Design of a Windmill for the Water Pumping in a Sprinkle Irrigation System

Diseño de un molino de viento para el bombeo de agua en un sistema de riego por aspersión

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Abstract

Introduction— The use of the wind energy with practical ends is referred from old times; however at the present time it recovers validity for the necessity of finding alternative sources of energy in front of the conventional fossil fuel that is more and more scarce and it causes serious problems of environmental contamination.

Objective— Design a windmill for the extraction of water in a simple and efficient way, from the principles of a multiblades windmill and the use of materials recovered in the locality that allows the irrigation of the garlic cultivation with sprinkle irrigation system at the minimum possible cost.

Methodology— Different methodologies like the experience of the producers, established technical approaches for the selection of the relationship of speeds diameter of the rotor, coefficient of sustentation; haulage coefficient and attack angle were used. The analytic method was used for the calculation of the coefficient of solidity, the cord angles, the coefficient of power, the useful power, real flow, hydraulic power of the pump, total force in the piston, centrifugal force, sustentation force, drag force and the starting torque generated in a windmill.

Results— They were obtained starting from the wind speeds registered in the locality during 30 years of systematic studies and the defined parameters and calculated for the wind rotor and the volumetric pump. It was possible to design a windmill with the mechanical and hydraulics characteristics appropriate to be used in the agriculture.

Conclusions— The investigation demonstrated that the design of the windmill allows to complete the demands of the pumping of water for the irrigation system when guaranteeing a real flow of 0.17 L s^{-1} and a volume of water of 0.30 L displaced by the pump in each revolution of the wind rotor. The power generated by the wind rotor satisfies the power required by the pump.

Keywords— Wind rotor; geometry of the blade; useful power; piston pump; solidity coefficient

Resumen

Introducción— El uso de la energía eólica con fines prácticos es referido desde tiempos antiguos; sin embargo en la actualidad recobra vigencia por la necesidad de encontrar fuentes alternativas de energía frente al combustible fósil convencional que es cada vez más escaso y causa graves problemas de contaminación ambiental.

Objetivo— Diseñar un molino de viento para la extracción de agua de forma sencilla y eficiente, a partir de los principios de un molino de viento multipala y la utilización de materiales recuperados en la localidad que permita el riego del cultivo de ajo con sistema de riego por aspersión al mínimo coste posible.

Metodología— Se utilizaron diferentes metodologías como la experiencia de los productores, enfoques técnicos establecidos para la selección de la relación de velocidades diámetro del rotor, coeficiente de sustentación; coeficiente de arrastre y ángulo de ataque. Se utilizó el método analítico para el cálculo del coeficiente de solidez, los ángulos de cuerda, el coeficiente de potencia, la potencia útil, el caudal real, la potencia hidráulica de la bomba, la fuerza total en el pistón, la fuerza centrífuga, la fuerza de sustentación, la fuerza de arrastre y el par de arranque generado en un molino de viento.

Resultados— Se obtuvieron a partir de las velocidades del viento registradas en la localidad durante 30 años de estudios sistemáticos y de los parámetros definidos y calculados para el rotor eólico y la bomba volumétrica. Se logró diseñar un molino de viento con las características mecánicas e hidráulicas adecuadas para ser utilizado en la agricultura.

Conclusiones— La investigación demostró que el diseño del molino de viento permite completar las demandas del bombeo de agua para el sistema de riego al garantizar un caudal real de 0.17 L s^{-1} y un volumen de agua de 0.30 L desplazado por la bomba en cada revolución del rotor eólico. La potencia generada por el rotor eólico satisface la potencia requerida por la bomba.

Palabras clave— Rotor eólico; geometría de la pala; potencia útil; bomba de pistón; coeficiente de solidez

I. Introduction

The total of solar energy that arrives at the planet Earth alone 2% becomes wind, which originates for the unequal heating of the Earth that is the causing of the imbalance and the displacement of big masses of air from the areas of high pressures toward those of low and for the rotation of the earth. Wind energy is the kinetic energy generated by effect of the currents of air and it is transformed in other useful energy forms for their use in human activities as mechanics and electric [1].

The renewable energy as the solar energy, the eolic, the hydraulics and the geothermal have been important part of the energy used by the humans from remote times, in the case of the wind energy, has taken advantage from the ancient times for the navigating or the operation of the windsmills. In general, renewable energy sources are different from fossil fuels or nuclear power plants due to their diversity and abundance [2].

The wind energy is the energy renewable source that has demonstrated certain superiority in comparison with the traditional energy sources; it is also recognized like one of the renewable energy most valuable, clean, abundant, cheap and inexhaustible that is part of the environment [3]. Energy production from the wind is the source of more use and growth among the other alternative sources of energy with the lowest generation prices [4], [5].

The wind energy takes advantage on one hand to take out water of the wells by means of the calls aero pumps; specifically, the multiblades mills of American type which are very widespread and on the other hand for the current production when the mills are together to an electric generator, that receive the name of aero generators or Eolic turbines [6].

The use of the wind energy as been largely studied in Cuba from the first half of the XX century, when the camagüeyanas savannas reached its cattle splendor with the windmills like efficient and effective energy technology for the water supply to the cattle raising, the irrigation to small parcels and the water supply to communities [7].

The wind pumping system is ideal to increase the production for area unit in cultivations with low cultivation coefficients (K_c), which constitutes an alternative of cheap pumping for small farmers; but it should be designed in a simple way so that the farmer can easily apply the required maintenance and deliver a reliable and uniform amount of water from a storage tank with a certain elevation to deliver adequate pressure to the irrigation system [8].

The aspects previously expressed allow to consider as the objective of the research to design a windmill for the extraction of water in a simple and efficient way, based on the principles of a multi-blade windmill and the use of materials recovered in the locality that allows the irrigation of the garlic crop with the sprinkler irrigation system at the lowest possible cost.

II. Materials and Methods

The investigation was carried out in the farm "La Cuchilla", located in the community of Sabicú in the Primero de Enero municipality of the Ciego de Ávila province, between the coordinates 21°52' of Latitude North and 78°18' of West Longitude, with an area of 7.5 ha in crops such as tomatoes, garlic, beans, corn, cassava, banana, lemon, mango, coconut and others. The experimental area consisted on a plot of 931.00 m² sowed with the garlic cultivation of the variety Gibara in a traditional way for farmers of the area with the use of sprinkle irrigation system with which acceptable yields are obtained [9], [10].

The irrigation system is worked with wind energy through a multiblades windmill with height of the tower of 10 m. For the design of the windmill we leave of the following initial data adopted according to the experience of the producers and established technical approaches for this device type: relationship of speeds (λ) of 1 [11]; diameter of the rotor (D_{rot}) of 2.52 m; sustentation coefficient (C_S) of 1.80; drag coefficient (C_D) of 0.03 and attack angle (α) of 5. Fig. 1 the fundamental parts of the wind rotor in a multiblades windmill are shown.

Fig. 1. Fundamental parts of the wind rotor.
Source: Authors.

Chord with the available resources for the farmer, a system of extraction of water was used composed by a volumetric pump with a diameter of the piston (D_{pis}) of 80 mm; displacement of the piston (S) of 60 mm and yield of the volumetric pump (η_{vol}) of 80%; as well as a convertor system compound for: teeth number of the smaller peanuts on the axis of the rotor (Z_{min}) of 17 teeth; teeth number of the bigger peanuts reducer of speed (Z_{max}) of 53 teeth. Average wind speed (v_{ave}) of the locality for a 30 year-old period was of 5.50 m s^{-1}. The solidity coefficient of wind rotor was determined of the relationship between the total area of the blades and area of wind rotor; for what depends on the number of aerodynamic blades that composes the mill and the area of a blade. The parameters were calculated with (1), (2), (3):

$$\Omega = \frac{A_{Tp}}{A_{rot}} \tag{1}$$

$$A_{Tp} = N_p \, . \, A_p \tag{2}$$

$$A_p = \left(\frac{B_p + b_p}{2} \right) . \, L_p \tag{3}$$

With, Ω: Solidity coefficient of wind rotor; A_{Tb}: Total area of the blades (m^2); A_b: Area of a blade (m^2); N_b: Number of blades; B_b: Width bigger of the blade (m): b_b: Width smaller of the blade (m); L_b: Longitude of the blade (m).

The calculation of the cord angles was carried out with base to the Fig. 2 in which the average speed of the wind (v_{ave}) of the locality is shown; the tangential speed on the tip of the blade (u); the apparent speed or relative speed of the wind that receives the blade (v_a); attack angle (α); inclination angle (β) and apparent angle of the wind (θ). The parameters were calculated with the following equation (4), (5), (6):

$$v_a = v_m + u \tag{4}$$

$$\theta = \frac{2}{3} \arctan \frac{1}{\lambda} \tag{5}$$

$$\beta = \theta - \alpha \tag{6}$$

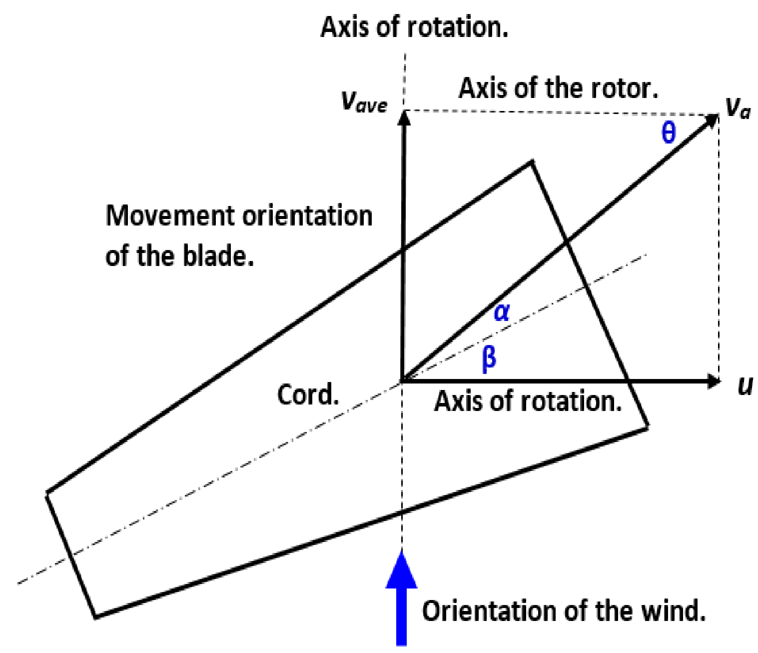

Fig. 2. Angles and velocities in a moving blade.
Source: Authors.

The power coefficient was determined by means of the application of a quadratic distribution that is adjusted satisfactorily to the curve of aerodynamic yield in function of the specific speed [12]:

$$C_p = 0.0976\lambda^2 + 0.322\lambda \quad (7)$$

With, C_p: power coefficient; λ: relationship of speeds.

The useful power of the windmill was determined according to mexican research [5] in function of the availability of wind resources and the area of wind rotor:

$$P_u = 0.5 \cdot \rho_a \cdot A_{rot} \cdot v_{ave}^3 \cdot C_p \quad (8)$$

With, P_u: useful power of the windmill (W); ρ_a: density of the air in the place of the location (kg m^{-3}); A_{rot}: area of wind rotor (m^2); v_{ave}: average speed of the wind of the locality (m s^{-1}).

The transmission relationship in the windmill was obtained of the relationship among rotation speed of the rotor and the axis revolutions that it works the crank system of the pump. This last one depends directly with of the number of teeth of the peanuts bigger and smaller. The parameters were calculated with the following equation (9)-(10):

$$r_t = \frac{n}{n_{\text{crank}}} \quad (9)$$

$$n_{\text{crank}} = \frac{n \cdot Z_{\min}}{Z_{\max}} \quad (10)$$

With, r_t: transmission relationship; n: rotation speed of the rotor (rpm); n_{crank}: turn speed of the crank system of the pump (rpm); Z_{min}: number of teeth of the smaller pinenut on the axis of the rotor; Z_{max}: number of teeth of the bigger peanut reducer of speed.

The real flow that contributes the windmill was considered from the volumetric efficiency and the theoretical flow. This last one was in function of the area of the piston of the pump, the displacement of the piston and the rotation speed of the rotor. The parameters were calculated with (11), (12), (13):

$$Q_r = Q_t \cdot \eta_{vol} \tag{11}$$

$$Q_t = A_{pis} \cdot S \cdot \frac{n}{60} \tag{12}$$

$$n = \frac{60 \cdot \lambda \cdot v_m}{\pi \cdot D_{rot}} \tag{13}$$

With, Q_t: theoretical flow (m³ s⁻¹); q_r: real flow (m³ s⁻¹); A_{pis}: area of the piston of the pump (m²). Hydraulic power of the pump was calculated with (14):

$$P_h = \frac{\rho_w \cdot g \cdot Q_r \cdot H_T}{\eta_{vol}} \tag{14}$$

With, P_h: hydraulic power of the pump (W); ρ_w: density of the water (kg m^{-3}); g: acceleration of the graveness (m s^{-2}); H_T: total height of pumping that includes the friction lost, the located losses and the static and dynamic levels (m).

The estimating of the forces in the piston due to the column of water in the pipe needed of the previous calculation of the load of pressure required by the volumetric pump for filling the storage tank of the system; for what the Bernoulli equation was applied, which can be written as follows (15), (16), (17) [13]:

$$\frac{P}{\gamma} = \frac{v_f^2}{2g} + h_{\tan} + H_T \tag{15}$$

$$v_f = \frac{Q_r}{A_{tub}} \tag{16}$$

$$A_{tub} = \frac{\pi D_{tub}^2}{4} \tag{17}$$

With, P: hydrodynamic pressure in the piston (N m^{-2}); v_f: speed of the fluid (m s^{-1}); h_{tan}: height of the storage tank (m); H_T: total height of pumping (m); γ: specific weight of the water (9800 N m^{-3}); A_{pipe}: area of the pipe (m^2).

The piston force, water force inside the pump and total force in the piston was determined with (18), (19), (20):

$$F_{pis} = P \cdot A_{tub} \tag{18}$$

$$F_{agua} = \rho \cdot g \cdot A_{pis} \cdot S \tag{19}$$

$$F_{total} = F_{pis} + F_{agua} \tag{20}$$

With, F_{pis}: piston force (N); F_{wat}: water force inside the pump (N); F_{total}: total force in the piston (N); A_{pipe}: area of the pipe (m^2); A_{pis}: area of the piston of the pump (m^2); S displacement of the piston (m).

The centrifugal force on the blade was determined by (21), (22), (23), (24), (25), (26) [14]:

$$F_C = \frac{m_p \cdot u^2}{r_G} \tag{21}$$

$$m_p = \rho_{mat} \cdot A_p \cdot e_p \tag{22}$$

$$\omega = \frac{2\pi \cdot n}{60} \tag{23}$$

$$u = \omega \cdot R_{rot} \tag{24}$$

$$r_G = R_{\text{int}} + L_{cg} \tag{25}$$

$$R_{\text{int}} = R_{rot} - L_p \tag{26}$$

With, F_C: centrifugal force in the blade (N); m_p: mass of a blade (kg); u: tangential speed of the rotor (m s^{-1}); ω: angular speed of the rotor (rad s^{-1}); r_G: distance from the center of the rotor to the center of gravity of the blade (m); ρ_{mat}: density of the material of the blade (kg m^{-3}); e_b: wideness of the blade (0.0003 m); R_{int}: radius of internal ring (m); L_{cg}: distance from the smaller base than the blade to their center of gravity (m).

The sustentation force that allows the ascent and rotation of the rotor and the drag force that generates the wind on the blade of the windmill were calculated from the following equations (27)-(28):

$$F_S = C_S\left(\frac{1}{2}\rho_a \cdot v_{\text{m}}^2 \cdot A_{rot}\right) \tag{27}$$

$$F_D = C_D\left(\frac{1}{2}\rho_a \cdot v_{\text{m}}^2 \cdot A_{rot}\right) \tag{28}$$

With, F_S: sustentation force (N); F_D: drag force (N); C_S: sustentation coefficient; C_D: drag coefficient.

The starting torque generated in a windmill in the moment in that their operation begins was considered by (29)-(30):

$$M_o = 0.5 \cdot C_{mo} \cdot A_{rot} \cdot R_{rot}^3 \cdot v_{ave}^2 \tag{29}$$

$$C_{mo} \approx \frac{0.31}{\lambda_d^2} \tag{30}$$

With, M_o: starting torque (N.m); C_{mo}: starting torque coefficient; λ_d: relationship of speeds so that the wind rotor delivery their maximum power.

III. Results and Discussion

Because the rotor is the main element of the windmill, has been dedicated the maximum attention to the determination of its fundamental parameters. In this sense in the Table 1 the geometric characteristics of the blades of the wind rotor and their solidity coefficient are presented.

The windmill was configured with a total of 15 galvanized zinc aerodynamic blades, to cause the maximum revolution in the rotor shaft. This quantity of blades is associated to the relationship of speeds with the objective of achieving the biggest aerodynamic yield. A profile of plane sheet in trapezoidal form was chosen according to suggestions of SIER [15] with bigger wide than 0.43 m, wide smaller than 0.24 m and longitude of 0.77 m.

Table 1. Geometric parameters and solidity coefficient of the wind rotor.

Parameters	Value
Number of blades (Nb).	15
Longitude of the blade, m (Lb).	0.77
Width smaller of the blade, m (bp).	0.24
Width bigger of the blade, m (Bp).	0.43
Distance from the bigger base of the blade to its center of gravity, m (ycg).	0.35
Distance from the smaller base than the blade to their center of gravity, m (Lcg).	0.42
Distance from the center of the rotor to the center of gravity of the blade, m (rG).	0.91
Radius of the win rotor, m (Rrot).	1.26
Radius of internal ring, m (Rint).	0.49
Area of a blade, m2 (Ab).	0.26
Total area of the blades, m2 (ATb).	3.87
Area of wind rotor, m2 (Arot).	4.99
Solidity coefficient of wind rotor (Ω).	0.78

Source: Authors.

The distance from the center of the rotor to the center of gravity of the blade reached a value of 0.91 m in function of the distance from the bigger base of the blade to its center of gravity, the distance from the smaller base of the blade to its center of gravity, the radius of the win rotor and the radius of internal ring.

Each blade of the wind rotor has an area of 0.26 m^2; for what the total area of all blades is of 3.87 m^2 and the area of wind rotor of 4.99 m^2 with what a solidity coefficient of wind rotor of 78% is reached, what indicates that 78% of the area of the rotor is covered for the blades. This result belongs together with the geometric dimensions for multiblades mills according to that exposed by MU [16] and MolinosJober[17]. The design of the wind rotor considered the mass of the fundamental components; for what the analysis gave as a result for the mass of a blade, the mass of the group of blades and the mass of the wind rotor values of 0.56 kg; 8.36 kg and 90.19 N respectively.

Results of the tangential and apparent wind speeds in the blade of the wind rotor for incident wind speeds in the range from 2.5 m s^{-1} to 12.0 m s^{-1} are shown in Table 2. In all the cases it is observed that the values of the incident wind speed coincide with those of the tangential wind speed, that which is logical of waiting because this last one is directly proportional to the relationship of speeds that was assumed with an unitary value; however, the apparent wind speed that is the vectorial resultant of the incident wind speed and the tangential wind speed is increased in a growing way in correspondence with the increment of the incident wind speed. This resulting force when acting on the blades allows the turn of the wind rotor [18].

Table 2. Tangential and apparent speeds of the wind rotor.

v (m s^{-1})	u (m s^{-1})	va (m s^{-1})	v (m s^{-1})	u (m s^{-1})	va (m s^{-1})
2.5	2.50	6.25	8.0	8.00	64.00
3.0	3.00	9.00	9.0	9.00	81.00
4.0	4.00	16.00	10.0	10.00	100.00
5.0	5.00	25.00	11.0	11.00	121.00
6.0	6.00	36.00	12.0	12.00	144.00
7.0	7.00	49.00			

Source: Authors.

An important factor in the design of the aerodynamic blades of a wind rotor is the determination of the cord angles as: inclination angle (β) that obtained a value of 30° in this investigation in function of the relationship of speeds (λ), apparent angle of the wind (θ) and the attack angle (α). In the case of curved surfaces, the angles β and θ, vary along the blade; however, in the multiblade windmill for reasons of simplicity and costs, opt to use blades of constant section and without curve.

The values of the angular speed of the rotor, rotation speed of the rotor, turn speed of the crank system of the pump and the transmission relationship regarding the speed of the incident wind are offer in the Table 3. In all the cases it is observed that the analyzed variables are increased with the increase of the incident wind speed. For Average speed of the wind of 5.50 m s^{-1} the values of the angular speed of the rotor, rotation speed of the rotor and speed of the crank system of the pump were respectively of 4.37 rad s^{-1}, 41.68 rpm and 13.37 rpm; while the transmission relationship remained with a constant value of three.

Table 3. Angular and rotational speeds and speed of the crank system.

v (m s^{-1})	ω (rad s^{-1})	n (rpm)	ncrank (rpm)	rt	v (m s-1)	ω (rad s^{-1})	n (rpm)	ncrank (rpm)	rt
2.5	1.98	18.95	6.08	3	8.0	6.35	60.63	19.45	3
3.0	2.38	22.74	7.29	3	9.0	7.14	68.21	21.88	3
4.0	3.17	30.32	9.72	3	10.0	7.94	75.79	24.31	3
5.0	3.97	37.89	12.15	3	11.0	8.73	83.37	26.74	3
6.0	4.76	45.47	14.59	3	12.0	9.52	90.95	29.17	3
7.0	5.56	53.05	17.02	3					

Source: Authors.

The results of flows, hydraulic power and useful power in the designed windmill are offer in the Table 4. It is observed that the theoretical and real flow of the volumetric pump varies proportionally with the incident wind speed and consequently with the speed of the crank system of the pump and the rotation speed of the rotor. When the wind speed increases, the flow of pumping, the hydraulic power of the installation in function of the real flow of the pump and the total height of pumping is increased; as well as the useful power generated by the windmill; therefore, the useful power satisfies the hydraulic power required for wind speeds from 2.5 m s^{-1} to 12.0 m s^{-1}.

Table 4. Flows, hydraulic power and useful power in the wind mill.

v (m s^{-1})	Qt (m^3 s^{-1})	Qr (m^3 s^{-1})	Qr (L s-1)	Ph (W)	Pu (W)
2.5	0.00010	0.00008	0.08	4.65	10.14
3.0	0.00011	0.00009	0.09	5.58	17.53
4.0	0.00015	0.00012	0.12	7.44	41.55
5.0	0.00019	0.00015	0.15	9.31	81.14
6.0	0.00023	0.00018	0.18	11.17	140.22
7.0	0.00027	0.00021	0.21	13.03	222.66
8.0	0.00030	0.00024	0.24	14.89	332.36
9.0	0.00034	0.00027	0.27	16.75	473.23
10.0	0.00038	0.00030	0.30	18.61	649.15
11.0	0.00042	0.00034	0.34	20.47	864.01
12.0	0.00046	0.00037	0.37	22.33	1 121.73

Source: Authors.

The useful power of the windmill allows that the piston pump displeases a volume of water of 0,30 L in each revolution of the wind rotor, being required of a total force in the piston of 42.23 N, corresponding a value of 39.27 N (92.9%) for the piston force and 2.96 N (7.01%) to the water force inside the pump.

The coefficient of useful power (K_u) with value of 0.13 was obtained in the investigation that allows in a practical and precise way the estimate of the useful power of the multiblade windmill for climatic conditions and similar design to the existent in the locality where the work was developed. This value is very close to that proposed in the literature for the American multiblade windmill, which ranges between 0.045 and 0.135 [19]. For these conditions it is proposed (31):

$$P_u = 0.13 \cdot A_{rot} \cdot v_{ave}^3 \tag{31}$$

For these conditions of incident wind speed the useful power of the windmill is increased according to the values of rotation speed of the rotor that oscillate between 18.95 rpm and 90.95 rpm, with a power coefficient of 0.22 according to the climatological conditions of the place and the specific characteristics of the designed windmill, that which is comparable with the results exposed by Cran.IT [12].

The wind generates a centrifugal force of 18.49 N and a sustentation force of 157.51 N, superior to the total mass of the rotor that it is of 90.19 N what allows that the rotor can rotate. Sustentation force allows to obtain with smaller weight of the rotor and cost bigger powers for unit of area of the rotor. This depends directly on the attack angle and it is increased as this increases until arriving to a critical attack angle that is of 5º in this case, what guarantees that the combination of the overpressure in the inferior part of the blades and the depression for above tend to rise them; the difference of pressures in the two faces generates a sustentation force that makes that the blade rotates [18].

The apparent wind speed in the designed windmill, exit of the blade originates a drag force with value of 2.63 N that causes the starting torque beginning with a wind speed of the of 2.5 m s^{-1}. It is a friction between the blade and the air through which the win rotor moves, for what represents the sum of all aerodynamic forces and it acts in opposed sense. This is solved with the centrifugal force which pushes to the blades toward out with a tendency to pull up them of the internal ring of the win rotor. In this type of mill due to their geometry, the drag force is much more important that the sustentation force, for what is able to conquer some appreciable mechanical resistances [20].

The starting torque generated by the mill reaches the value of 32.49 N.m in correspondence with the area of wind rotor, radius of the win rotor and the square of the incident wind speed. When acting on the wind rotor produces the rotation around the turn axis under some minimum conditions of wind speed, being also obtained a high torque [21].

This system constitutes a practical solution for the efficient use of the energy resources in Cuba with positive impacts as the proposal for UNICA [22] in the case of the stability of the ethanol mixture with naphtha for the saving of fuels.

IV. Conclusions

The results of the investigation demonstrate that the windmill designed presents mechanical and hydraulic characteristics that allow to complete demands of the water pumping for a sprinkle irrigation system through a storage tank. This presents a wind rotor with a of 2.52 m and 15 m aerodynamic blades of galvanized zinc with geometric dimensions that provide an area of 4.99 m^2 and a solidity coefficient of 78%.

The water extraction system adopted consists of a piston pump with a diameter of 80 mm coupled to the wind rotor by means of a vertical axis and a reduction system that guarantees the transformation of the rotary movement of the rotor axis into an alternative linear movement to press the piston pump.

The real flow of 0.17 L s^{-1} and a volume of water of 0.30 L displaced by the piston pump in each revolution of the wind rotor is achieved. The power generated by the wind rotor satisfies the power required by the pump for wind speeds between 2.5 and 12.0 m s^{-1}.

The power coefficient reached for the designed wind rotor is of 0.22; but the new proposed useful power coefficient corresponds with the climatic and design conditions that allows in a practical and precise way to determine the useful power of the windmill for the specific context of the locality.

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