Construction of Kaplan turbine test bench for mini hydraulic power generation

Construcción de un banco de pruebas de turbinas Kaplan para la generación de energía minihidráulica

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Abstract

The general objective of the work was the design, development, and construction of a Test Bench for Kaplan type turbines suitable to be installed in a rural environment, through which we can check if the characteristics of the turbines are ideal to meet the generation goals of electrical power required. To carry out this purpose, a Kaplan-type turbine prototype was designed and built-in order to install it in our Test Bench and verify that this Bench is adequate to check the operation of the turbine subjected to different input conditions and for Therefore, this will help us to arrive at an ideal turbine design to take advantage of the mechanical energy of water and therefore the generation of electrical energy. This is a project that was developed with the design objectives from scratch to the physical creation of a test bench for turbines, specifically for a Kaplan type turbine where tests can be carried out in a controlled environment where new designs are put into practice. of turbines to know their operation in a scaled manner and then be able to take them to production and installation in different regions.

Kaplan, Mini hydraulic, Testing bench, Electricity

Resumen

El objetivo general del trabajo fue el diseño, desarrollo y construcción de un Banco de Pruebas para turbinas tipo Kaplan adecuadas para instalarse en un medio rural, mediante el cual podamos comprobar si las características de las turbinas son las ideales para cumplir con las metas de generación de potencia eléctrica requerida. Para llevar a cabo este fin, se diseñó y construyó un prototipo de turbina tipo Kaplan con el objetivo de instalarla en nuestro Banco de Pruebas y verificar que este Banco es el adecuado para comprobar el funcionamiento de la turbina sometida a diferentes condiciones de entrada y por lo tanto, esto nos a va servir para llegar a un diseño de turbina ideal para aprovechar la energía mecánica del agua y por consiguiente, la generación de energía eléctrica Este es un proyecto que se desarrolló con los objetivos del diseño desde cero hasta la creación física de un banco de pruebas para turbinas, en específico para turbina tipo Kaplan donde se puedan llevar a cabo pruebas en un ambiente controlado donde se pongan en práctica nuevos diseños de turbinas para conocer su funcionamiento de manera escalada para luego poder llevarlas a la producción e instalación en diferentes regiones.

Kaplan, Minihidráulica, Banco de pruebas, Electricidad

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Introduction

The general objective of the work was the design, development, and construction of a Test Bench for Kaplan type turbines suitable for installation in a rural environment, through which we can check if the characteristics of the turbines are ideal to meet the goals of generating required electrical power. To carry out this purpose, a prototype of a Kaplan type turbine was designed and built with the aim of installing it in our Test Bench and verifying that this Bench is suitable to check the operation of the turbine subjected to different input conditions and, therefore, this helped us to arrive at an ideal turbine design to take advantage of the mechanical energy of water and therefore, the generation of electrical energy.

Hence, a Kaplan-type turbine was first printed using an ABS filament through a 3D printer; subsequently, the Test Bench was designed and built taking advantage of an existing structure in the Technology Center and providing it with all the necessary components to make some first basic measurements and thereby verify the proper functioning of our Test Bench and therefore the behavior of the turbine previously installed and with it will have the necessary elements to analyze the feasibility of building it in aluminum or another material for a greater duration of use in rural areas.

1. Test Bench

This section is dedicated to the assembly of the Test Bench from scratch, using to verify its operation the installation of the prototype of a Kaplan type turbine, includes the development of the corresponding plans, as well as the calculations involved for the test of the turbine.

What is a test bed?

A test bed can be defined as a space designed with the characteristics of a given environment to provide a form of rigorous, transparent, and repeatable verification of scientific theories, computational elements, new technologies, etc.
These banks can be found in many industries, which install their parts.

For example, to know the resistance of the materials that are used, testing the various efforts that can be achieved depending on the work to which it is going to be subjected; know if the new designs of parts comply as they were designed or if some changes must be made to improve or perfect the design, or in such a case to eliminate it in case it is not profitable. About our test bench, you will have the function of experimenting if our prototype Kaplan turbine or any other turbine that you want to install, will have the appropriate design to be able to be used on a larger scale with respect to a river.

1. Some of the characteristics that our test bench has is that you can experience different types of flow that our flow (laminar or turbulent) can have to which the turbine can be subjected, the height of the waterfall modifying the height of the pipes, the position of the turbine depending on the base that is designed.
2. It can be moved in a relatively simple way.

Next, we will present the development that had its assembly along with its justification, the errors that were had at the beginning, the way we corrected the problems, in addition to the plans for the design of the pieces.

1.1. Construction of the Test Bench

For the construction of our test bench, we occupy materials that do not suffer any type of damage or wear to be in constant contact with water. They also came to consider the cost of the products, the way to be able to obtain them, which will cover the needs during the testing, installation, and measurement periods.

Storage tank – Rotoplas

At the beginning it was proposed that the equipment be connected to an outlet of the Technology Center to provide water to the test bench for its operation, but for reasons of time and optimization of the development of this project, the decision was made to install a water storage tank with return of the same to the tank to use it continuously in the project, that is, we made the test bench a closed cycle, this means that there should be no significant losses of the amount of water stored by our tank.
But why choose a Rotoplas tank?

A. Dimensions: you have the right size with which you can hold most of your body on the top base of our test bench.
B. Capacity: its storage becomes sufficient to be able to have the necessary water to perform the tests and the movement of the turbine.
C. Stamina: thanks to the low-density linear polyethylene material with which the tank is manufactured, it is resistant to various conditions, in addition to which it does not oxidize or corrode. As an extra fact some suppliers mention that they get to have a lifetime warranty.
D. Easy Maintenance: suppliers mention that it must be kept always closed to avoid the development of bacteria and contaminants, in addition to recommending that it be washed every 6 months.

Characteristics:

– black Rotoplas
– Stores up to 250 liters of some fluid
– Nose valve
– Hose connection
– Connection for a 4-inch Cople
– Cost of 1,200.00 pesos.
– Height of 75 cm
– Diameter of 60 cm
– Weight of 1 kg

Figure 1 Rotoplas Water Storage Tank
Own Elaboration

Base structure

The function of this structure is to be able to load all the components that our test bench needs to be able to perform the simulation of the water of a flowing river and that gives movement to the Kaplan turbine.

We took advantage of a structure belonging to the technological center, which allowed us to use it as the base. We used the features we already had to be able to couple all our components and build the river simulation.

Figure 2 Test bench base
Own Elaboration

Characteristics:

1. The total length of the test bench is 147.5 cm
2. Its width is: 47.4 cm
3. It has three sections on one side, where in the upper part the Rotoplas will be placed, in the middle part a part of the step valve will be placed and in the lower part will be an empty space to place equipment that is needed (Tools, accessories, etc.)
4. It has 4 wheels to make your transfer to another place is easier.
5. Here we will only have a cost of 50 pesos for the purchase of the tables in the upper section and in the middle.

PVC pipes

These pipes are the ones that will help the water to reach its destination, pvc was selected for the following reasons:

1. It is an easy material to find and suitable for water management, plus it was easy to acquire (pipes, fittings, etc.)
2. Its low cost, easy installation, and low maintenance.
3. Durability, this type of materials does not need to be changed frequently.
4. Light Elements, with what was investigated it was found that the pipes of these materials are the lightest on the market, this helps that at the time of their installation and transfer there is too low a risk for there to be any possibility of being damaged.
5. Resistant to corrosion and erosion, since PVC is a material that is not affected by corrosion both underground and outdoors or indoors and this is a very important factor because as we mentioned above the contact with water will be constant since in addition to working with it, it is located to the environment in the State of Mexico, where there is constant rain.
6. Long Shelf Life, PVC suppliers mention that they have recorded more than 50 years of useful life in this type of pipes and scientists from Australia made a study in 2014 in which they mentioned that they can last more than 100 years.

During the test bench, 2 types of PVC pipes, sanitary PVC and hydraulic PVC were occupied.

Figure 3 Sanitary PVC Pipe
Own Elaboration

Figure 4 Hydraulic PVC
Own Elaboration

Characteristics:

1. The two PVC pipes are 4 inches in diameter
2. The existing difference from one to the other is that the thickness of the wall is larger in the Hydraulic than in the sanitary, so it resists better the high temperatures.
3. Sanitary PVC pipe 76 cm long
4. Hydraulic PVC pipe 50 cm long
5. Cost: PVC Sanitary 40.00 pesos
6. PVC Hydraulic 0 pesos, the reason why the store gave it to us.

Note: Our system is not going to be exposed to high temperatures which is one of the reasons why hydraulic PVC is used, but the only valve that met the measures we needed was this type of PVC.

Step or ball valve

This is one of the valves that are most used when a constant opening and closing is required in a piping system. The main reason why we came to install this valve was because we could control in a more precise way the passage of water to modify the necessary amount that passes and be able to determine the ideal flow to have the best performance of our turbine.

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Also, for its size and the way in which it is constituted, it is one of the most resistant valves that could be obtained, in addition to comparing it in price with other valves that were for sanitary PVC, this was the best option if we see it in the cost-benefit way.

Figure 5 Ball Valve
Own Elaboration

Characteristics:

1. 4-inch Ball Valve.
2. Valve for hydraulic PVC making it stronger than a normal valve
3. PN10 150 PSI 10K
4. Cost of $1,050.00 pesos

90° elbow

Accessory that was acquired to be able to connect with the correct direction the Rotoplas tank to the balloon valve, using of course the PVC pipes, in this part of the project a 90° elbow was used because there was the need to place the PVC pipe where the water passes in the first section parallel to the tub.

Characteristics:

1. Cost 167.00 pesos
2. 90° elbow for Hydraulic PVC

Figure 6 45° elbow
Own Elaboration

Accessory used to define the output of the water to the tub that contains the Kaplan turbine, with this elbow we could define the angle of attack of the water towards the turbine so that it was the ideal since this would serve to give a greater power to the turbine, this in the way that the water would enter with the flow that would be leaving the pipe without having losses somewhere in the tray, in addition, its displacement to enter the turbine was not complicated. (see its placement in Figure 34, the final assembly)

Figure 7 45° elbow
Own Elaboration

1. Cost: 21.00 pesos
   PVC sheet

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Polyvinyl chloride sheet provided by Professor Franco David to help the test bench in two ways:

1. To be able to define a curve in the tray and that there would be no water losses on our test bench.
2. It also helped us to adjust the sanitary PVC pipe to our valve since there was a separation in the thicknesses of these that made our pipe not completely impregnate with the risk that it would decouple from the valve (Observe in the final assembly)

Figure 8 PVC sheet
Own Elaboration

Aluminum Disc

As we can see in the figure below our aluminum disc occupies the function of holding the Kaplan turbine while it performs its movement and is supported with a complement which has a built-in bearing. In addition, it also has the task of holding the power generator so that the process of transformation from mechanical to electrical energy is carried out in a corresponding manner.

Figure 9 Aluminum Disc
Own Elaboration

This aluminum disc was already in the Technology Center, but it was necessary to make the modification to adapt it and comply with the conditions.

Characteristics:

1. Aluminum Composition
2. Weight 3 kg
3. Diameter 356 mm = 35.6 cm

Sealed ball bearing

This bearing is one of the most common on the market, being able to withstand axial and radial loads. One of its main characteristics is the speed of rotation that these counts since it is higher than that of other types of bearings.

This was one of the main characteristics that we considered to select this bearing, since it was going to be coupled to the Kaplan turbine, which will have the work of turning to transform the mechanical energy into electrical, therefore, it was important that the rotation was not limited in some way.

Figure 10 Ball Bearing
Own Elaboration

Characteristics:

1. Outside Diameter of 16 mm
2. Interior diameter of 8 mm
3. Width 5 mm
4. Material: High carbon steel
5. Cost: 20 pesos

Asparagus 1/2''

The asparagus has the function of holding and giving the necessary height to the turbine to be in the ideal area at the entrance of the water, these bars would be placed in the supports responsible for keeping the aluminum disc static.

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At the beginning they chose to place some construction rods of 1/4 "to support the turbine, but they began to find some small inconveniences at the time of the first assembly of the test bench, so it was recommended to change the rods for asparagus.

Figure 11 Asparagus
Own Elaboration

Characteristics:

1. 1/2" threaded rod or sprat
2. Length of 91 cm
3. Quantity 2
4. Material: Metal
5. Cost 50 pesos each, total: 100 pesos

Base/Bra/Disc Holder

One problem was the way in which the disk would have to be held so that there was no movement in the turbine (only its rotation) and in the generator when the flow of water met our turbine. So the following design was made in the Solidworks software:

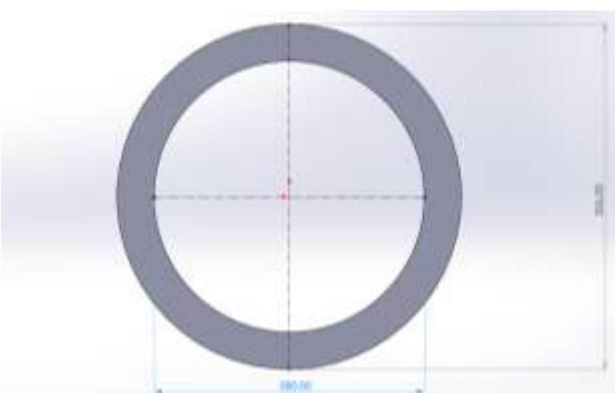

Figure 12 Top View of the Media Design
Own Elaboration

The diameter of the aluminum disc was replicated in the design so that the entire circumference was the same and there were no problems where the curves did not fit into the disc and its support. While the inner diameter was designed of 280 mm so that the area it held was spacious enough to keep the disc without fear of it coming out and that it was not too large so that at the time of being printed a lot of material and hours were used, since it was prototype.

Figure 13 Side View of the Media Design
Own Elaboration

With respect to the separation distance between the upper and lower face so that the disc entered adjusted and did not get to move was 7 millimeters. Then we proceeded to cut the support at an angle of 45 ° to cover a wide distance from the disc and not get to occupy a large amount of material in these first pieces.

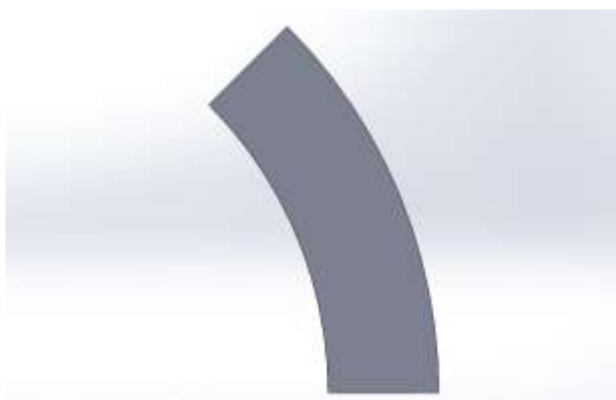

Figure 14 Top View of Clipped Bracket
Own Elaboration

After the cutout, what was seen was the thickness of the face of the top and bottom, where the bottom would have priority with respect to its thickness since it would be the one that carried the weight of the aluminum disc so based on trial and error it was determined that it had a thickness of 4.7 millimeters while the upper face was 2.7 millimeters.

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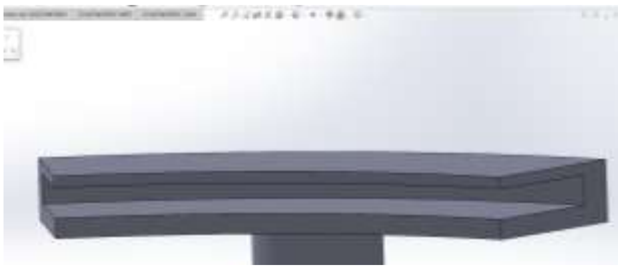

Figure 15 Media Faces
Own Elaboration

Then the next process was the design of a Coupler which met the following requirements:

1. Have the diameter corresponding to the 1/2" rod
2. Cover a relatively wide space for efforts
3. Have a thickness in such a way that it does not break.

And this was the result.

Figure 16 Test couple
Own Elaboration

The final design of the piece was as follows:

Figure 17 Aluminum Disc Support
Own Elaboration

In the end we occupied the 3D printer to be able to have three prototypes in physical and begin to perform the tests with these supports and realize the defects that could come out and the improvements that they could have.

Figure 18 Printed Media, Front View
Own Elaboration

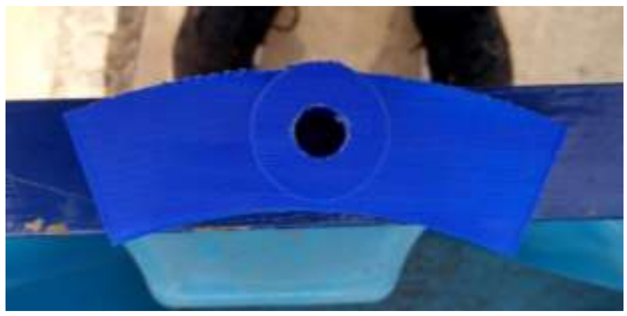

Figure 19 Printed Media, Bottom View
Own Elaboration

Bearing and its compartment

Figure 20 Bearing
Own Elaboration

For this design we based ourselves on the bearing and the compartment that was originally in the aluminum disc but adjusting it to the necessary measures for our new bearing, in addition to the fact that the previous compartment was already in oxidation condition and the bearing was broken.

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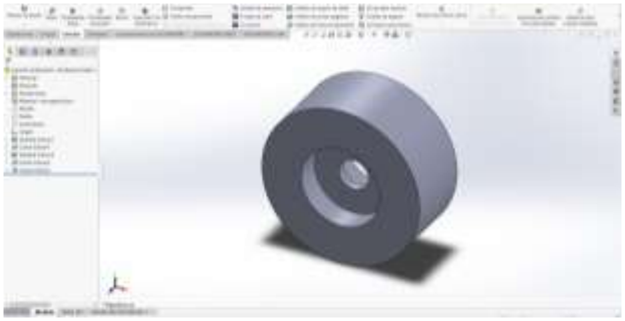

Figure 21 Bearing Compartment Design
Own Elaboration

Characteristics of the part:

1. Outside diameter of 64 mm (Original size)
2. Inside diameter of 32.05 mm (Adjusted to bearing diameter)
3. Auger diameter of 12.10 mm (Made with respect to turbine shaft diameter)
4. Volume 28.75 mm (Original size)
5. 9.96 mm cut on the front face with respect to bearing volume
6. Material: PLA (Also known as Polylactic Acid)

Bearing couple

This part was based on the design of the original couple which was responsible for pressing the bearing compartment and as a result remained static while the turbine was rotating by the impulse of the water.

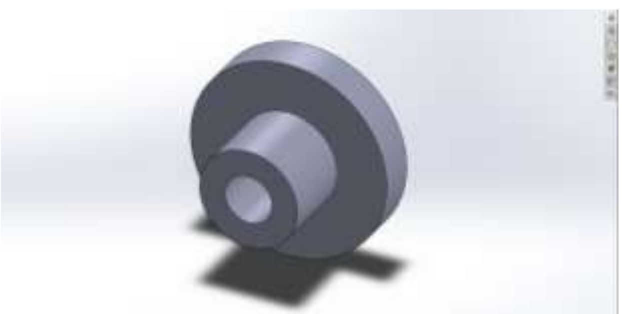

Figure 22 Compartment couple
Own Elaboration

As well as the bearing compartment, some adjustments had to be made to be able to be used with respect to the needs of our test bench.

Characteristics:

1. Auger 12.50 mm in diameter
2. Outside core diameter 51.65 mm
3. Outside body diameter 25.80 mm
4. Inside body diameter 25.80 mm
5. Core height 10 mm
6. Body height 20 mm
7. Total height 30 mm
8. Material: PLA

Asparagus stands

Other problems that came to be had were the way in which the asparagus would be held to always stay straight while there was movement and the weight of the disc, the generator and the turbine were constant. What was devised was the design of some supports which could cover a certain length of the base of the asparagus to keep it fixed while working so the first design was as follows:

Figure 23 Asparagus Support
Own Elaboration

This support was designed with a base of 30 millimeters in diameter with the aim that for some effect the support did not get to pass to the other side of the tray and with a thickness of 5 millimeters.

Then that the body had an outside diameter of 15 millimeters so that it entered the tray under pressure and that at the time of receiving the load weight it was not pushed easily and as a result it went out of the tray.

And finally, with an interior diameter of 12.40 millimeters that would be the size of the auger. At first it was thought that the supports were designed in such a way that a rod crossed them with relative ease but then with the advice of Mr. Franco it was determined that it would be better to make inner rope.

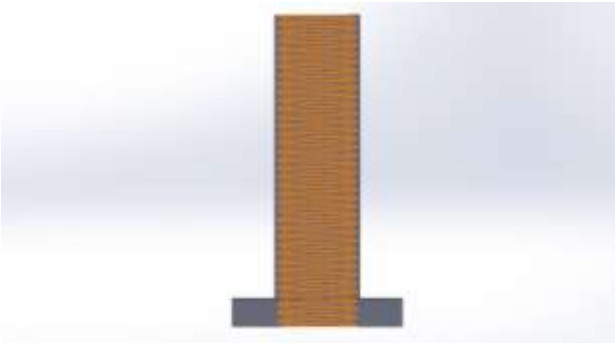

Figure 24 Inner Thread
Own Elaboration

By means of boards and with the threading that has the asparagus was chosen in the design a thread M20x1.5 since this measure is used for the female thread that has a diameter of 18 millimeters and as our asparagus is 17.8 millimeters was the closest value to the ideal.

Figure 25 Asparagus Support Prototype
Own Elaboration

The first design that was printed had the defects that the body of the support was a little thin so that in the first installations they came to break and came to separate from the base applying a not-so-great force. Then with these attempts, a redesign was made to the piece covering the errors that occurred and the piece was as follows:

Figure 26 Asparagus 2.0 Support
Own Elaboration

Now for this second piece the aspects that had failed in the first version were improved as follows:

1. The walls of the body thickened, so from having a 1-millimeter wall it thickened to a 3-millimeter wall.
2. The auger was made of the measure corresponding to asparagus.
3. A chamfer was made to make it difficult to separate the body from the base.
4. For the final piece the quality of the material was improved, and more material was added at the time of printing.

Tray

Figure 27 Tray
Own Elaboration

One of the main instruments where the stud supports are going to be placed and which has the job of holding the asparagus, the Kaplan turbine, the aluminum disc, and the power generator.

This idea was proposed because of the features we needed for a base that were as follows:

1. Have a size that covered 44 centimeters to be able to have the support of the base structure
2. That it did not suffer any damage when in contact with the water
3. A non-high cost
4. Preferably had a structure of circular shape or with some curvature to be able to define the water inlet in a simpler way
5. Walls high enough to prevent water from leaving the structure, even if the flow of water was large

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Complying with the following characteristics we observed that this tray was the best option we had, so after this we proceeded to prepare it to start with the first assembly.

The modifications that were made were as follows:

1. The measurements were made to make 3 holes and that they were at an equal distance and to be able to introduce the first supports
2. Holes were also made to the sides to be able to attach to the base structure and with this avoid unwanted movement

Figura 28 Interior of the Tray with the brackets
Own Elaboration

After making the adaptations for the tray proceeded to perform the first assembly of the test bench.

1. Cost: 97.00 pesos

Water drain pump

For our project to be a closed cycle we require that there is a return of the water that falls in the tub to the Rotoplas, so we use a washing machine drain pump to be able to return the water that accumulates in the tub to the Rotoplas.

This pump had a cost of $ 199 pesos, although we had to make some small modifications to be able to have it submerged in our tub without there being the problem of a short circuit (but for any risk it can also be used outside the tub).

2. Kaplan turbine

Our main objective in our project is the realization of the design and construction of the test bench, but with regard to the construction of the Kaplan turbine it is also important here since it is the equipment, which would make the transformation from mechanical to electrical energy and which will say if our test bench is functional, so we made the decision to select the design of a Kaplan turbine awarded by Engineer David Franco that would fit the size of the test bench to begin printing it in 3D and abs plastic.

Kaplan Turbine Printing Time:

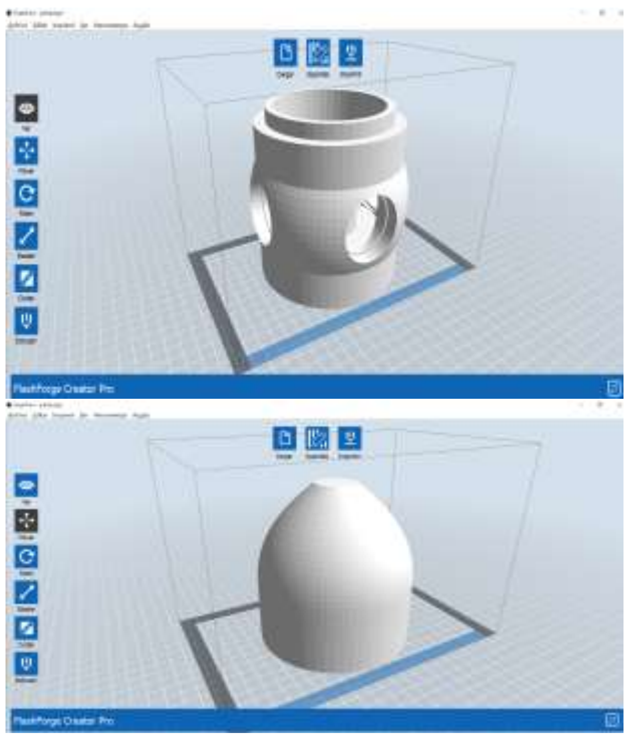

Figure 29 Turbine body: 10 hours and Turbine head: 8 hours
Own Elaboration

Figure 30 Kaplan Turbine
Own Elaboration

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Although it is not the purpose of this thesis to carry out a cost analysis of the project, it includes as a reference the total cost of all the components we acquired for our test bench, which amounted to 3495 Mexican pesos, to which we will have to add the cost of the structure and the components that we were granted free of charge, labor, as well as the use of software and overheads.

After knowing the components, their characteristics and function, now it's time to join the whole test bench.

3. Arming the Test Bench 1

1. After the tub was painted, we proceeded to mount it inside the base structure and arrange it so that it was in the ideal position so that there would be no leak when the water came out of the channel.
2. The Rotoplas was drilled at the bottom and inserted (in addition to fixing) the couplet where the PVC pipe that would serve as a channel was to be placed.
3. It was mounted on top of the base structure of the Rotoplas, accommodating the couple with respect to the auger made in the wood of the upper part so that it was the best centered.
4. Then the first section of hydraulic PVC was mounted that would be the exit of the water from the Rotoplas to then the balloon wrench.

Figure 31 Section #1
Own Elaboration

5. The 90° elbow was connected to the first section, which would serve to orient the channel towards the tub and the turbine that would later be placed.
6. The tray was placed in the third section of the base structure, put on the tub and then tied to the ends to give it more stability in this first assembly.
7. At that time the rods were inserted into their supports and then placed on top the supports that were going to be attached to aluminum disc.
8. We place the aluminum disc in each of its supports.
9. When we finished seeing that there was not much movement until I developed the work, the turbine support, and the Kaplan turbine itself were placed on the aluminum disc.

Figure 32 Mounted Tray
Own Elaboration

1. After we finished assembling the turbine section, the second section corresponding to the step valve and the last section of the PVC that ends up running off in the turbine section was placed. In the following image you can see the final assembly.

(Note: During the first assembly of the test bench no modification had been made to the problems that were encountered and then changed.)

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Figure 33 Test Bench 1
Own Elaboration

When the first assembly was finished, the first tests were made regarding the discharge of water into the canal and that all sections were properly connected so that there would not be a leak at some point.

Figure 34 Water flow test
Own Elaboration

After the first assembly was carried out, the first problems were discovered, which were:

1. Lack of stability with only 3 supports
2. The rods placed denoted a little volume that affected by holding the structures at the top
3. The supports of the rods were broken when they were removed.

For the resolution of these problems, I will make a summary and list of them:

1. Lack of stability and Rods

   About the lack of stability, the way it was solved was to first change the rods we used to asparagus that had a larger diameter, this would bring greater stamina to the efforts and.
   Modification: Change from 1/4" Rod to 1/2" Threaded Rod

2. Broken Supports
   For the broken supports, it was modified in design of them increasing the thickness of these, in addition to which a chamfer or bevel was made to reinforce the resistance to the load that the supports would have with respect to the asparagus.
   For each reprint with the improvement of the supports it took us a total of 51 minutes, for 4 pieces, then we took a total of 3 hours and 24 minutes to have all the pieces ready.

After the correction and printing of the new pieces proceeded to perform the second assembly of the test bench, but now if in order that this test bench was the end.

4. Arming the Test Bench 2

During the start of the second assembly of the test bench we began by adding a wire with peg to the drain pump and sealing the ducts through which the electricity comes to pass so that there is no short circuit, since our pump will be submerged to raise the water to a height of 1 meter and 60 cm.

Figure 35 Pump
Own Elaboration

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After we took the height with which our pump could raise the water, we fixed a couple in the Rotoplas where the water would enter and then placed the hose, in addition to that to solve the problem that there was no garbage, leaves or sticks inside the tub we placed a metal mesh

Figure 36 Rotoplas and hose
Own Elaboration

We then placed the asparagus in the new tray with its new supports, which caused the stability problems and weak structures to be corrected and left in such a way that the stability was greatly improved without being completely aligned at first.

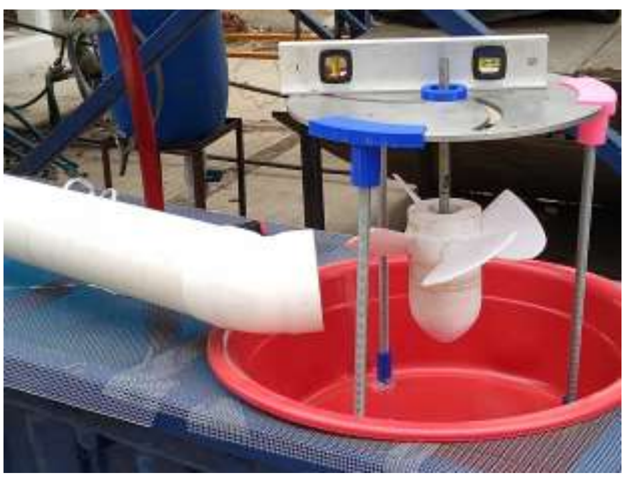

Figure 37 Disk Alignment
Own Elaboration

After these changes, we made sure that both the tank and the tub no longer had any kind of solid, be it a garbage, rock inside them so that they did not affect our system, especially the pump and the turbine, all this to start starting our test bench.

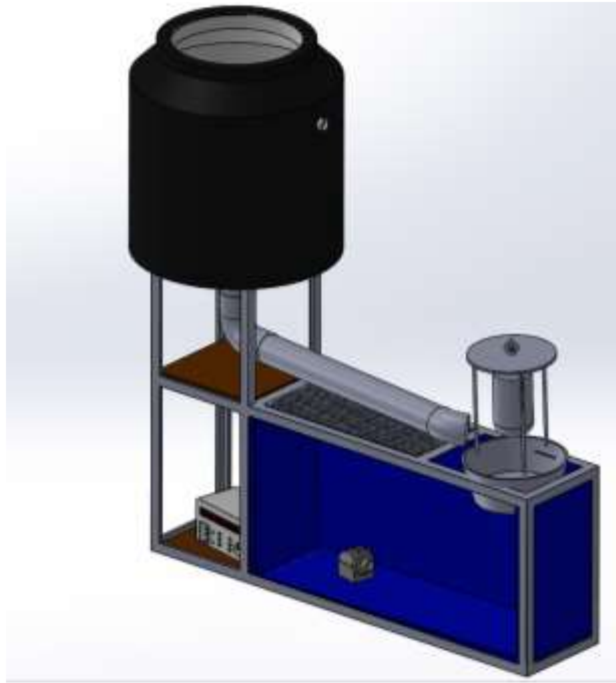

Figure 38 Bench Design in Solidworks
Own Elaboration

5. Calculations

In this section we develop the calculations of the main values that must be corroborated in the test bench, they will be calculated in a theoretical way at this time since the pandemic has not allowed us to start real tests.

Hydraulic diameter

For the hydraulic diameter when having a circular pipe its measurement will remain at 4" = .1016 m = 10.16 cm

Using the following formula:

$$Dh = \frac{4\cdot\frac{\pi\cdot D^2}{4}}{\pi\cdot D} = \frac{4\cdot\frac{\pi\cdot(.1016\,m)^2}{4}}{\pi\cdot(.1016\,m)} = .1016\,m \qquad (1)$$

Flow in the pipe

About the measurement of the flow what was done was that the Rotoplas of 120 Liters was filled, then we proceeded to open the key to passage to 3/4 where it was the ideal opening and took the time in which it was emptied, and it was obtained that in 2 minutes our tank was empty.

$$Q = \frac{120\,litros}{4\,minutos} = 30\,\frac{L}{m} = 500\,\frac{ml}{s} \qquad (2)$$

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Average Speed

Occupying the formula 2, using the transverse area occupied in the hydraulic diameter and substituting the variables we have:

$$500\ \frac{ml}{s} = (8.10x10^{-1})\bar{v}$$

Changing positions, you have:

$$\bar{v} = \frac{.500\ \frac{m^3}{s}}{(8.10x10^{-1})m^2} = .6172\ \frac{m}{s}\left(\frac{3600s}{1h}\right)\left(\frac{1km}{1000m}\right) = 2.2\ \frac{km}{h} \qquad (3)$$

Yields

For the calculation of the yields in our test bench when having the turbine installed, we must consider the equation of the transformation of the energy that will exist from the top of the Rotoplas (point A) to the bottom of the tub (Point B).

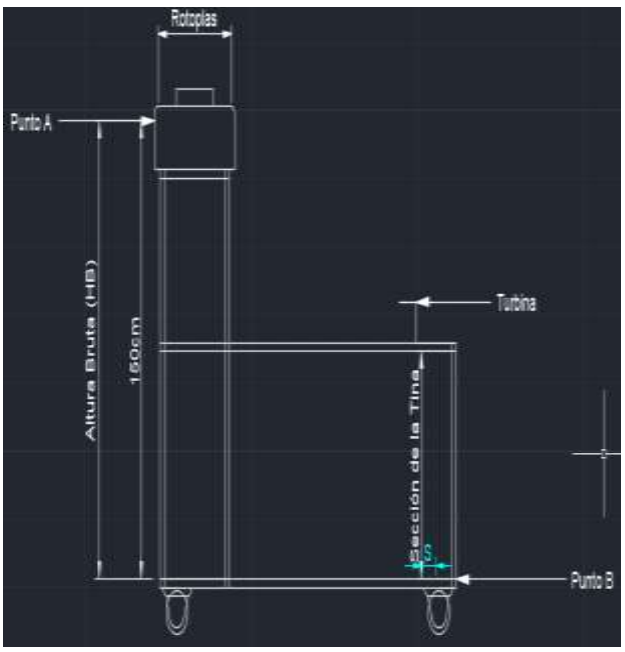

Figure 39 Benchmark Schematic
Own Elaboration

$$z_A + \frac{P_A}{\gamma} + \frac{V_S^2}{2g} = z_S + \frac{P_S}{\gamma} + \frac{V_S^2}{2g} + \sum h_{A-S} \qquad (4)$$

$$\gamma = \rho * g = Densidad * gravedad$$
$$Z_{Punto} = Energía\ Potencial\ en\ el\ punto$$

This variation of energy will be established by Bernoulli's equation, where the energy of point A minus the energy extracted by the turbine will be equal to the energy in the output section (S) plus the sum of all load losses from point A to point S.

As our test bench is not an ideal system, there will be friction losses from point A to point E (from rotoplas to the turbine inlet). These load losses are due to friction losses and the loss due to accessories of our hydraulic system represented in the following equation.

$$H_B = H_E + \sum h_{a-s} \qquad (5)$$

Then the next equation represents the height in the output or discharge chamber

$$H_s = Z_s + \frac{Ps}{\gamma} + \frac{v_2^2}{2g} \qquad (6)$$

And its differential will give us the Net Height that exists in our system

$$H = H_E + H_s \qquad (7)$$

Load losses

To know the yields that will exist in the turbines used in the test bench we first have to know the losses that will exist in the route using the Darcy-Weisbach equation:

$$hf_{A-s} = F\ \frac{L_T}{D}\ \frac{v_2^2}{2g} \qquad (8)$$

Where we do not know the coefficient of friction, so we occupy the coefficient of friction Swaime-Jaine that gives us a result very similar to the ColeBrooke:

$$F = \frac{1.325}{\left\{\ln\left[\frac{\varepsilon_r}{3.7D} + \frac{5.74}{Re^{0.9}}\right]^2\right\}} \qquad (9)$$

But before we need to know the reynolds number and the absolute roughness of our pipe (PVC), for the latter we are going to tables 1 and 2.

Material	Manning's Coefficient n	Hazen-William's Coefficient C_H	Absolute roughness Coefficient e (mm)
Asbestos (cement)	0.011	140	0.0015
Brass	0.011	135	0.0015
Partition Wall	0.015	100	0.6
Cast iron (new)	0.012	130	0.26
Concrete (metal formwork)	0.011	140	0.18
Concrete (wooden formwork)	0.015	120	0.6
Concrete	0.013	135	0.36
Plastic (PVC)	0.009	150	0.0015
Lead	0.011	135	0.0015
Copper	0.011	135	0.0015
Corrugated steel	0.022	---	45

Table 1 Absolute Roughness of Materials
Source: Computer Applications in Hydraulic Engineering, 5th Edition, Haested Methods

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And for Reynolds number we occupy his formula:

$$Re = \frac{v*D*\rho}{\mu} = \frac{(Velocidad)(Diámetro)(Densidad)}{Viscocidad} \quad (10)$$

Where we know that our speed is .6125 m/s, the diameter of our pipe is .1016 m, the density of water is 1 kg/m^3 and the dynamic viscosity is obtained by tables.

Tempeture °C	Dinamic viscosity Kg/(m*s)	Tempeture °C	Dinamic viscosity Kg/(m*s)	Tempeture °C	Dinamic viscosity Kg/(m*s)
0	0.001792	34	0,000734	68	0,000416
1	0.001731	35	0,000720	69	0,000410
2	0.001674	36	0,000705	70	0,000404
3	0.001620	37	0,000692	71	0,000399
4	0.001569	38	0,000678	72	0,000394
5	0.001520	39	0,000666	73	0,000388
6	0.001473	40	0,000653	74	0,000383
7	0.001429	41	0,000641	75	0,000378
8	0,001386	42	0,000629	76	0,000373
9	0,001346	43	0,000618	77	0,000369
10	0,001308	44	0,000607	78	0,000364

Table 2 Dynamic Viscosity of Water at various temperatures
Source: https://www.academia.edu/7129909/Viscosidad_din%C3%A1mica_del_agua_l%C3%ADquida_a_varias_temperaturas?auto=download

Using the viscosity of 0.0015 (pa/s) we have:

$$Re = \frac{\left(.6125\frac{m}{s}\right)(.1016\,m)\left(\frac{1kg}{m^3}\right)}{0.0015\frac{kg}{m*s}} = 41.4867\ldots\ldots Flujo\ Laminar \quad (11)$$

Since we have the Reynolds number what we do is replace the unknowns in our Swaime-Jaine formula:

$$F = \frac{1.325}{\left\{\ln\left[\frac{0.0015\,kg/m*s}{3.7(.1016m)}+\frac{5.74}{41.4867^{0.9}}\right]^2\right\}} = 0.5269 \quad (12)$$

We now replace our Friction factor (F) in our loss calculation along the pipe:

$$hf_{A-S} = (0.5269)\left(\frac{1\,m}{0.1016\,m}\right)\left(\frac{(0.6125\frac{m}{s})^2}{2\left(9.81\frac{m}{s^2}\right)} = 0.0991\,m \quad (13)$$

We will have to have a loss of 0.0991 along our pipe, but by having a 90° elbow and a ball valve we must get their losses that exist. By tables we find the coefficient of friction of each accessory, considering that all the accessories are coupled and 4 ":

Nominal Diameter, in									
	Thread				Coupled				
	½	1	2	4	1	2	4	8	20
Valves									
Ballon	14	8.2	6.9	5.7	13	8.5	6.0	5.8	5.5
Gate	.30	0.24	0.16	0.11	0.80	0.35	0.16	0.07	0.03
Retention	5.1	2.9	2.1	2.0	2.0	2.0	2.0	2.0	2.0
Angle	9.0	4.7	2.0	1.0	4.5	2.4	2.0	2.0	2.0
Elbows									
45°	0.39	0.32	0.30	0.29					
90°	2.0	1.5	0.95	0.64	0.50	0.39	0.30	0.26	0.21
180°	2.0	1.5	0.95	0.64	0.41	0.35	0.30	0.25	0.20

Table 3 Coefficient of loss K, for open valves, elbows and te
Source: Fluid Mechanics, Frank M. White

Calculation of Load loss for the elbow of 90°:

$$h_{90} = k\frac{v^2}{2g} = (0.30)\left(\frac{(0.6125\frac{m}{s})^2}{2\left(9.81\frac{m}{s^2}\right)} = 0.0057\,m \quad (14)$$

Calculation of Load Loss for the balloon valve:

$$h_{va} = k\frac{v^2}{2g} = (6.0)\left(\frac{(0.6125\frac{m}{s})^2}{2\left(9.81\frac{m}{s^2}\right)} = 0.1147\,m \quad (15)$$

We add up all load losses:

$$\sum pc = hf_{A-S} + h_{90} + h_{va} = 0.0991m + 0.0057m + 0.1147m = 0.2195\,m$$

Pressure Drop

By having all the load losses, we can now calculate the pressure drop that exists:

$$\Delta P = \gamma * \sum pc = \left[\left(1\frac{kg}{m^3}\right)\left(9.81\frac{m}{s^2}\right)\right](0.2195\,m) = 2.1533\frac{kg}{m\,s^2} = 2.1533\,Pa \quad (16)$$

Our pressure drop is 2.1533 Pascals.

Now that we have the load losses, we can go back and find the yields that are going to exist in the occupied turbines on the test bench as follows:

We have that H_B is equal to 190 cm, our losses to 21.95 cm, so we clear the formulas

$$H_E = H_B - \sum h_{a-s} = 190cm - 21.95cm$$

$$H_E = 168.05\,cm = 1.68\,m$$

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Now for Hs we replace the unknowns considering that our pressure at the outlet will be atmospheric as at the entrance, this will cause that being the same will give us 0 and our Zs will be given by the height of the water outlet in the turbine:

$$H_s = Z_s + \frac{Ps}{\gamma} + \frac{v_2^2}{2g} = .5700\ m + 0 + \frac{(0.6125\frac{m}{s})^2}{2(9.81\frac{m}{s^2})} = .5700m + +.0191m$$

$$H_{s=}.5891\ m = 58.91\ cm$$

By having our heights both at the entrance and at the exit we can now know our net height:

$$H = H_E + H_s = 1.68\ m + .5891\ m = 1.8691\ m = 186.91cm$$

Then these are all the data that are obtained in our test bench and that influence when making calculations in the turbines that are installed, for example:

If we want to know the power in a turbine what we do, we use the formula:

$$P = Q * \rho * H * g \tag{17}$$

By substituting with our variables and converting our flow rate to (m^3/s)

$$P = 0.0005\ \left(\frac{m^3}{s}\right) * \left(1\frac{kg}{m^3}\right) * (1.869\ m) * \left(9.81\frac{m}{s^2}\right)$$

The power absorbed from the turbine used is $9.1674x10^{-3}$ watts, power suitable for a small turbine. To know the manometric performance we can use the formula:

$$n_{man} = \frac{H_{u\infty}}{H} = \frac{175\ cm}{186.9\ cm} = 0.9363 \tag{18}$$

Which falls into the range of gauge efficiency.

And we can complete all the necessary calculations that involve the turbines in our system, varying the factors of fluid entry, opening, and closing the valve, etc., until we find the ideal point that allows us to make the turbine design more efficient, using the facilities that our test bench gives us, which behaved as expected.

Conclusions

The generation of hydroelectric power in Mexico is a very important resource, since not only Mexico has been a precursor since the beginning as other countries to build hydroelectric plants using turbines of different types, also because in our country we have a geography which helps the creation of new hydroelectric plants. This has the advantage that it is currently being tried in various parts of the world, both in Europe and in South America, to make a change from the use of hydrocarbons to forms that pollute the environment less and these plants are a quite viable option because they have low pollution rates.

This is a project that was developed with the objectives of the design from scratch to the physical creation of a test bench for turbines, specifically for Kaplan type turbine where tests can be carried out in a controlled environment where new turbine designs are put into practice to know their operation in a scaled way and then be able to take them to production and installation in different regions.

While the second objective is linked to the academic field, referring to the possible development of test benches where students can learn in a practical way lessons such as the triangle of speeds, flow, calculation of losses, behavior of Kaplan turbines and their use in electric power generation, among other lessons of the subject of Hydraulic Machines since talking to friends of other engineering many of them present problems when they come to eat near to see these lessons and do not know how to interpret as the physical effect of all these variables.

This document has the realization of various plans with all the specifications to recreate the test bench for future users interested in its recreation and I leave the recommendation to make a turbine in aluminum or some alloy to improve its characteristics, in addition to that it could improve the base where the turbine is placed.

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