ARGENTINA

DESIGN OF AN ENERGY GENERATOR DEVICE FROM WATER CURRENTS

The present document develops a source of renewable energy from the water stream in high-flow plain rivers using helical turbines and permanent magnet generators. Its main advantages are the low speed of rotation and its easy construction.



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1 General Introduction

Generally hydraulic accumulation uses are used where reservoirs are built and by means of turbines turbines that are in extreme limit so much in the production as in its structure that does not allow to extend them and that they have complex mechanical systems amplificadores of speed, as well as the electric generators must comply with restrictions on weight dimensions and capacity.

These systems obstruct the courses of the rivers in their channels, in the navigation and in the alive beings that depend of these courses for their subsistence.

In the rivers used as an example for this equipment such as Paraná, Paraguay, Uruguay, Limay, Neuquén, Negro, Colorado, Bermejo, Atuel, Pilcomayo, etc. The characteristics common to all of them is that they possess great flow or volume of water that transports.

The substantial advantage of our proposal is that it can be expanded, moved, does not obstruct the nature of the river and innumerable generators can be placed throughout the course of the river chosen. Both in line or series and in parallel if the width of the river allows. Its action does not contaminate since its parts have components that already exist naturally and do not make noises. In addition, they are able to eliminate floating residues such as discharges into the large rivers that circulate in cities. Waste of all types would not be an obstacle to its proper functioning.

Because of its versatility, its ability to capture even the slowest currents is apt to locate them on the coasts of cities or municipalities that are coastal expanding and distributing the energy load appropriately as required by industries and households.

Its manufacture is very simple and can be armed according to size at the place of placement for later appropriate placement.

Having a river that the bed circulates water as can be a channel also, we see that the energy circulates this is taken advantage of in several branches of the course since it is not easily lost in all its trajectory.

For each particular river case, or if it manifests differences in its flow, velocity, width and other characteristics typical of the energy source, some modifications that have already been thought would have to be adapted. From small to large projects the team is able to give an effective and permanent solution.



2 Marco Teórico

The generator that is intended to be developed is governed by the variation of the amount of movement applied to the fluids.

$$\bar{F} = \frac{d}{dt}(m\bar{V})$$

A control volume is defined that circumscribes the volume of the propeller of the turbine.

Ω_c = Control volume

$\emptyset$ = Outer diameter of the propeller

L = Length of the propeller

The deduction of the general equation of the amount of movement applied to the fluids is obtained by raising the total variation, it can be evaluated by parts, a first taking into account at a given instant the balance between the amount of movement in and out of the surface of control and a second one, taking into account its variation in time, within the control volume, for the time tending to the instant considered.

$$F = \Delta cm_{\Omega_c} + \Delta cm_{t_c}$$

The following differential equation is obtained which expresses the force resulting from all the actuators in the control volume, taking into account the actions that take place over the entire surface of the control volume at a given instant and the dynamic effect of the the variation of the amount of movement within the volume, for the instant under consideration.

$$\bar{F} = \int \rho\bar{V}\bar{V}d\bar{\Omega} + \frac{d}{dt}\int \rho\bar{V}dt$$

This complex equation applies to the one-dimensional flow in a current pipe that has the property of being impermeable (impossibility of normal components) causes the summation to be reduced to only input and output.

By operating and integrating the equation we arrive at the equation of the dynamic action

$$\bar{F} = \rho Q\left(\beta_i\bar{U}_\iota - \beta_f\bar{U}_f\right)$$

To apply the equation the following considerations must be taken into account:

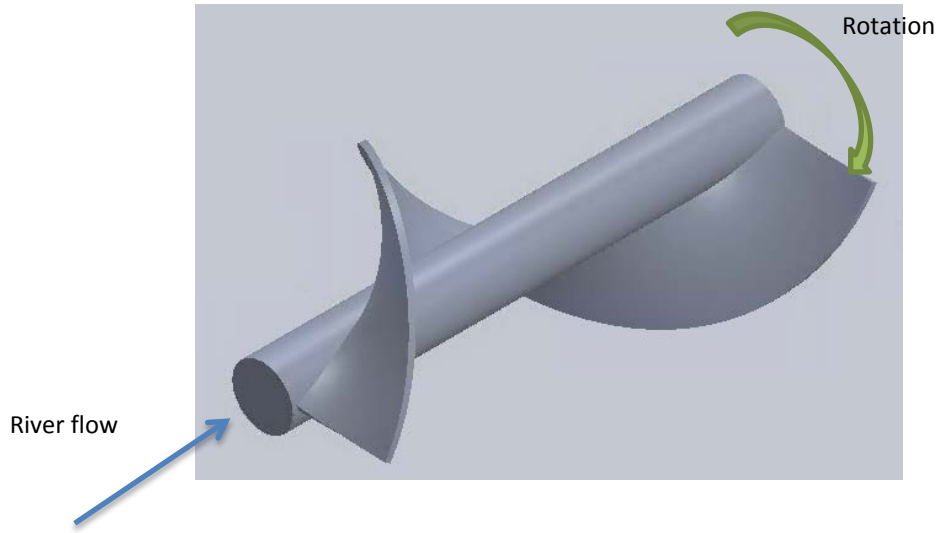
Choice of a control volume, with the necessary amplitude so that the element under study, on which the actions will be determined, is perfectly delimited and can be applied the concept of "free body in balance with the acting forces".

- The volume must be fully filled with the liquid whose actions are evaluated
- The resultant of all forces F must include all forces acting on the control volume.
- The average velocity vector U results from the flow rate Q passing through the considered control surface portion. It is considered applied in the barycentre of the reference section and in the normal direction to it.
- Each product (ρQβU) that integrates the summation will be a vector with the same direction of the velocity vector and with the direction that the runoff takes when passing through the considered surface.

- For the sign the convention (previously advanced) is adopted to consider positive the forces coming from flows out of the control volume and negative for the case of incoming flows.
-

3 Technical aspects of the turbine

Obtaining the formulas that govern the behavior the objective is to deduce the power generated in the axis from the constructive characteristics of the turbine and the speed of the fluid that impinges on the same. The turbine has a single helical blade to maintain the flow as laminar and not to incur turbulence.



In the fluid vein, a differential force is obtained by dynamic action as a function of the fluid velocity and the angle of advance of the propeller:

$$dF = \rho V \sin \propto dQ$$

dF = force differential, $[N]$

ρ = water $[Kg/m^3]$

V = water instant velocity, $[m/s]$

$\sin \propto$ = Tilt angle of propeller

dQ = flow differential$[m^3/s]$

As the flow can be expressed as area by velocity we get:

$$dF = \rho C_p V^2 \sin \propto dA$$

C_p = Coefficient of power (Ver Anexo)

Multiplying the force by the distance to the axis is obtained the torque of differential way:

$$dM = \rho C_p V^2 \sin \propto r dA$$

Integrating the equation gives a theoretical calculation of the torque:

$$M = \int_0^A \rho C_p V^2 \sin \propto r dA$$

The area differential is rewritten as $dA = rdrd\theta$ and the integral is solved:

$$M = \frac{2}{3}\rho V^2 \pi r^3 C_p \sin \propto$$

$M =$ Torsional moment resulting in the axis, $[Nm]$

$$\omega = 2\pi n$$

$n =$ Propeller revolutions, $[1/s]$

$\omega =$ Angular velocity, $[rad/s]$

$P = M\omega =$ The power is equal to the torque by the speed so that operating is obtained

$$P = \frac{4}{3}\rho V^2 \pi^2 n r^3 C_p \sin \propto$$

To simplify the equation we proceed to group design constants.

$$K = \frac{4}{3} C_p \pi^2 \sin \propto$$

The final equation remains:

$$P = \rho V^2 r^3 n K$$

From this formula, it follows that the power depends on the square of the speed and the hub of the radius (dimensions of the helical blades), so that the latter is the preponderant variable when generating power.

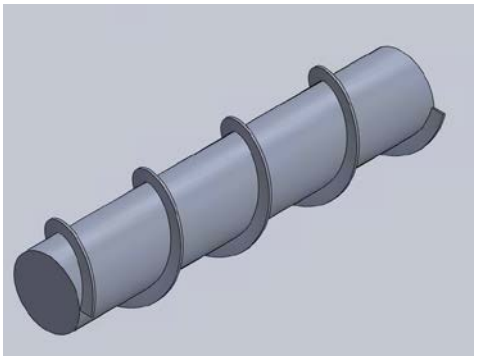
This calculation is based on the hypothesis that the regime at all times is laminar due to the low rotation speeds and the fluid current. The presence of turbulence will cause the value of the power coefficient to drop so that a lower power will be obtained on the axis.

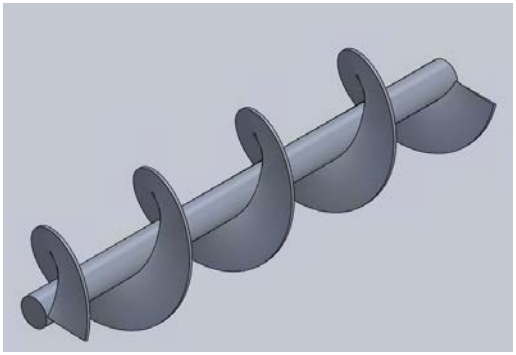
The equation governing the behavior of propeller revolutions will be determined empirically once the pilot plant is available because all system design variables are affected. The adjustment parameter will be the coefficient Cp which will include the friction losses of the system. Also as load is added from the generator we will have lower revolutions on the shaft.

4 Simulations

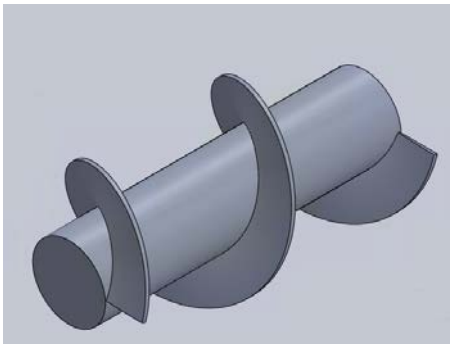
In this section several simulations were made with the Flow Simulation complement of Solidworks modifying the different variables of design of the propeller with the aim of optimizing the obtained power levels. Each of the variables and their incidence is detailed below.

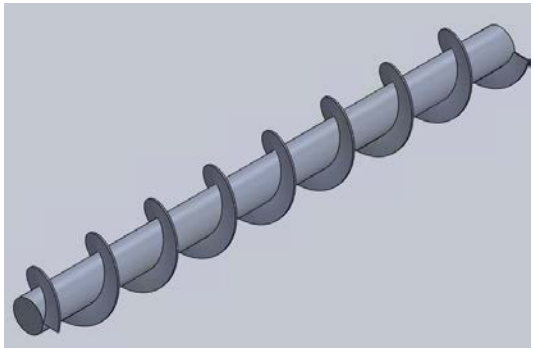
- Relationships between diameters: The relationship between the diameter of the propeller and the one corresponding to the axis has a direct relation to the useful area on which the water flow affects. The objective is to maximize such area by minimizing shaft diameter up to the technical limit of the material and maximizing the diameter of the propeller.





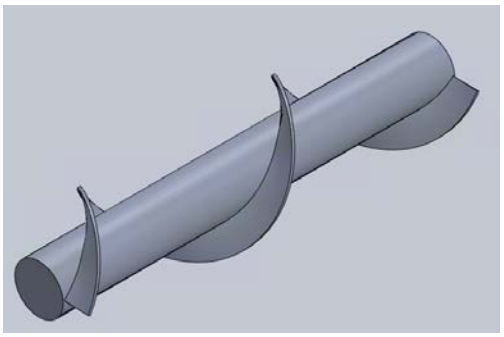
- Length: As the length increases, there is more contact area between the propeller walls and the water flow. This implies a greater power in the shaft but the length cannot extend indefinitely as the losses by friction begin to be too large. Therefore there is a point of maximum power with respect to the length around double the diameter of the propeller.

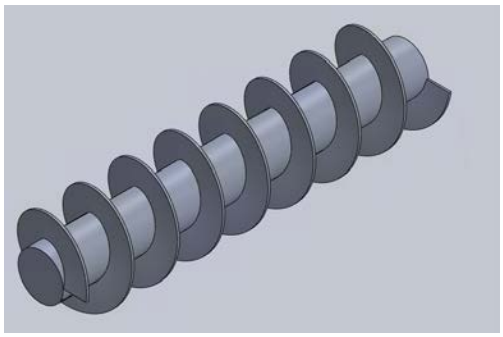




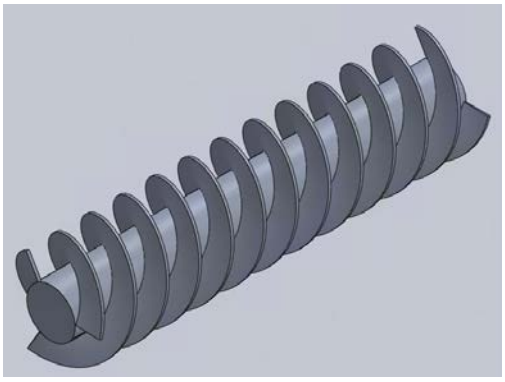
- Step: This variable is fundamental for the operation of the turbine. The higher the passage the less disturbance will be the flow of water so there will be less friction and better power levels will be available. In this case it was obtained that a good starting point for the pitch is that it is

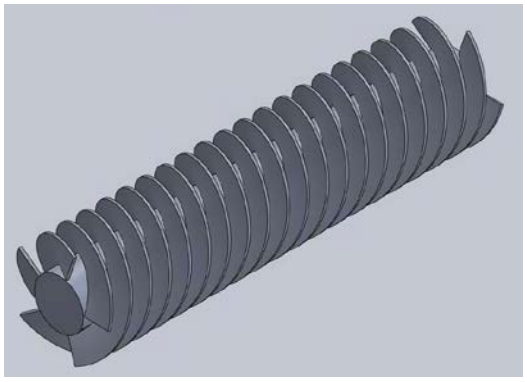
equal to twice the diameter of the propeller. Consequence of this and the previous point will obtain a propeller of 1 single revolution.



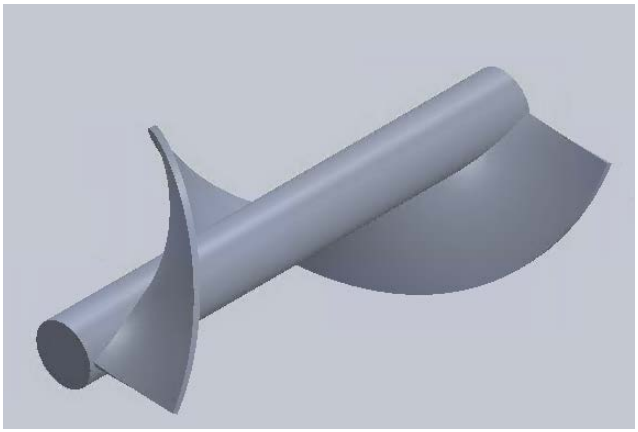


- Number of blades: the simulation showed that the best performance is obtained with a single blade. This is also beneficial for constructive turbine issues

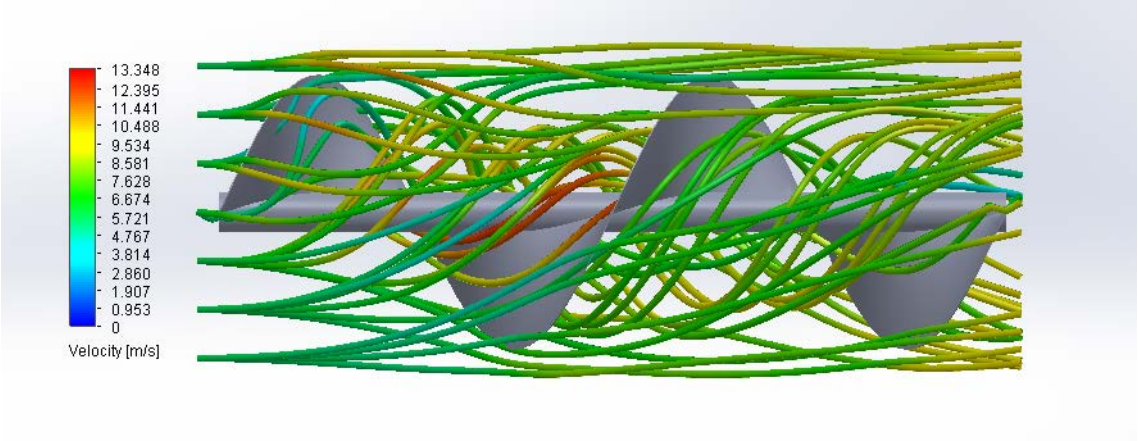




Once the propeller constructive characteristics are simulated individually, we proceed to design the same bearing in mind the conclusions. The following is an optimized propeller. It is dimensionless so that proportions can be maintained regardless of size.



The following is a simulation of a propeller of optimum design but of two revolutions.



It is possible to be observed as the lines of current undergo major change of speed in the first revolution. This again indicates that the second revolution has a smaller contribution to the power generation so it can be omitted. In addition, this variation corresponds to a pressure change by energy conservation in current lines (Bernoulli).

$$P_1 + \frac{\rho {V_1}^2}{2} = P_2 + \frac{\rho {V_2}^2}{2} = cte.$$

$$P_1 - P_2 = \frac{\rho}{2}({V_2}^2 - {V_1}^2)$$

Then we can conclude that the greater the pressure variation obtained, the greater energy transfer will be from the water flow to the propeller, which will result in greater power to the axis.

5 Development of the propeller

In this section we will discuss the mathematical development of the propeller to obtain the design of the turns that once welded will form the propeller from the desired measurements, which are detailed below.

Propeller Design Parameters

$\emptyset_e =$ Outer diameter of the propeller

$\emptyset_i =$ Inner diameter of propeller

$P =$ Propeller pitch

$$A = \frac{\emptyset_e - \emptyset_i}{2}$$

$$E = \sqrt{(\emptyset_e \pi)^2 + P^2}$$

$$I = \sqrt{(\emptyset_i \pi)^2 + P^2}$$

$$r = \frac{PI}{E - I}$$

$$R = r + A$$

$$\Delta = 2\pi R$$

$$\beta = \frac{E \cdot 360°}{\Delta}$$

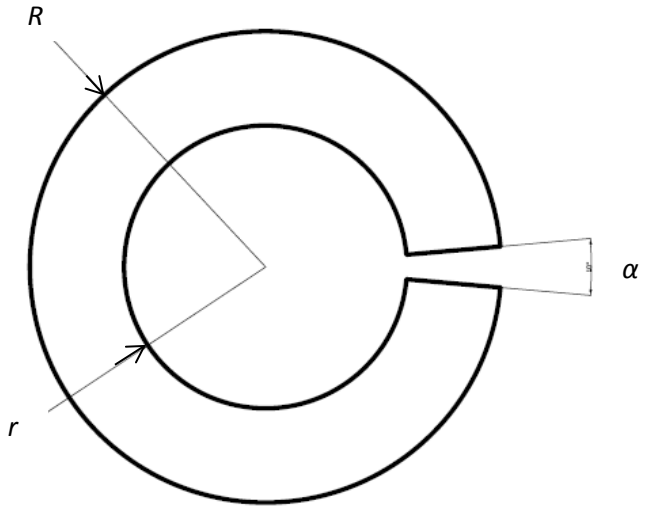
$$\alpha = 360° - \beta$$

Template design parameters

$r =$ Internal spiral template radius

$R =$ Outer spiral template radius

$\alpha =$ Turning angle of the spiral template



From the aforementioned calculations, the measurements of the exact flat template are obtained, which will be used in the manufacture of the helical coils.

The materials with which they will be constructed will vary according to the budgets, the constructive characteristics and the efforts involved. The main material choices are:

- Fiberglass: ease in forming the turns and low stress tolerance.
- Steel: greater complexity in forming and stress tolerance

The maximum dimensions will be subject to the materials used for the construction arriving even to the 4 meters of diameter. The main advantage is when the technological limit is reached it´s simply add additional propellers to reach the required power.

Given the simplicity of the work, the level of training required for manufacturing is not high, which implies a great advantage.

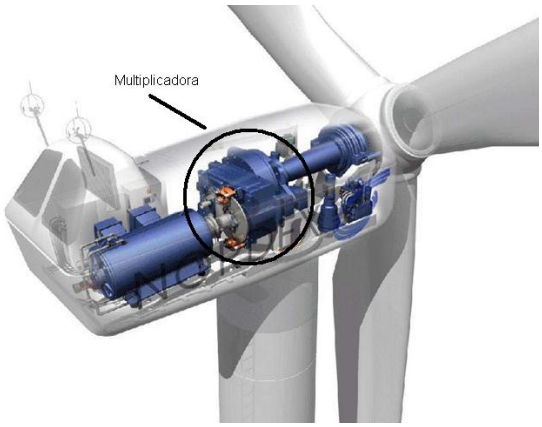


6 Technical aspects of the multiplier

6.1 Planetary multiplier

The planetary multiplier is composed of three elements: a central gear and multiple gears called satellites or planets located around the central axis (hence the name of planetary multiplier) and an inner crown. The input shaft is connected to the central gear, which transmits rotational movement to the planetary gears, which in turn rotate on the internal gear of the multiplier, transmitting movement to the output shaft of the multiplier. The planetary multipliers can be of one or two stages with multiplication ratios of 3 to 200. They are widely used in wind towers because they are compact. The main characteristics of planetary multipliers:

- Helical gears: increase the contact surface by 33% compared to the straight gear, thus achieving reduced play and low noise.
- Thermal treatment of the own gears of plasma nitriding that allows to increase the hardness of the flanks of the teeth achieving a great resistance to wear.
- Monoblock planetary bearing system and conical roller bearings provide high radial and axial loading capacity, increasing system reliability and strength. This minimizes misalignment of the gear and achieves greater accuracy.
- Triple-slot clamping system and balanced coupling ring for power transmission without play or sliding. Total concentricity of the shaft that provides smooth turning and allows to support higher speed of entry.





6.2 Parallel Axis Multiplier

Geared multipliers are simpler than planetary gears because they have fewer moving parts and therefore are more economical. As a disadvantage we can mark that they need more space to be able to match the multiplication ratio than a planetary one. As an example we have a gear multiplier for a tractor power take-off that have a multiplication factor of about 3.3 (usually the power take-off is 450 rpm and delivers 1500 on the high shaft).





7 Technical aspects of the generator

Once extracted the power of the river, and transferred to the axis of the generator, it is necessary to convert that mechanical power of rotation into electrical power. To this end a synchronous generator is coupled to this moving shaft.

A single-phase synchronous generator consists of an elementary rotary machine formed by a rotating constant magnetic field and a static flat coil; then such rotation of the field causes a temporary variation of the magnetic flux through the flat coil, then this variation induces a sinusoidal alternating voltage at the coil terminals due to the variation in the time of the flux bound by it. The frequency of this voltage sinusoid will be directly related to the rotation frequency of the coil that links the magnetic flux, hence the synchronous name, since both frequencies, both the mechanics of rotation of the field and the electric of the voltage, are synchronized, according to the number of magnetic poles (responsible for generating the magnetic field through the coil) that the generator has.

In the practical designs, the above-described configuration is adopted to facilitate access to the coils, since if they were moving, the use of contact contacts to maintain the conduction of electric current would result in a more complex solution.

As for the machine poles, it can be found that for a p-pole stator winding, against which a p-pole magnetic field rotates at certain rpm, the frequency of the generated voltage is given by the ratio.

$$f = \frac{pn_s}{120}$$

$f =$ Frecuency, (Hz)

$p =$ Number of

$n_s =$ Turning speed (rpm)

It is important to note that to keep the frequency of the generated voltage constant, as required by the vast majority of the equipment currently used, the variables that can be manipulated are the number of poles or the speed of mechanical rotation. Since the project consists of supplying energy to an isolated community of the grid through wind generation, the ways to control the frequency would be two:

1. Check the speed of rotation of the generator shaft as it depends on the instantaneous wind speed.

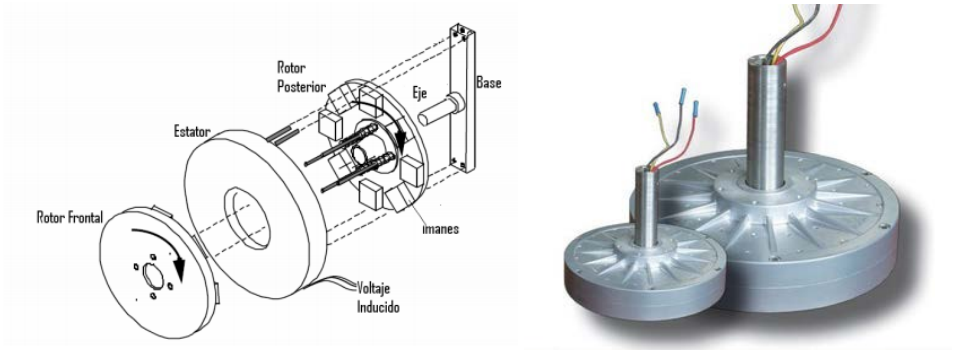
2. Rectify the generated voltage and then reverse it in a controlled way achieving the desired magnitude and

Considering the different complexities offered by both alternatives, it is decided to opt for the second one, since the speed control of the generator axis involves the use of sophisticated in-line control equipment, which is not justified for a small machine such as the one is posed here.

7.1 Axial Flow Permanent Magnet Generator

In this generator type, the ratio of the generated voltage frequency to the rotational speed is described with the same expression of the conventional synchronous generator, the number of poles corresponds to the number of magnets used in the rotors. In the following points, reference is made to the principle of operation and configuration of an axial flow generator.

In an axial flow generator, the magnetic flux passes through the coils in a direction parallel to the axis of the machine. It consists of a front rotor, a stator and a rear rotor. Both rotors are connected by a longitudinal axis. The arrangement of these parts in the generator can be seen in the following figure:

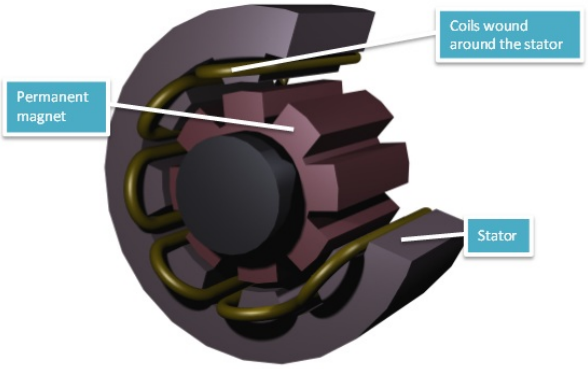


The stator contains copper wire coils in which the output voltage of the variable flux produced by the magnetic field of the permanent magnets located in the front and rear rotors is induced. The stator is mounted on a fixed, immobile base.

The permanent magnets are located such that the magnetic flux passes from one rotor to another, crossing through the stator coils, while the rotor shaft rotates; the sinusoidal voltage at the coil terminals is thus induced.

7.2 Radial Flow Permanent Magnet Generator

This type of generator has the same operating principles as those of axial flow but they have the advantage that they can be manufactured for greater powers, up to 5 Mw. The permanent magnets are integral with the rotor and the windings are in the stator.





7.3 Conventional generators

They are widely distributed in the market and are achieved in the whole range of powers either single-phase or three-phase. The problem is that they are usually made with 2 or 4 poles so the rotation speeds required to reach 50 Hz is 3000 and 1500 rpm respectively.



8 Pilot Plant development

8.1 Propeller

n this experimental stage a helical propeller of the following characteristics was designed:

$\emptyset_e = 1.4$ meters $\emptyset_i = 1.5''$ $P = 3.4$ meters





The propeller was constructed of fiberglass and epoxy resin with a 1.5 "galvanized pipe as shaft. At the ends were mounted low speed bushings to be used as anchor points to the piles. At one of these ends a cardan joint was mounted and then the mechanical energy was taken on the shaft and taken to the speed multiplier. Finally it was given an asphalt coating to guarantee a longer life.



According to theoretical calculations a propeller of these dimensions must deliver a torque of 623 N.m and a power of 3.92 kW at a speed of 1.5 m / s of river. Because we do not count for the pilot test with a generator of such power we will realize measures of torque to later estimate the mechanical power in the motor axis.

The propeller will be mounted on a metal structure that allows the anchorage to the spring where the system will be installed. The same one was realized in rectangular structural pipe of 40 x 20 mm and 2 mm of thickness. By means of a shaft of 4 meters in length the mechanical energy is brought to the speed multiplier. In case of downstream of the river can extend the shaft to 6 meters.





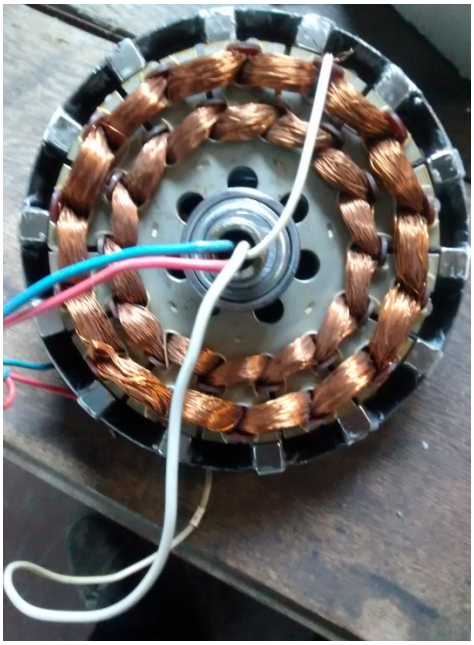
8.2 Multiplier and generator

For the same it was designed a chassis on which several multiplier stages were mounted. The set has 3 configurations according to the torque obtained in the drive shaft namely:

- Stage 1: total multiplication ratio of 16.
- Stage 2: total multiplication ratio of 32.
- Stage 3: total multiplication ratio of 66.

The higher the ratio of multiplication the greater the angular velocity in the generator, the greater power will generate and therefore the greater the motor torque required.





A fan motor was modified to obtain a low power permanent magnet generator (125 w). While clearly this element is below the required capacity it will be useful to test the system's motor torque in all possible configurations. If the motor torque is high, more powerful generators can be placed.

The control panel has indicator light, AC output for illumination and regulated direct current output for battery charging.



Due to the low power of the built generator, torque measurements will be taken to estimate the mechanical power of the turbine. The resistive torque of the multiplier - generator set in each of its stages is tabulated.

Etapa	Relación de Multiplicación	Torque Resistivo [Kg.m]
1	16	1,38
2	32	4,83
3	66	8,29

Once the installation is completed, measurements of the installed power, the stability of the generated voltage and the motor torque at each stage will be taken. This information will be used in the next stage.

8.3 Pilot Plant Test

Tests were carried out on the banks of the Paraná Guazú River in Talavera Island. The results were favorable considering the very low river velocity (0.30 m / s). With this data a necessary torque was obtained to drive the multiplier-generator set in the first stage of multiplication with a torque greater than 1.38 Kg.m. In the process it was possible to obtain electrical energy and it was possible to corroborate the true value of Cp of the system from the constructive data of the propeller and our mathematical model. The value of Cp = 0.55, slightly lower than the theoretical maximum of 0.59. This value depends on the characteristics of the turbine such as the pitch, diameter, angles of attack and output, the turbine clamping system and its general hydrodynamic profile. The installation is simple and can be done without problems by 2 people. These power values extrapolated to greater diameter and river speed give us very attractive power levels that can be reached at very low cost.









Links

https://www.youtube.com/watch?v=9vH0on3ci2c

https://www.youtube.com/watch?v=yATePtE4T-E

https://www.youtube.com/watch?v=CWCGiZrCMUY

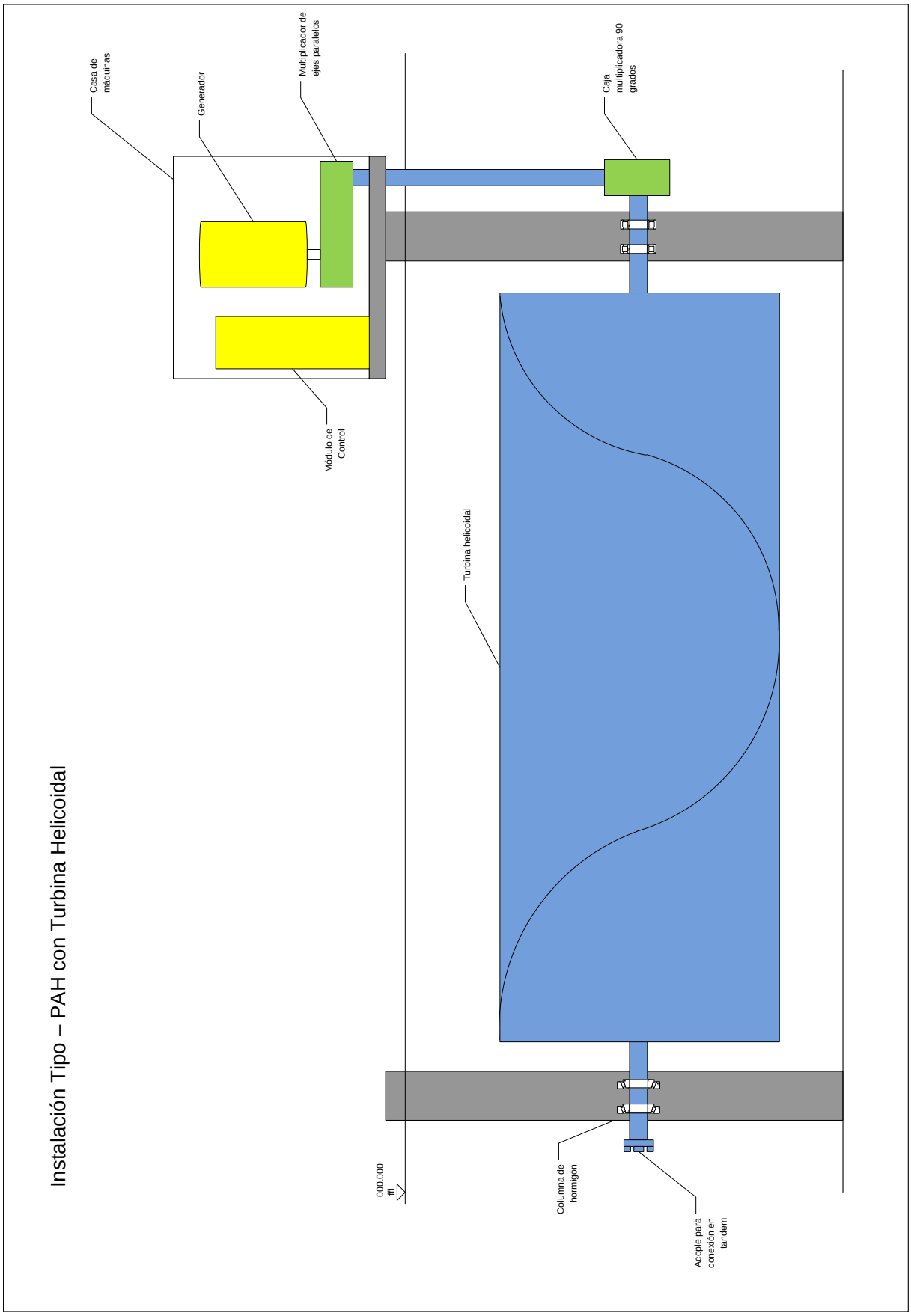
9 Future Projets

The development of a system of generation of 10 - 20 KVA of installed capacity reason why the turbine already must have 4 meters of diameter. Then we will use a tractousine as a multiplier-generator set and as a cardan we will use a special sleeve with the adapted length.





The ideal arrangement is shown below allowing the immediate scalability of the system by elastic couplings and additional turbines. It also shows the ideal layout of the engine room with the option of the board installed directly on the ground. The transmission of the mechanical energy is carried out by means of a submerged bent gearbox, a vertical axis that reaches a double stage of multiplication of gears of parallel axes and then to feed the generator.


Instalación Tipo – PAH con Turbina Helicoidal
Casa de máquinas
Generador
Multiplicador de ejes paralelos
Caja multiplicadora 90 grados
Módulo de Control
Turbina helicoidal
000.000 ffl
Columna de hormigón
Acople para conexión en tandem

10 Annex 1: Sizing the installation

We assume the axial force as the actuator on a flat plate perpendicular to the direction of the river. By fluid dynamics it is:

$$F = \frac{1}{4}\rho V^2 \pi \emptyset^2$$

The torque can be written as:

$$M_t = \frac{2}{3}\rho V^2 \pi r^3 C_p \sin \propto$$

10.1 Piles

The piles will be made of H30 concrete with $\sigma_{adm} = 300 \frac{\overline{kg}}{cm^2}$ $\tau_{adm} = 240 \frac{\overline{kg}}{cm^2}$

- Cut check $\tau_{adm} \geq {}^{4F}/_{\pi \emptyset_p{}^2}$
- Flex check $\sigma_{adm} \geq M_f y/I = 4FH/\pi R_p{}^3$ where H is distance from the bed to the axis.

10.2 Shafts

The shafts will be manufactured in structural pipe (steel SAE1020) $\sigma_{adm} = 4575 \frac{\overline{kg}}{cm^2}$

$\tau_{adm} = 3660 \frac{\overline{kg}}{cm^2}$

- Torsion check $\tau_{adm} \geq {}^{32M_t}/_{\pi(D^2 - d^2)}$

11 Annex 2: Costs Estimation

We define [C] as the estimated direct costs for an installation.

The annual energy generated is:

$$E\left[\frac{Mwh}{año}\right] = 8760\ P[Mw] * f$$

f is the power factor of the installation (usually 0.6 for PAH).

$$C_i \left[\frac{usd}{{Mwh}/{año}}\right] = {C}/{E}$$

The value Ci is the one used to compare how economic the energy production results. In the case of our proposal we estimate the direct costs of a 32 kw installation at 5800 usd. This value gives us a Ci of 34 usd / mwh / year which is extremely competitive even against the cut values used in the renewal program (Ci PAH = 105) or even against other types of facilities = 50). The advantage of our proposal derives from the use of elements of low technological complexity and of wide use such as agroindustrial parts (tractousines, sleeves, cardan couplings, agricultural boxes, etc.).

12 Annex 3: Nomogram

