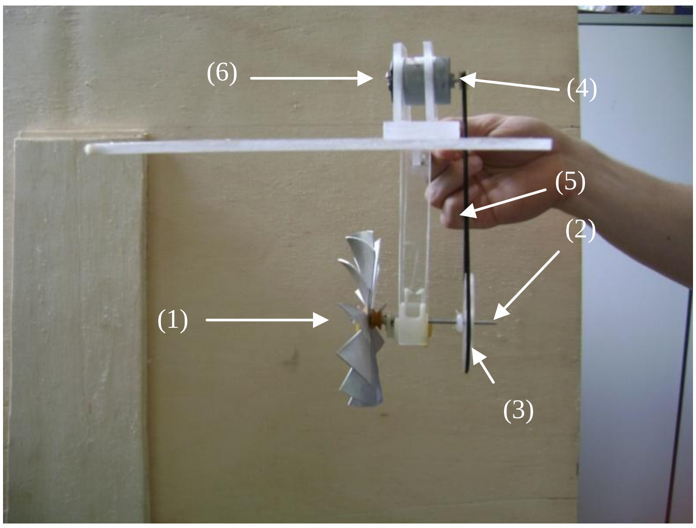

Figura 6. Prototype components

The rotor is composed of the mechanical component blades that are responsible for harness kinetic energy present in the water flow and turn it into kinetic energy of rotation. The geometric characteristics of these blades directly affect the performance of the turbine and therefore should be studied and controlled. This studies in are important for the optimization of blade shapes and profiles and for the advancement of this technology, which increases the efficiency of the turbine and its use becomes even more interesting from the standpoint of energy supply capacity. If this work was chosen rotor with a curved aluminum plates, which although not present good efficiency compared to the profiles used in the turbines meets the real needs of the project in question.

Mechanical transmission subsystem is needed for the coupling between the rotor shaft to the generator shaft. Its efficiency is also important because it greatly affects the overall performance of the prototype. To improve the efficiency of the transmission parameters must be observed and concepts on the subject. The gear, which is the ratio between the diameter of the pulley driven by the drive pulley, is one of the parameters that should be well calculated, it greatly influences the generation system. The belt drive was chosen because it is easier to be built and good visual access by the observer.

The electric generator is the component responsible for converting of the energy from the mechanical power transmission. Special attention should be given to this component, because its mode of operation and substantially affects the efficiency of power generation turbine. To get an idea for a single rotor and two different generators may be more or less efficiency in the system. For example, the use of an asynchronous electric generator systems with high degrees of speed is less efficient than a permanent magnet synchronous generator, which is appropriate at low rpm and high torque, and are more suited to large variations in speed, as they occur in small turbines. Thus, for an engineering student such knowledge is important, because the decision on the type of electrical generator to be used in an axial turbine directly affects the proper sizing of the system

3. THE CHALLENGES AND SOLUTIONS FOUND DURING OF THE CONSTRUCTION AND OPERATION

During the phases of testing it was noted that the flow inside the tank was very turbulent, which have negative influence on the rotation of the turbine, reducing its efficiency. Turbulence is a phenomenon characterized by random three-dimensional movements of fluid particles and reduces the amount of energy available in the water flow incident to use the turbine. So the flow of water should be present as laminar as possible for better efficiency of the rotor. Taking into account this observation, we decided to introduce a device called a "hive" to ease the turbulence. The fig. 7 shows the different types developed in this work.

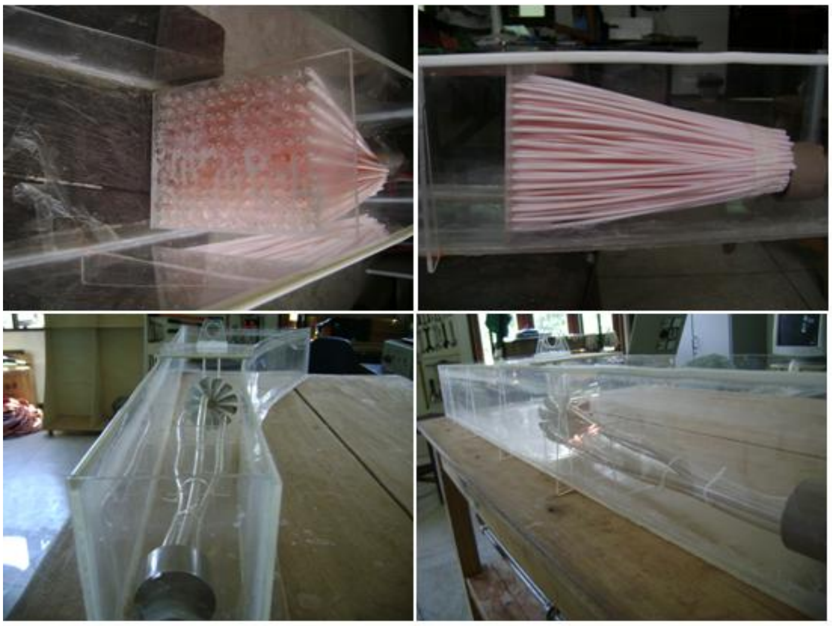

Figure 7. Hive to reduce the effect of the turbulent flow.

We applied three types of hive, with 154 pipes and a 3 mm diameter, with three other pipelines with diameter of 9 mm and one with 4 pipes of the same diameter of the former. The first became the laminar flow, but there was a great loss of power due to the large number of pipelines and the small diameter of these. This fact decreases the velocity of the fluid, does not meet satisfactorily the system, reducing the power of the rotor. The second triggered the electrical system and called the nine LEDs, however, due to poor flow distribution in rotor blades, a great vibration generated in the rotor, which was felt in the luminosity of the LEDs. The third, with four ducts, the system triggered and maintained relatively constant voltage leaving the brightness of the LED's more uniformly.

As for rotors, tests were made with two types, one with four and one with 12 blades all designed with curved plates. We chose the rotor blades 12 due to its higher torque and lower vibration obtained by comparison with the 4 blades. The vibration causes energy dissipation in the system, causing loss of overall efficiency and the oscillation voltage generated. Figure 8 illustrates the rotors.

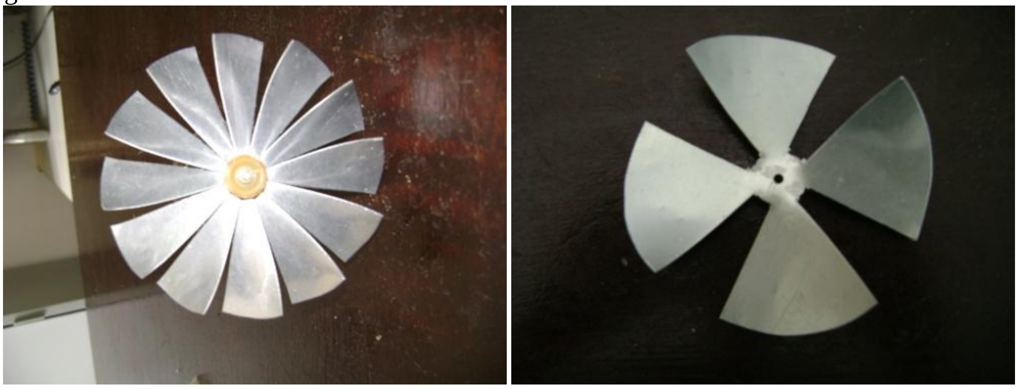

Figure 8. Rotors used. 12 blades (left) and 4 blades (hight) .

Another problem was found to fit a generator to power supplied by the turbine shaft. Whereas the model in question is presented in smaller scale, the rotor shaft must provide a value sufficient torque to overcome the resistance efforts of the transmission system and turn the generator shaft which, in turn, should offer the least resistance possible the torque provided through the pulleys. The solution to this problem was achieved through the installation of generator with low torque resistance shown in Figure 9 below.

Figure 9. Electrical generator.

Like most of the components was done without the aid of machines of precision enhancements to the prototype were not enough to totally eliminate the voltage oscillation. Therefore, we employed an electronic device (capacitor) to accomplish this task. Before and after the installation of capacitors and comparisons were made measurements of the tension generated in the circuit with the aid of a digital multimeter capable of data acquisition. In figure 10 are shown two plots of voltage as a function of elapsed time obtained by the device. The capacitor is an electrical charge storage device and acts as a filter in the circuit in order to partially reduce the oscillations of the generator voltage. The moment is the drop in power supplied by the generator acts by replacing the capacitor in the circuit electrical charges.

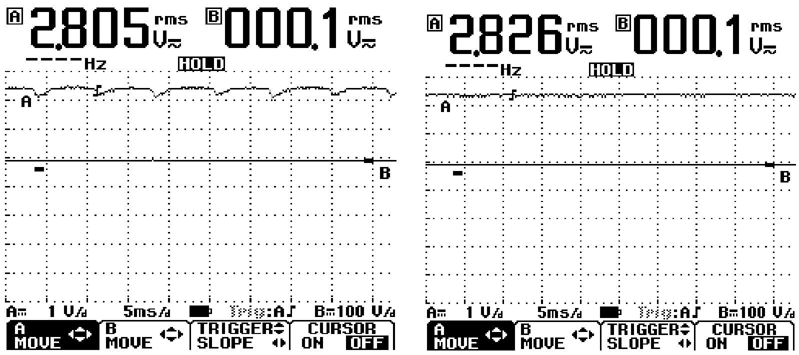

Figure 10. Without capacitor (left) and with capacitor (right).

All the challenges and solutions that were found during the process of making the bench are discussed together presentations to students during the project, giving greater attention to undergraduate commenting on the theoretical foundations used for each stage of the project.

6. RESULTS AND DISCUSSIONS

For academic purposes was calculated loss of load in the hydraulic system. This calculation serves to quantify the power transferred by water movement, where the student can learn about energy conservation in hydraulics. Therefore, knowing the value of the power carried by the water and electricity supplied by the generator can calculate the total income of the system.

By definition the pressure drop is the pressure drop of fluid along a pipeline. The energy loss takes place due to friction between the fluid and the walls of the duct. This process is divided into two types: the localized loss (due to friction in the bends, elbows and other parts of the circuit that do not have constant area) and the distributed loss (due to friction in parts of the circuit constant area).

The calculation methodology used to determine the losses in the system is presented below:

- **Distributed loss Eq. 1**

$$h_l = f\frac{1}{2}v^2\frac{L}{D} \tag{1}$$

Where: L = duct stretch length;
D = duct stretch diameter;
v = velocity at the stretch;
f = friction factor.

- **Localized loss Eq. 2**

$$h_{lm} = \frac{Kv^2}{2} \tag{2}$$

where: v = speed at the stretch;
K = loss coefficient

- **Energy conservation Eq. 3**

$$\frac{P_e}{\rho} + \frac{v_e^2}{2} + gz_e = \frac{P_S}{\rho} + \frac{v_S^2}{2} + gz_S \tag{3}$$

where: v_e = input speed;
v_s = output speed;
P_e = input pressure;
P_s = output pressure;
g = local gravity;
z_e = elevation on the input suction;
z_s = elevation on the output flow;
ρ = density

- **Results:**

Localized load loss result

$$h_{lm} = 39,688 J / kg$$

Distributed load loss result

$$h_l = 13,167 J / kg$$

Total load loss

$$H_{total} = \frac{h_{lm} + h_l}{g} \tag{4}$$

$$H_{total} = 5,387 mH_2O$$

Where: H_{total} is the sum of the localized and distributed load loss in meters of water column.

- **For calculating the hydraulic power it was used the Eq. 4 below:**

$$W_h = \rho Q g H_{total} \tag{5}$$

Where: ρ = specific mass of the water;
Q = volumetric flow rate;
g = gravity acceleration

- **Result of the system hydraulic power:**

$$W_h = 42{,}579 \text{ W}$$

Though these data it's possible to calculate the system efficiency which is given by the Eq. (5), considering that the generator power depends of the multiplication of the tension and the electric current.

$$\eta = \frac{W_{ger\ ador}}{W_h} 100 \quad (5)$$

$$\eta = \frac{W_{gerador}}{W_h} 100 = \frac{2{,}8x0{,}8x10^{-3}}{42.57819071044089} x100 = 0.0053$$

With the value of the total income you can realize the great loss of energy in the set. According to Betz, the fluid energy drawn by the rotor can not exceed 59.26% of the energy transported by water. Taking into account that no profile has not been used effectively in the known rotor blades, but were used blades curved plates of craftsmanship, this withdrawal of energy by the rotor became low. The belt drive is its efficiency in the range of 30% and the loss on the pulley, and finally the engine generator is not used as a specific use for this purpose, which was taken from an electronic circuit, and its generation efficiency is low. This low efficiency calculated above was expected. However, the system is appropriate for assistance in practical activities in mechanical engineering disciplines such as hydraulics and turbomachinery fluid mechanics, where the student can observe the fundamentals acquired in the classroom, and therefore have a more interesting learning.

6. CONCLUSION

The project developed contributes to the spread of harnessing the energy of water flow in the form of electricity, aiming to use renewable energy with low environmental impact. Of course, because it is a small-scale prototype generates only small powers. However, it is presented as a practical way of raising awareness of hydrokinetic energy to undergraduates in engineering, especially the fact that despite the technology being new hydrokinetic turbines already exist in the larger operation can generate more power and trigger devices household are important to people's routines as computers, televisions, refrigerators, lamps, fans etc.

It is very important for teaching degrees in engineering the creation of learning programs that encourage the use of new energy alternatives in development. With the visualization of the model in operation, the student may have a better understanding of the functioning of the turbine, the devices attached to it, the physical principles involved, the application of the model, difficulties in design and facilities used. The model also opens the agenda for several areas of study such as structural modeling profile blades, aerodynamics, vibrations and other .

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8. RESPONSIBILITY NOTICE