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Fluid Dynamic and Structural Analysis of A Hydrokinetic Turbine For A Gravitational Vortex Hydrogeneration System. Case study.

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Abstract

This work was carried out with the objective of fluid dynamic and structural evaluation of a hydrokinetic turbine with a 30° blade rotation configuration, based on a Darrieus H-type turbine to be attached to a gravitational vortex hydrogeneration system (GVHS) by means of Computational Fluid Dynamics (CFD). ANSYS software affers a wide range of modules for structural and fluid dynamics analysis. The fluid dynamic simulation uses the k-ε turbulence method and the turbine coupling simulation uses rotational flow modeling with “moving references frames”. Values of the velocities and pressures around the turbine blades are obtained to use this information as input data in the structural simulation of the hydrokinetic turbine.

Keywords: *Hydrokinetic Turbine, fluid, structural, deformation, stress.*

1. Introduction

Power generation from small hydropower plants provides supply to isolated areas where carrying an interconnection line from the main power system can be very costly, and there are many difficulties in the geographical aspect. These situations have given rise to off-grid solutions, in which the generation of clean and renewable energy is *in situ* [1].

Among the alternatives studied is the gravitational vortex hydrogeneration system (GVHP). The system is based on the use of the kinetic energy stored in an induced vortex at the potential energy in a small gap between the intake and the water outlet (Figure 1). A turbine is adapted that has a rotating motion due to the force generated by the vortex. Engineer Franz Zotlöterer designed and built a pilot plant that yielded about 1 MW with a flow rate of 1 m^3/s and velocities below 1 m/s.

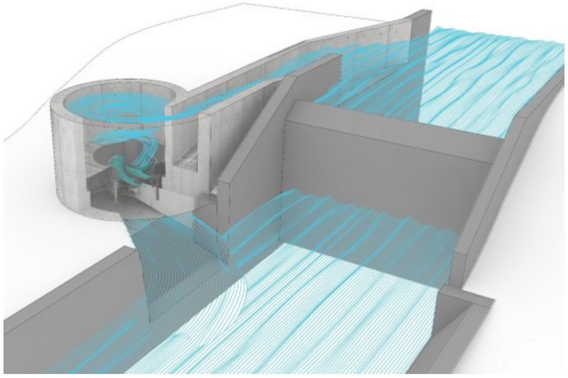

Fig. 1. Gravitational vortex hydrogeneration system [2].

2. Case study

Hydrology is the science that studies terrestrial waters, their origin movement and distribution on our planet, physical and chemical properties interaction in the physical and biological environment and influence on activities. This information allows us to know the conditions in which the surface and subway water resources are found. The data are contained in different publications such as hydrological charts and studies available in different formats for consultation or download.

Hydrometric stations are graduated rulers placed staggered in a river, stream or reservoirs that measure the amount of water available in these bodies of water from rainfall and runoff. Qualified people oversee recording water levels at pre-established times, during a storm or the release of water from a dam. By knowing the quantity of water resources, a better distribution is made for the supply of municipal drinking water and water used for industry, hydroelectric power generation, and irrigation of fields, among other activities.

Due to its hydrological characteristics and based on the hydrological basin limits established by the National Water Commission, four hydrological regions are delimited along the coast of Veracruz from north to south: RH-26 Panuco, RH-27 North Veracruz or Tuxpan-Nautla, RH-28 Papaloapan and RH-29 Coatzacoalcos.

This case study will be carried out in the region RH-26 Panuco because it is one of the most affected non-interconnected areas in the Veracruz state and CONAGUA has the data record of the hydrometric station located in Poza Rica de Hidalgo, belonging to the Northern region of Veracruz.

2.1 Panuco River Basin

The Panuco river basin (Figure 2) is geographically located between 19°01’ and 23°50’ north latitude and between 97°46’ and 101°21’ west longitude; it has an approximate area of 84, 956 km^2 which places it in fourth place in the Mexican Republic [3].

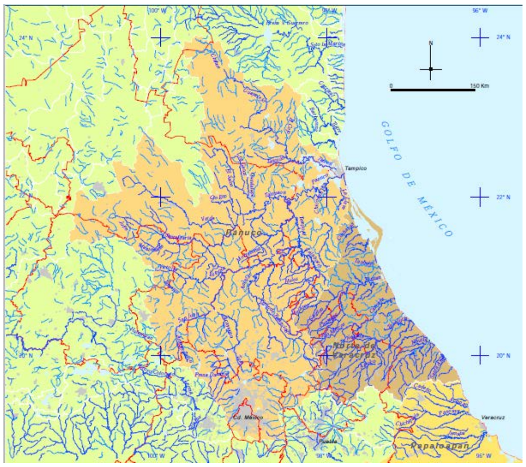

Fig. 2. Panuco River Basin [2].

The flow curve graphic indicates the percentage of time during which the flow rates have been equaled or exceed. In addition, the curve indicates the value of the flow rate as a function of the frequency of its occurrence. The curve can be constructed from daily, monthly, annual, etc. The flow duration curve is almost importance when developing water projects. For this reason, the following figures show the flow duration curves for three different periods of the year 2021 for the Panuco hydrographic station with code PNVCV. This information is provided by CONAGUA [3].

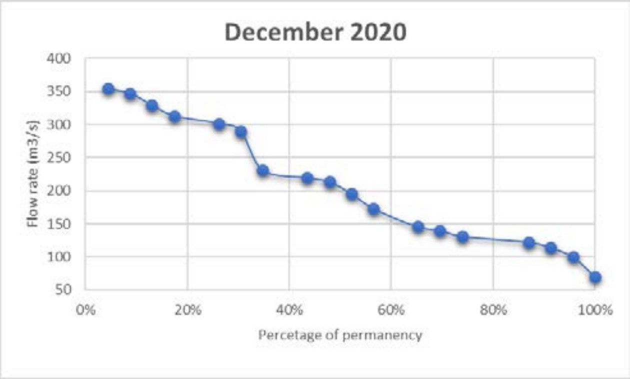

Fig. 3. Panuco river flow duration curve for the eriod December 2020.

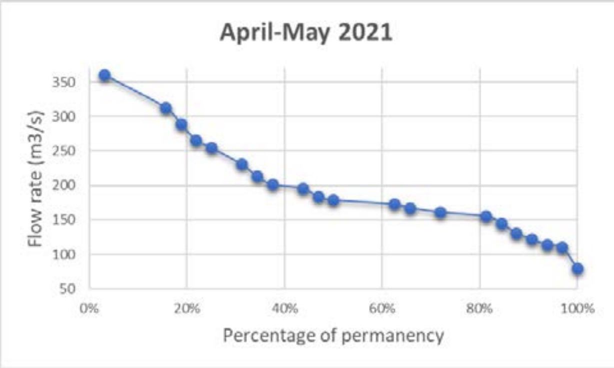

Fig. 4. Panuco river flow duration curve for the period April and May 2021.

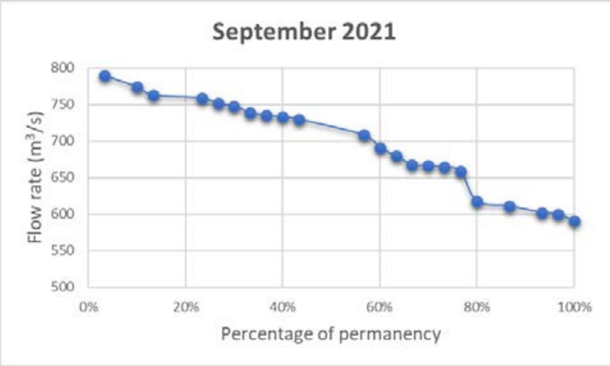

Fig. 5. Panuco river flow duration curve for the period September 2021.

The flow duration curve for the period April and May represents the low water level period which is extremely important because this is the season when the level and flow of the river decreases drastically due to the absence of rainfall, but as can be seen in Figure 4, the minimum flow is 80 m^3/s and the maximum flow recorded is 360 m^3/s. On the other hand, for the rainy season, shown in Figure 6 for the period of September a minimum flow of 590 m^3/s and a maximum of 789 m^3/s can be seen. Finally, Figure 3 shows the December period where cold weather is present and has an impact on river levels and flows. However, for this period the minimum flow is 70 m^3/s and a maximum of 355 m^3/s.

All these minimum flows at 100% permanence, even in the low water seasons in this river, guarantee the operation of hydrokinetic turbine.

3. Turbine design

The following figures show the 30° blade rotation with respect to the top of the blade for Darrieus H-type hydrokinetic turbine.

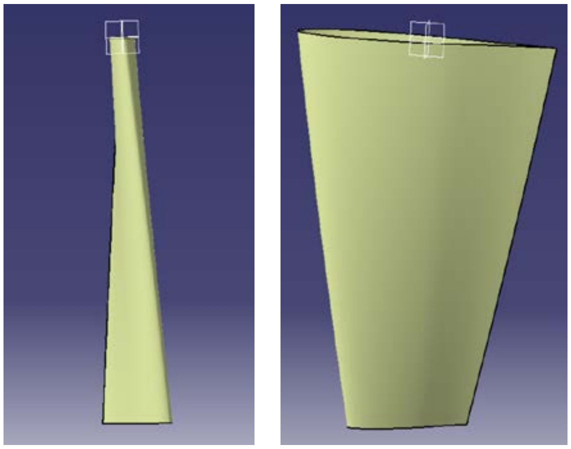

Fig. 6. 30° blade rotation. Lateral and frontal view.

The size of the blade chord changes along the entire length of the blade. These modifications are due to the fact that the vortex chamber is conical, and this geometrical configuration is being exploited for the turbine.

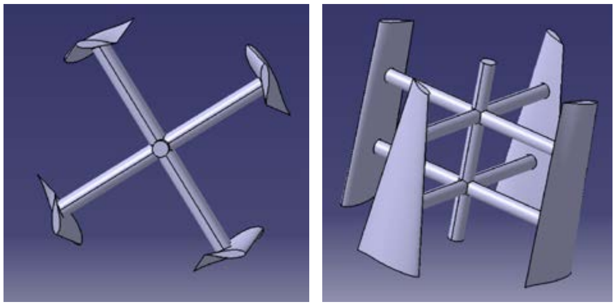

Fig. 7. Hydrokinetic turbine with blades rotated at 30°. Top and isometric view.

The hydrokinetic turbine has two supports that connect the turbine shaft to the blades. They are symmetrical distributed along the blade. The turbine has the following dimensions.

Table 1: Turbine configuration

Chord	0.06 m
Turbine diameter	0.18 m
Rotor radius	0.09 m
Blade thickness	0.012 m
Axis radius	0.02 m

A hydrodynamic simulation was carried out followed by a structural simulation of the hydrokinetic turbine configuration with blade rotation.

4. Hydrodynamic simulation

The hydrodynamic simulation setup was based on own research work [4]. In this work the hydrokinetic turbine was tested in a rectangular computational domain to obtain the dynamic forces influenced on and by the turbine in the water.

Figures 9 and 11 show the velocity and pressure contours, respectively, from the above-mentioned work to make a comparison of both configurations where the turbine has no blade rotation.

Figure 8 shows the velocity contours in the XY axis around the turbine. Velocity ranges from 0 to 1.86 m/s can be visualized. The highest velocity zone is concentrated on the blades located perpendicular to the water flow direction. It can also be seen that the velocity decreases in the blade behind the other blade due to the obstruction of the flow path.

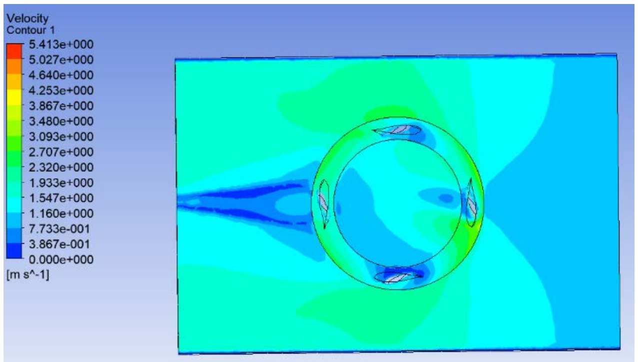

Fig. 8. Water velocity contours. XY Plane.

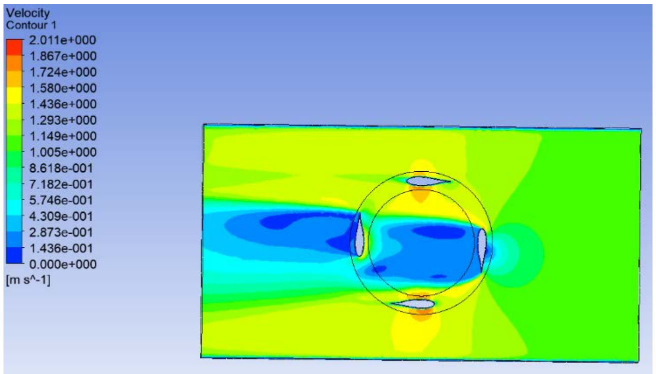

Fig. 9. Velocity contours of a hydrokinetic turbine with non-rotatin blades.

Figure 10 shows the pressure contours around the blades. The pressure near the blades is approximately 560 Pa in negative suction, while in the rest of the zones it is 260 Pa.

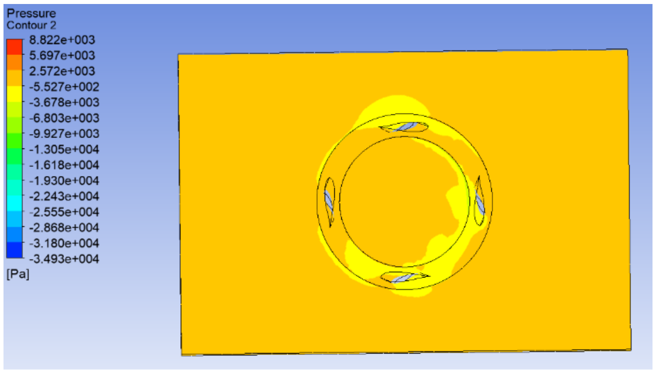

Fig.10. Pressure contours.

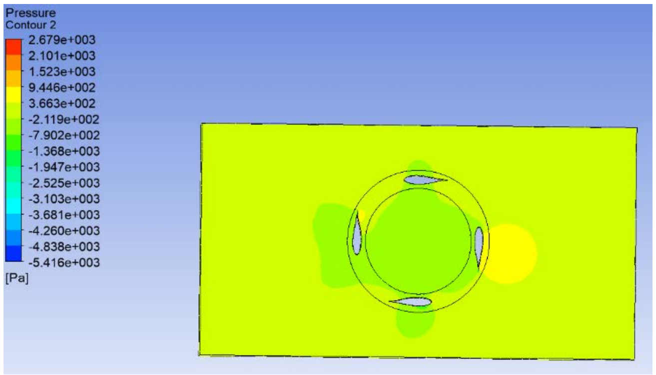

Fig. 11. Pressure contours of a hydrokinetic turbine with non-rotating blades.

5. Structural simulation

The inputs for the structural simulation were the angular velocity in the turbine, the pressure detected in the blades and the torque generated in the fluid dynamics analysis.

5.1 Theorical foundations of material mechanics

Mechanics of materials is the science that analyzes the stresses and deformations produced by the application of external forces to a body.

Stress and deformation

Stress is a function of the internal forces in a body, and mechanics of materials is a study of the magnitude and distribution of these forces. The intensity of force is called stress, or unit stress. Unit is defined as the force and per unit area [5].

$$\sigma = \frac{P}{A} \qquad (1)$$

Where,

σ = unit stress in N/m^2
P = load applied in N
A = area on which the load acts in m^2

When lad is applied to a body a unit stress is developed. In addition to this, the body lengthens, slightly due to the application of the load. In strength of materials, these changes in length (also known as elongations or contractions) are known as deformations. Therefore, a deformation is the change in length of a part. The total deformation is the change in length of the member. Unit strain is defined as the change in length per unit length [5].

$$\epsilon = \frac{\delta}{L} \qquad (2)$$

Where,

ϵ = unit deformation in m/m
δ = total deformation in m
L = original length in m

The unit stress-strain diagram is obtained through laboratory tests. The properties of the materials must be known through tensions tests. In these tests, simultaneous measurements, are made of the load applied against the deformation until fracture occurs. From these measurements, a graph of the stresses against the unit strain is generated. The values of the unit stress (P/A) are plotted on the ordinated and the corresponding values of the unit strain (δ/L) on the abscissa [5].

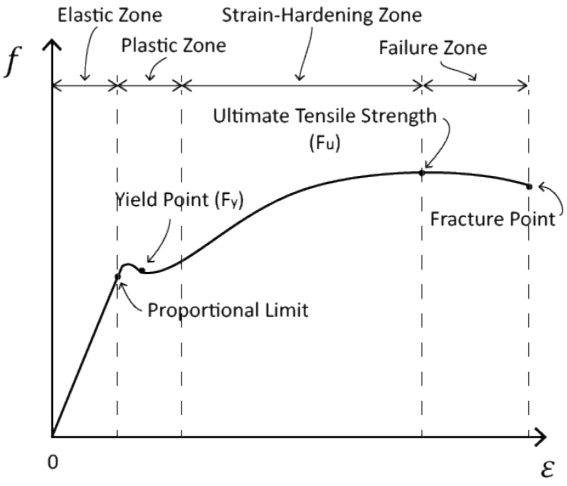

Fig. 9. Unit stress-strain diagram [5].

Figure 12 shows the final configuration for the structural simulation of the hydrokinetic turbine. The displacement, momentum, rotational velocity, and pressure acting on the hydrokinetic are shown in Figure 12.

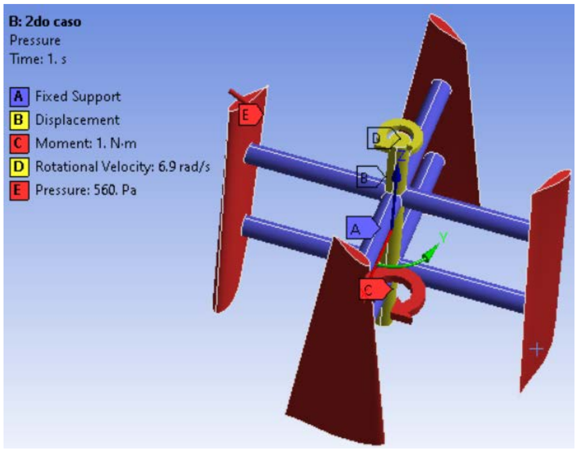

Fig. 12. Structural simulation step.

The following figures show the results of the structural analysis of the turbine obtaining the total deformation and normal stresses.

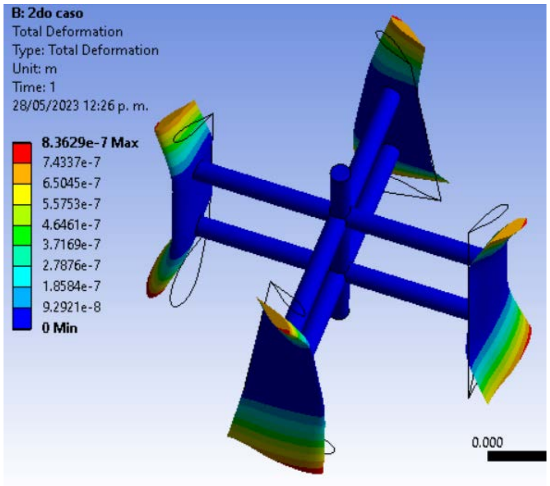

Fig. 13. Total turbine deformation concentrated on the blades.

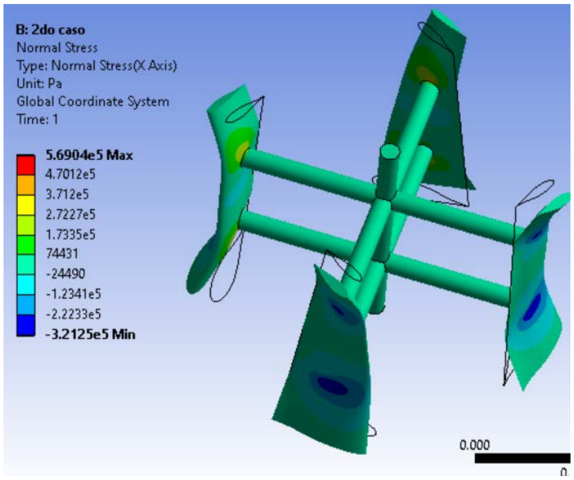

Fig. 14. Normal stress concentrated at the union of the blade supports to the turbine shaft.

6. Conclusions

Finally, it can be concluded that the turbine with a 30° rotation in its blades has a better functionality for the gravitational vortex hydrogeneration system. This is since there is a greater angular velocity in the configuration of the rotated blades than without such rotation.

From the structural simulation it can be concluded that the total deformation is maximum, as expected, at the blade ends. This is since the supports are centered in the widest part of the blade, being the profile the most structurally vulnerable part.

Acknowledgments

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