Design and Construction of Horizontal Axis Wind Pump

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Abstract- The purpose of this paper is to provide water supply from wind energy for local area. Wind energy is one the lowest-priced renewable energy technologies available today. The horizontal axis wind pump is designed to derive 48W pump. The blades of wind pump are designed by using the NACA 64-215 series. The multi-blade wind pump can produce 51W. 48W pump can be used with low speed. Blade is divided into 8 elements with equal length forming 9 sections throughout the blade. The blade length is obtained 0.701 m and rotor swept area is 2.5847 m^2. Diameter of rotor is 1.8288 m. The rotor speed is 157 rpm. Therefore, the transmission system is used to get less revolution from output shaft of the wind pump. The speed-down spur gear (315 mm diameter, 5 mm module, face width 0.785 mm and 63 teeth) are used. The design of pinion is 140 mm diameter, 5 mm module, face width 0.785 mm and 30 teeth. Material of spur gear and pinion are selected with cast steel.For utilization of house-hold wind generation, the calculation of rotor swept area and selection for height of tower is the most important factor. The technical data, capacity and testing results of the designed wind pump are also presented.

Indexed Terms- Wind Energy, Pump, Multi-Blade, Gear, Blade

I. INTRODUCTION OF WINDMILL

Windmills are classified as 'horizontal-axis' and 'vertical-axis' depending upon the orientation of the axis of rotation of their rotors. A wind mill operates by slowing down the wind and extracting a part of it's energy in the process. For a horizontal axis, the rotor axis is kept horizontal and aligned parallel in the direction of the wind stream. In a vertical-axis turbine, the rotor axis is vertical and fixed, and remains perpendicular to the wind stream. Windmills have blades fixed to a central shaft. The extracted energy causes the shaft to rotate. This rotating shaft is used to drive a pump, to grind seeds or to generate electric power. Two important aerodynamic principles are used in windmill operations, i.e. lift and drag. Wind can rotate of a wind mill either by lifting (lift) the blades or by simply passing against the blades (drag).

Slow-speed mills are mainly driven by the drag forces acting on the rotor. The torque at the rotor shaft is comparatively high which is of prime importance for mechanical applications such as water pumps. For slower mills, a greater blade area is required, so the fabrication of blades is undertaken using curved plates.

High speed mills utilize lift forces to move the blades, which phenomenon is similar to what acts on the wings of an aero plane. Faster mills require aero foil-type blades to minimize the adverse effect of the drag forces. The blades are fabricated from aerofoil sections with a high thickness-to-chord ratio in order to produce a high lift relative to drag.

II. HORIZONTAL AXIS WINDMILL MACHINE

Horizontal axis wind turbines resemble an airplane propeller with either two or three blades. Horizontal axis wind generator may be drag systems. The axis rotation is horizontal and the rotor plane is vertical facing the wind.

The shaft is mounted on two bearing. Blades on rotor is usually designed to be oriented in front (upwind) or behind (downwind) of the tower. Upwind machines need a tail or some other mechanism to maintain orientation. Downwind machines produce wind shadow and turbulence in the blade path. This may be quite seriously affected by the tower.

III. MAIN COMPONENTS OF WIND PUMP

There are seven main components in the windmill. These are described as the followings:

(i) Rotor
(ii) Tail vane
(iii) Shaft
(iv) Bearing
(v) Gear Box
(vi) Pump and
(vii) Tower.

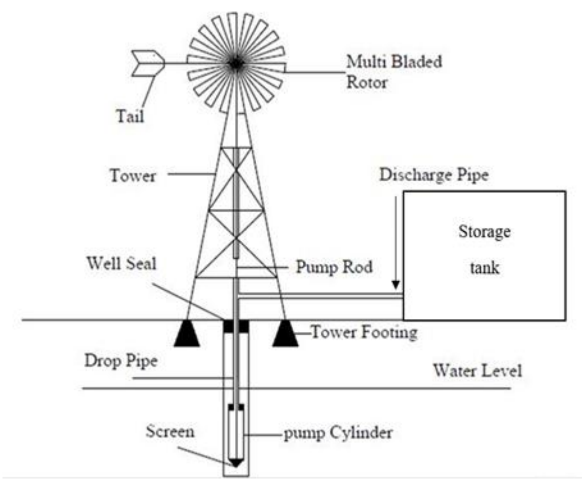

Figure.1. Main Components of Wind Pump

IV. DESIGN CALCULATION OF BLADE DESIGN

Mechanical efficiency is 95% for wind machine and pump efficiency is 80%. In practice values of system efficiency commonly range from 10% to 50% although higher and lower values are possible.

Design Specification

Pump power $P_p = 51$ W
Wind speed u = 5 m/s
Safety factor = 1.3
Density of air $\rho = 1.2$ kg/m^3
Number of blade B = 18
Power coefficient $C_p = 0.45$
Tip-speed ratio $\lambda = 3$
Overall efficiency η_0 is

$$\eta_0 = C_p \times \eta_{mech} \times \eta_{pump}$$
$$= 0.45 \times 0.95 \times 0.8$$
$$= 0.342$$

$$\eta_0 = \frac{\text{output power}}{\text{input power}}$$
$$= \frac{\text{pump power}}{\text{wind power}}$$
$$= \frac{51 \times 1.3}{\frac{1}{2} \times \rho \times A \times u^3}$$
$$0.342 = \frac{51 \times 1.3}{\frac{1}{2} \times 1.2 \times A \times 5^3}$$
$$A = 2.5847 \text{ m}^2$$

Rotor swept area A = 2.5847 m^2

$$\pi R^2 = 2.5847$$
$$R = 0.907 \text{ m} = 2.9757 \text{ ft} \approx 3 \text{ ft}$$

Take hub radius, r = 0.2413 m

And following simple formulas are needed:

$$\lambda_r = \lambda \times \frac{r}{R}$$
$$c = \frac{2\pi r}{B} \times 0.7 \times \cos\beta$$
$$\phi = \tan^{-1}[\frac{2}{3} \times \frac{1}{\lambda_r}]$$
$$\beta = \phi - \alpha$$

The air foil shape is NACA 64-215 type. α can be chosen from C_d/C_l is minimum value , α is 7 degrees and 8 segments.

$$\lambda_r = 3 \times \frac{0.2413}{0.907} = 0.7981$$
$$\phi = \tan^{-1}[\frac{2}{3} \times \frac{1}{0.7981}] = 39.87°$$
$$\beta = 39.87 - 7 = 32.8725$$
$$c = \frac{2\pi \times 0.213}{18} \times 0.7 \times \cos 32.8725 = 0.0495\text{m}$$

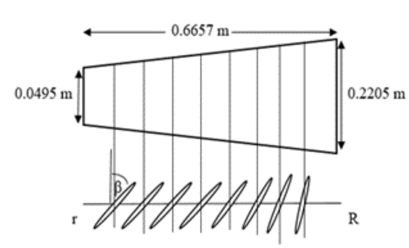

Figure 2. Profile and Blade Angle of Various Sections

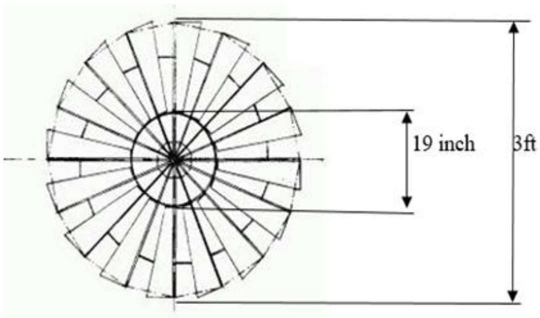

Figure 3. Design of Blade Assembly

Table 1. Result of blade chords and blade angles

Cross Section No.	R (m)	λ_r	α°	ϕ°	β (deg)	c (m)
1	0.2413	0.7981	7	39.87	32.8725	0.0495
2	0.3364	1.1126	7	30.9299	23.9299	0.0751
3	0.4315	1.4272	7	25.0379	18.0379	0.1002
4	0.5266	1.7417	7	20.9452	13.9452	0.1248
5	0.6217	2.0563	7	17.963	10.963	0.1491
6	0.7168	2.3708	7	15.7059	8.7059	0.1731
7	0.8119	2.6854	7	13.9421	6.9421	0.1969
8	0.907	3	7	12.5288	5.5288	0.2205

V. CALCULATION OF ROTOR SPEED, ROTOR POWER AND TORQUE

Design Data: $u = 5\ ms^{-1}$

$R = 2.9757$ m

$\rho = 1.2\ kgm^{-3}$

$A = 2.5847\ m^2$

From Figure 3.3,

$\lambda = 3$

$C_p = 0.45$

The rotor speed = $N = \frac{60\lambda u}{2\pi R}$

$$= \frac{60\times3\times5}{2\pi\times0.907}$$

= 175.926 rpm

The rotor power, $P_R = C_p P_w$

$$= C_p \times \frac{1}{2}\rho A u^3$$

$$= 0.45\times\frac{1}{2}\times1.2\times2.5847\times5^3$$

= 87.2336 kW

Torque, $T = \frac{P\times60}{2\pi N}$

$$= \frac{87.2336}{2\pi\times175.926}$$ = 0.1578 N-m

Figure 4. Horizontal Axis Wind Pump

VI. CALCULATION OF TAIL DESIGN

Design Specification

$d_1 = 0.0889$ m (3.5 inch)

$d_2 = 0.7581$ m (2.48 ft)

Area of rotor $A_R = 2.5847\ m^2$

$$A_{Tail} = \frac{d_1}{d_2} \times 2.5847$$

$$A_{Tail} = \frac{0.0889}{0.7581} \times 2.5847$$

A_{Tail} = 0.334 m^2

Take b_1 = 0.457 m

b_2 = 0.3810 m

h = 0.6 m

Tail vane area is the combination of the trapezium area, A_1 and the triangle area, A_2.

The total area for tail vane,

$$A_{tail} = A_1 + A_2 = \frac{1}{2}h(b1 + b2) + \frac{1}{2}xb2$$

0.3031 = {0.5×0.6(0.457+0.3810)} + {0.5×x×0.3810)}

0.3031 = 0.2514 + 0.1905x

x = 0.271 m

Thus, the height of triangle is 0.271 m.

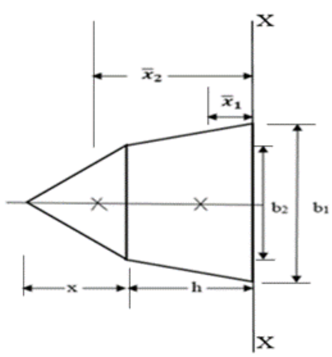

Figure 5. Center of Gravity of Tail Vane

The Center of Gravity of composite Tail Vane

(i) For Trapezium,

A_1 = 0.2514 m^2

$$\bar{x}_1 = \frac{h(2b_2 + b_1)}{3(b_2 + b_1)} = \frac{0.6(0.762 + 0.457)}{3(0.381 + 0.457)}$$

= 0.291 m

(ii) From Triangle, $A_2 = \frac{1}{2}xb_2$

$$= \frac{1}{2} \times 0.271 \times 0.38$$

= 0.0516 $m^2$the centroid of triangle,

$$\bar{x}_2 = \bar{x}_1 + \frac{1}{3}x = 0.291 + (\frac{1}{3} \times 0.271) = 0.381 \text{ m}$$

$$\bar{x} = \frac{\sum \bar{x}A}{\sum A} = \frac{(0.291 \times 02514) + (0.381 \times 0.0516)}{(0.2514 + 0.0516)}$$

= 0.306 m

The distance of $\bar{x}$ is 0.306 m from XX line and the tail vane is 0.93 m from the unit.

Table.2. Result Data of Wind Pump

Rotor Speed	175.926 rpm
Rotor Power	87.2336 kW
Torque	0.1578 N-m
Area of Tail Vane	0.334 m^2
Hub Height	4.572 m
Tower Height	4.26 m
Tower Type	Lattice Tower
Blade Length	0.7545 m
Rotor Swept Area	2.5847 m^2
Number of Blades	18
Blade Material	16 gauge Iron Plate
Revolution	157~789 rpm
Type	Horizontal-Axis Propeller Type
Rotor Placing	Upwind Rotor
Gear Type	Speed-down Spur Gear
Gear Ratio	1-2.25
Shaft Material	Solid Shaft Commercial Steel
Bearing	Bearing Block
Type	Reciprocating Piston Type
Power	51W
Rating	2.4337 L/s at 175.926 rpm
Yaw Control	Tail Vane
Pump Input	51 W
Pump Output	48W
Pump Efficiency	94%
Rated Wind Speed	5 ms^{-1}
Cut-in Wind Speed	4 ms^{-1}
Cut-out Wind Speed	10 ms^{-1}

VII. CONCLUSION

In the design and construction of wind pump, all materials are selected that are available from the local market. The rotor blades are made by 16 gate iron plate. According to the design result the optimum angle of attack is 7 degrees. The blade length is obtained 0.7547 m and rotor swept area is 2.5847 m2. The multi-blade wind pump can produce 87.2244 kW. So we can drive 51 W pump. This wind pump can produce 51 W at 5m/s. the rotor speed at 5m/s is 175.926 revolutions per minute. Gear box is required to reduce the shaft revolution.

To consider tail vane area, practical ratios of vane span to chord are between two and ten. A typical vane might be five times as tall as its width. In this research, the tail vane span to chord ratio is practically 5 times and it is free within 45 degrees inclination. Therefore, tail vane can give power enough. The more van span ratio is within the range, the better it will be.

The power production of Wind Pump increases significantly with height of turbulence. The choice of location and height of wind mill machine should be a synthesis of the wind speed, topography, obstruction, cost and every local status. Application of wind energy for water supply has many different options. One of them is to build wind farm and provide water supply for rural areas.

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