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Turgo Micro Turbine Test Bench

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Abstract: Small hydroelectric plants are those that have the capacity to produce less than 5,000 kW or 10,000 kW, depending on the classification criteria. They are used to provide electricity to isolated villages, without access to the electricity grid, avoiding the environmental impacts of damming and energy losses in electricity transport. The Turgo turbine is an action turbine, which arises from the Pelton turbine at the end of the 19th century. It is a machine that is easily built and maintained, which, despite presenting lower efficiencies than most other large turbines, is widespread in small hydroelectric uses for large hydraulic jumps. In these machines, a great difference is observed between the results obtained in the computational simulations and the test benches or installations made with said turbines. In this work, after analyzing the design process of a Turgo micro turbine and its materialization with 3D printers, a test bench was made with the aim of showing its operation in teaching areas and obtaining efficiency values. The initial design parameters of the turbine were adapted for the test bench to be transported to the classrooms. From this, the best performance conditions were evaluated according to the angle of the injector and the pressure applied.

Key words: renewable energies, micro hydraulic turbines, Turgo turbine, test bench

1. Introduction

Hydroelectricity occupies an important place within the renewable energy sources of greater diffusion since a long time ago. However, in recent decades, the environmental impact generated by the damming of large rivers, generating significant floods and changes in the present ecosystem, have highlighted some of the major drawbacks of this energy source. In this way, the mini and micro hydroelectric plants have taken on greater importance by avoiding the aforementioned negative impacts.

One of the most widely studied parameters of hydroelectric plants are hydraulic turbines: the component that allows energy exchange between the fluid and a shaft, which then, with the coupling of a generator, will produce the desired electricity. The Turgo turbine is an action turbine, patented by the Gilkes Company in 1919 [1], designed to cover a range of large loads and small flows according to the environmental conditions where the turbine will be located. It resembles the Pelton's turbine, with differences in the rotor: the Pelton turbine has double ladle shaped blades and the Turgo turbine a single ladle. The biggest differences are in the simplicity of manufacture of the Turgo rotor, ignoring part of Pelton´s efficiency. This leads to a difference in the way the jet impacts the Turgo turbine: it must be given an inclination, an axial component, to impact correctly to the blades.

The Turgo turbine is widely used in small hydroelectric plants. That is, those where the power does not exceed 10,000 kW. In these plants, the design procedure is simply an adaptation of the large hydraulic turbines. This means that there is no extensive study in the operating conditions of the turbines on these smaller scales. In turn, in a large part of the research work carried out, the efficiencies achieved by these machines are very low, between 20 and 50%. If these values are compared with the design efficiency provided by the Gilkes Company, always greater than 85%, this decrease is striking. In turn, the research

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work developed in the computational simulation of these machines in general provides efficiency results generally greater than 70%.

This document presents the design of a test bench for a previously designed Turgo turbine, printed on 3D plotters and used in a test bench where it is intended to measure the efficiency of the machine. Besides, this work looks the dissemination of turbines among students and improvements in its teaching process in the Faculty of Exact, Physical and Natural Sciences of the National University of Córdoba.

Prior to work with the test bench, the geometric design of the rotor and injector of the Turgo turbine was developed [2]. This project is linked to the design of other types of turbines by the National University of Córdoba, working with the application of hydraulic turbines to small hydroelectric plants for some years.

First, a Michell Banki turbine was designed to produce a useful power of 18kW, which was later machined in local workshops and installed in the University's Hydraulics laboratory [3]. In addition, an Helix turbine was designed and then built by Cristo Obrero's Technical Institute of Carlos Paz, to produce a useful power of 2.9 kW. Then we started working with the Turgo turbine, a Pelton turbine and lastly a Francis turbine [4].

2. Background

In previous works, the Turgo turbine was designed for a flow rate of 10 l/s and a head of 26 m. Considering an efficiency of 60%, 1.5 kW of useful power will be produced. The results obtained in the geometric design of the Turgo turbine are shown in Table 1. This turbine was printed in 3D in the Integrated Biomedical Design Laboratory (di Bio) of the National University of Córdoba. The metal containment box was built in local workshops, as well as the injector and shaft. We can observe this in Fig. 1.

In turn, an investigation of the published works on this type of turbine was developed to evaluate the state of the art of the Turgo turbine applied to small

Table 1 Turgo turbine previous design.

Parameters		
β1	30°	Blade entry angle
β2	10°	Blade departure angle
N	975.5 rpm	Rotational speed of the rotor
d0	31 mm	Jed diameter
D	21 cm	Rotor diameter
Z	16	Blade number

Fig. 1 Turgo turbine's box.

hydroelectric plants. It was concluded in the first place that the available bibliography [5] is too limited to allow the complete design of a small hydroelectric plant [6, 7]. In turn, the variation in the efficiencies obtained from test benches, installed turbines and computer simulations couldn't let us to any conclusions. Within this research, we participated in the meetings generated by the Ibero-American Small-Scale Hydropower Network, belonging to the Ibero-American Program of Science and Technology for Development (CYTED) during the month of November 2019 in the City of Cuernavaca, Mexico [8]. In these meetings, progress on this issue in Latin America was observed: certain researchers are working on the development of new types of small-scale and kinetic hydraulic turbines, while manufacturers of small hydraulic turbines adapt designs from large to small turbines. In this second case, manufacturers have difficulties in defining hydraulic efficiency and adjust designs to available information: Pelton turbine is taken for smaller scales ignoring the design of the Turgo turbine.

3. Material and Methods

Based on the studies carried out, a test bench was designed. The initial objective for the design of this turbine was to bring the research within the students. Then, as a second point, it was sought to measure the efficiency obtained from the operation of the machine. A mobile table was designed to transport the turbine inside its containment box. In it, a pump was included that allows the operation of the turbine as well as a tank for feeding and collecting the water used (Fig. 2).

The pump was designed to generate a sufficient flow for the operation of the turbine but not excessively large to be contained in a transportable tank; besides, the load had to be adapted to cheap materials and to avoid large sound impacts and vibrations. These considerations took the turbine's bench to operate far from the parameters used for its geometric design. In other words, we are not at the point of highest performance of the machine.

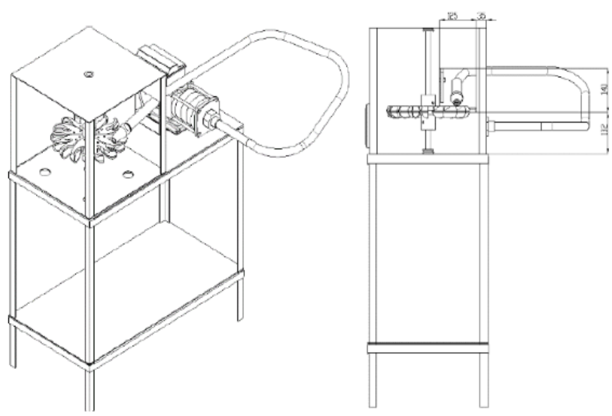

Fig. 2 Turgo turbine's mobile table.

With the participation of the Cristo Obrero's Technical Institute of Carlos Paz, the table previously planned was built containing a Motorarg centrifugal pump, called BC 50, a 10-liter tank, a discharge container with holes and connections necessary to reach the tank, and an electrical system with its corresponding protections (Fig. 3).

3.1 Efficiency Measurement

To know the efficiency of the machine, it is necessary to know the theoretical and real power of the recently designed turbine. The theoretical power is defined as a function of H-Q (load and height), Eq. (1):

$$P_t = \gamma * Q * H \tag{1}$$

Being P the theoretical power in W, γ the specific weight of the water in N/m^3, Q the flow in m^3/s and H the head in m. To know the load and flow provided by the pump, on the one hand we have the H-Q curve of the pump and on the other we install a pressure gauge at the outlet of the pump [9]. The flow is estimated based on the measured head with the known H-Q curve of the

Fig. 3 Turgo turbine's test bench.

installed pump, load losses were estimated (both individual and frictional).

To measure the real power generated, where efficiency in energy transformation is considered, a braking system was installed to measure the variation in the angular speed of the turbine shaft as a function of a known variated weight. By adjusting the weight applied to the brake and measuring the rotation speed (with a tachometer), the rotor output power can be calculated (Eq. (2)). The efficiency will be obtained by comparing the theoretical power with the real one [10] (Eq. (3)):

$$P_u = T * \omega = (F * R) * \omega \quad (2)$$

$$\eta = \frac{P_u}{P_t} \quad (3)$$

Being P_u the real power in W, T the torque in Nm, F the friction force (represents the applied weights multiplied by the friction coefficient) in N, R the radius or the distance between the axis of the torque and the force of friction generated in m and η the efficiency. The material used for the brake was ferodo with a friction coefficient f = 0.4.

Within the measurement procedure it was decided to vary the position of the injector, since it impacts on the efficiency of the machine. Four angles were defined for it: 13°, 15°, 16° and 17°. In turn, different weights were calibrated to generate the power curve and find the maximum point: from 500 g to 2,000 g with a variation of 100 g. These measurements were made in the process of loading and unloading the machine to avoid, in the first place, the errors of reading and recording the measurements and also the effect of inertia in the rotation of the turbine. The rotational speeds of the machine were noted as a function of the inclination of the injector, the pressure observed in the pressure gauge (which was also varying) and the loading and unloading process of the brake.

3.2 Flow Simulation — SolidWorks

To compare the results obtained with the test bench, the behaviour of the fluid through the turbine is analysed with SolidWorks 3D software [11]. We used Flow Simulation, a tool that allows us to simulate the flow of fluids through CFD tools.

Fig. 4 Power measurement.

Fig. 5 Pressure gauge and tachometer.

The same SolidWorks model sent to the 3D printers, used for the materialization of the Turgo turbine, is used for the computational simulation. Certain simplifications were adopted: roughness is not taken into account, the rotation zone is incorporated as a boundary condition and the box is filled with water (it is not possible to simulate the water-air interaction that occurs in this type of turbines). The boundary conditions used were: pressure at the inlet of the injector (according to what was measured with the pressure gauge), atmospheric pressure on the sides of the box, rotation zone with the measured angular velocity.

For the meshing of the model an iterative methodology was chosen in which the effect of reducing the size of the mesh elements was evaluated according to the parameters calculated, with a convergence criteria for speed and pressure.

4. Results and Discussion

In a first place, we have got results from the test bench. Different power curves were obtained for each load and injector angle. In this case, we shows up the results obtained for 10 meters of load since they were those that were later simulated (Fig. 6). This power curves were drawn for the weight increasing and decreasing, and in two times measured.

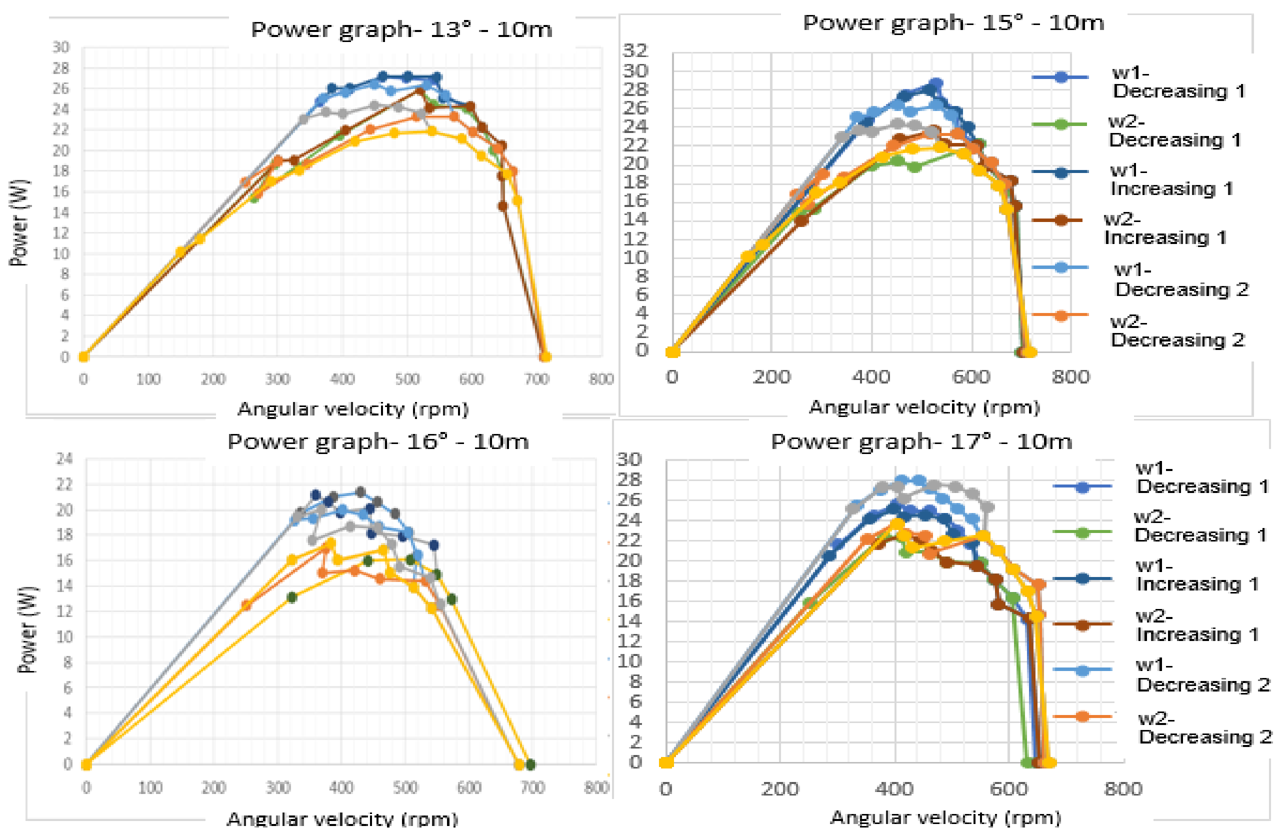

Fig. 6 Power curves obtained for a pressure of 10 m.

It was observed that the maximum power and efficiency were achieved for the injector placed at 15°. However, the maximum average efficiency is given for angles of 13°. This means that, despite the 15° angle is the one that generates the greatest energy transfer efficiency, the 13° angle allows more stable power to be generated, being the average of the efficiencies greater than the one in cases of 15º and 17°.

In general, the power obtained between the angle of 15 and 17° are similar, however, the average efficiencies for the angle of impact of 17° is much lower than those observed for the angle of impact of 15°, generating increased instability.

On the second place, we obtain other results from the computational simulation. Despite the differences between the simulation and the normal operation of the machine (especially the fact of simulating the box filled with water), the software clearly shows the function of the injector, where the potential energy of the water is transformed into kinetic energy. Besides, as the fluid exits the injector nozzle, the jet hits the blades and the water speed decreases. This is optimal for the operation of the machine since, with lower output speeds, the energy transferred to the impeller is greater.

We can observe the variation of pressure and velocity in the following Fig. 7: in this case, with an injector angle of 15° and the load of 10 m.

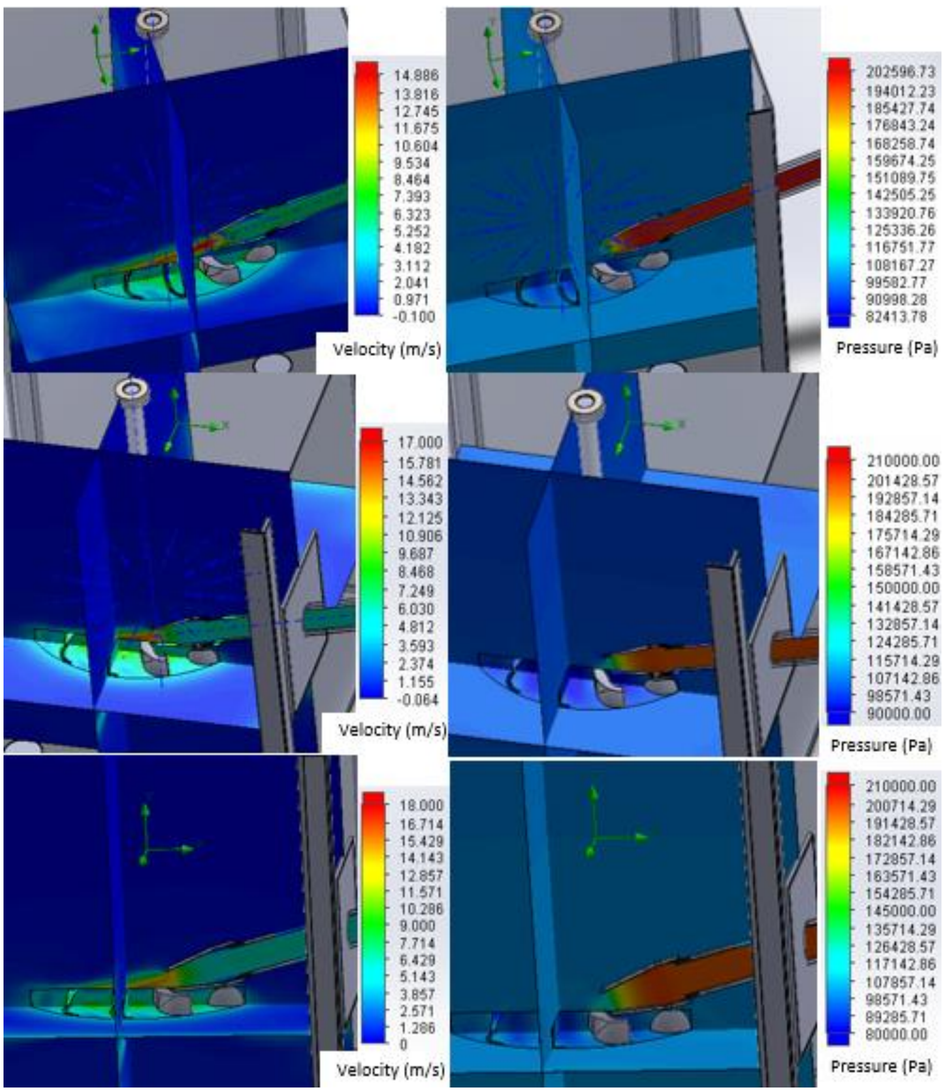

Fig. 7 Results obtained from the turbine with an injector angle of 13°, 15° and 16° - 10 m pressure.

To evaluate the efficiency of the turbine, the variation of the tangential velocity of the fluid between the inlet and outlet of the rotor was used. The equation that justifies this concept is the power equation as a function of the external moment M:

$$P = M * \omega = Q * \rho * \omega * (V_{u1} * R_1 - V_{u2} * R_2) \quad (4)$$

Where Q represents the flow, ρ the density of the water (997 kg/m^3), Vu the tangential velocity, R the respective ratio and ω the angular velocity, 1 represents the inlet fluid and 2 the outlet.

As we use the angular velocity as a boundary condition, we can only compare different cases, through the variation of the tangential component of the absolute velocity of the fluid, as an indicator of the power parameter. First, we analyze the general behavior of the tangential velocity in a plane defined by the author: at the entrance of the buckets it must be the highest magnitude possible and at the exit practically zero. This could be seen in the simulation results.

Next, the tangential velocity values obtained at the rotor inlet are compared in Table 2.

Table 2 Turgo turbine simulation results – variation of tangential velocity.

°	w [rad/s]	Absolute velocity[m/s]			Q [m^3/s]	Tangential velocity [m/s]
		Max.	**Mín.**	**Av.**		
13°	46.0	5.74	5.39	5.57	-0.00112	14.49
15°	51.1	5.85	5.47	5.66	-0.00114	16.42
16°	46.0	5.96	5.59	5.78	-0.00116	16.45
17°	45.6	5.84	5.79	5.82	-0.00117	14.18

It is observed that the injector angle that would generate the most efficient energy transfer is applying an injector angle of 15°. This is observed in the practically equal values of the tangential velocity, between 15º and 16° (difference of 0.2%), with 16° having an angular velocity 10% less than that of 15°.

5. Conclusion

Micro hydroelectric plants are today an excellent solution for the use of water resources, on a small scale, avoiding the main negative effects in relation to large uses: they do not require damming or energy transport. That is, they are bypass plants with on-site electricity production.

One of the main components of hydroelectric plants are hydraulic turbines. At present, the turbines applied in mini hydroelectric plants are scaled from the design processes of large turbines. A type of turbine widely used in this type of power station is the Turgo's turbine. It is an action turbine, easy to build, whose design is complex due to the lack of available bibliography. In turn, within the different research works found, a great variability is observed between the efficiencies obtained from the simulations and the efficiencies of the test benches and turbines installed.

Faced with this scenario, a Turgo turbine test bench was designed and built, for teaching and general studying of the behavior of this type of turbine. The Turgo turbine was designed for a head of 26 m and a flow rate of 10 l/s. The use of 3D printers for the materialization of the rotor is economical and practical for the construction of test benches. In this case, the installed test bench consists on a pump, a tank, an electrical system and a turbine container box. In turn, a pressure gauge is added to this bench to measure pressure and a Prony brake to measure power. In future studies, a flow meter should be installed to know more precisely the operating flow of the turbine.

At the same time, if it is desired to have greater precision in the measurement of the generated power, a dynamometric balance should be applied to avoid the instability of the braking generated by the Prony brake.

Within the results obtained from the test bench, it can be concluded that, for each load, there is an optimal injector angle. For the 8 and 10m load, the optimal angle is 15° while, for the 14 m, 17°. It should be noted that the load and flow used for the operation of the machine were restricted by the size of the pump, as well as by the size of the tank, being a mobile project to be taken to the classrooms, finding the machine tested outside of design parameters. Besides, we have observed that a study should be made in order to decide whether we choose the more efficient turbine or the more stable one, depending on the needs and technology available in each place.

After the measurements were made, the computational simulation of the turbine was carried out. The SolidWorks software, Flow Simulation complement, was used, where the operating conditions of the turbine were simulated for a load of 10 m with the different impact angles, averaging the results of the angular velocity measured on the test bench to apply it to the area. rotation.

As for the simulation itself, it is considered that the software clearly represents the operation of each of the elements of the turbine. In this case, the injector and the rotor. The injector is in charge of converting the pressure energy into kinetic energy and the rotation of the flow lines is observed when entering the rotor.

The behavior of the speeds through the machine, in the case of the design conditions simulation, was similar to that calculated analytically. In turn, the variations found in the simulation of the operating conditions of the test bench are not important but expected, it is the same phenomenon observed in the collection of antecedents of this type of machines in which the efficiencies obtained from the simulations they are very far from those obtained in the test benches. It is assumed that it is due to limitations in the simulation conditions: lack of fluid-structure interaction (a rotation zone must be incorporated as a boundary condition), lack of water-air interaction (it is assumed that the box is full of Water). It is recommended to use other software later.

In this case, the full power equation cannot be considered valid since the angular velocity is imposed by the user. In this way, to generate comparisons between the results obtained, the variation of the tangential velocity through the rotor is observed, concluding that the angle of the injector where the absolute velocity of the fluid decomposes in a more favorable way for energy transfer is for 15°. This angle coincides with the optimum according to the test angle measurements.

List of Simbols

ρ the density of the water (997 kg/m^3),

Vu the tangential velocity,

R the respective ratio and ω the angular velocity

P_u the real power in W,

T the torque in Nm,

F the friction force (represents the applied weights multiplied by the friction coefficient) in N,

R the radius or the distance between the axis of the torque and the force of friction generated in m

η the efficiency.

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