International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161

Available at http://inpressco.com/category/ijcet

Research Article

Design of Blade for a Wooden Small scale wind turbine for domestic purpose

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Accepted 01 May 2014, Available online 01 June, **Vol.4, No.3 (June 2014)**

Abstract

This paper focuses on the design and manufacture of a wind turbine blade which is utilized to generate the power of 375 Watts. The objective of this work is to develop a domestic wind turbine which works at low wind speeds and which can be made available to the common man at a very low price. Teak wood, which is easily available, is utilized to fabricate the blades and hub of the wind turbine. In the design process, basic aerofoil section is considered and various forces like axial, lift and drag acting on the blades is calculated theoretically and the design is optimized to get the optimum power output.

Keywords: *Wind Turbine, Lift, Drag, hub, blade, fabrication*

1. Introduction

Wind energy, like most terrestrial energy resources, comes from solar energy. Solar radiation causes the regions of unequal heating over land masses and oceans. This creates regions of high and low pressures and this causes the flow of air called wind.

Wind energy is one of the prominent renewable energy sources on earth. Wind power utilization for electricity production has a huge resource and proven itself to be capable of producing a substantial share of the electricity consumption. The fuel of this electricity production is wind and it is the most important constraint for turbine design, as it creates loads the turbine has to withstand.

Therefore, accurate knowledge about the wind is needed for planning, design and operation of wind turbines. This paper provides the process of fabricating the blades of a wooden wind turbine of 375 watts capacity.

A. Beneficial characteristics of wind power

Wind power produces no emissions and is not depleted overtime. A single one megawatt (1MW) wind turbine running for one year can displace over 1,500 tons of carbon dioxide, 6.5 tons of sulfur dioxide, 3.2 tons of nitrogen oxides and 60 pounds of mercury (based on the US average utility generation fuel mix).Wind plants can provide a steady flow of income to landowners, while increasing property tax revenues for local communities.

It can take many forms, including large wind farms, distributed generation and single end user systems. It also reduces the import of fossil fuels and lessens the dependence on foreign governments that supply these fuels.

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The present work focuses on design of wind turbine that can work in relatively low wind speeds. The manufacturing costs of this turbine are also considered as this paper mainly concentrates on the availability of this work to a common man.

2. Design calculations

The power in the wind, $P_w = 1/2\rho AV^3$

Where V is the velocity of wind at the blades, ρ is the density of the air, A is the area of the blade.

Maximum extractable power from wind,

$P_{max} = 16/27(1/2\rho AV^3)$

Actual power developed by a propeller type wind turbine shows that power coefficient is strongly dependant on tip speed ratio.

As tip speed ratio of high speed wind turbine is 8 times that of incoming velocity. Corresponding to this tip speed ratio power co-efficient, Cp will be 0.35 from the plot between power co-efficient Co and tip speed ratio. Therefore, practical power obtainable from wind is

$Po = 0.35 \times \eta_t \times P_{max}$

Where η_t is transmission efficiency.
Taking a transmission efficiency of 56%,

$Po = 0.196\ P_{max}$

As power density in kalukala konda is 326.3 w/m^2 (http://globalenergyobservatory.org/geoid/6677)
Power density, $Pd = P/A = 0.196P_{max}/A$

As the required power is 375W at the rated wind speed of 8m/s

$375/A = 0.196 \times 326.3$
$A = 5.863\ m^2$
Since, $A = \Pi/4 \times D^2$
$D = 2.93m$

Solidity of the high speed wind turbine range from 0.01 to 0.5 and for optimum power extraction taking solidity to be 0.059 (solidity is defined as the fraction of total circumferential either at tip or sometimes at 2/3 if the tip radius) that contains blades.

Solidity = total area of blades / swept area of rotor
$0.059 = 3 \times A_b / A$
$A_b = 0.1153\ m^2$

Taking length of wind ratio for high speed 3 bladed wind turbine blades as 10:1

Area of blade $A_b = l \times b = 0.1153m^2$
$10b^2 = 0.1153m^2$
Breadth at base, b= 0.10732m
Length of blade, l= 1.073m

Material of blade is chosen as teak wood.

To find the thickness of the blade, referring to process by Rayner M. Mayer, who suggests that thickness of teak wood should range between 20mm and 70mm. Taking a thickness of the blade to be 50mm to suit the density of Teak wood.

Tensile strength = breath x thickness x tensile stress of teak wood = 34.775 KN

Taking factor of safety 5.56 (approx. 6). Tensile strength = (Tensile strength / factor of safety) = 34.775/5.56 = 6.25KN

As the tensile strength is below that of Teak wood, the blade can withstand this force.

Density of teak wood = 660 Kg/m^3

Volume of the blade = 0.10732 x 1.0732 x 0.006 = 0.6907 x $10^{-3}\ m^3$
Mass of blade = 660 x 0.6907 x 10^{-3} Kg = 0.45 Kg
Radius of wind Turbine is, r = D/2 = 2.932/2 = 1.466 m
As tip speed ratio is taken as 8,

$T_s = V_{tip} / V_1$ = (Velocity at tip)/ (upwind velocity)
Upwind velocity = 2/3 x undisturbed wind velocity
$V_1 = 2/3\ V$
Therefore, $V_{tip} = 16/3 \times V$

Angular velocity of the wind turbine is related to velocity at the tip of the blade as

$V_{tip} = \omega \times (D/2)$

So, the angular velocity at the cut – in speed,
$V_c = 3.5$ m/s
$16/3 \times 3.5 = \omega_c \times 1.466$
Therefore $\omega_c = 17.733$ rad/sec

Rotational Speed corresponding to this angular velocity, N_c is
$N_c = (60 \times \omega_c)/ (2\Pi) = 121.59$ RPM

Angular velocity at rated speed $V_{rt} = 8.16$ m/s
$16/3 \times 8.16 = \omega \times 1.466$
$\omega = 29.68$ rad / sec

Rotational speed corresponding to this angular velocity, N_c is
$N = (60 \times 29.68)/2\Pi = 283.42$ rpm

Angular velocity at cut out speed $V_{ct} = 25$m/s
Is, $16/3 \times 25 = \omega_{ct} \times 2.231$
$\omega_{ct} = 90.95$ rad/sec

Rotational speed corresponding to this angular velocity is,
$N_{ct} = (60 \times 90.95)/ 2\Pi = 868.50$ rpm

As the maximum centrifugal force acting on the blade occurs at cut out wind speed of 25 m/s

$F_c = m \times r \times (\omega_{cf})^2 = 5.45$ KN

As allowable tensile strength = 10 KN, the calculated centrifugal force is well below the prescribed limit. Hence, the blade withstands the centrifugal force safely.

As the section of the blade near the hub is hollow, the dimension of which is obtained by equating the cross section of the blade of the aerofoil to the circular section. The outer diameter of circular section is taken as 300mm, taking into account stress concentration,

$3002 \times \Pi/4 \times (1-(d/300)^2) = 107.32 \times 4$
d= 299.08mm

Outer diameter of the flange = 1.5 x (outer diameter of circular section) = 450mm.

Thickness of flange is obtained from shear stress considerations.

Here, centrifugal force acts as the shear force,

Area resistivity is $300\Pi \times T_f$
Where T_f = flange thickness
$F_c = 300 \times \Pi \times T_f \times F_s$
Where Fs = shear force,
$T_f = F_c / (0.3 \times \Pi \times F_s)$
= 3.2m

Total axial force acting on turbine,

$F_t = \Pi/9 \times \rho \times d^2 \times (V1)^2$
For the axial force to be maximum, taking upward velocity V_1 to be equal to cut out wind velocity V_{ct},

F_{tmax} = Π/9 x 1.2 x 2.932 x 252 (taking ρ = 1.2 Kg/m^3) = 2.247 KN

Forces acting on the blades:
Lift Force = $F_l = C_l \times ½ \times A_b \times V_r^2 \times \rho$
Drag force = $F_d = C_d \times ½ \times A_b \times V_r^2 \times \rho$

Where V_r is the relative velocity, A_b is the area of the blade, C_l and C_d are coefficient of lift and drag respectively.
C_l and C_d are dependant mainly on angle of attack
For angle less than 8^0, the coefficient of lift $C_l = 2 \sin \alpha$
(From, Modi and Seth, fluid mechanics and hydraulic machines)

For high lift to drag ratio, taking $\alpha = 7^0$
Therefore, $C_l = 0.765$
As $C_l/C_d = 20$
$C_d = 0.038$

Considering an ambient temperature 35^0 C

Air density will be 1.2 Kg / m^3

The maximum lift force is calculated at cut – out wind speed V_{ct}

$F_{lmax} = C_l \times ½ \times 0.3 \times 25^2 \times 1.2 = 33.07$N
$F_{dmax} = Cd \times ½ \times A_b \times V_{ct}^2 = 1.64$ N

A. Diameter and number of bolts:

The centrifugal force acts as tensile force on the bolts. Taking 8 bolts, we have,

$8 \times Π/4 \times d_b^2 \times F_t = F_c$

Where, d_b = diameter of the bolt
F_t = tensile stress of mild steel = 250 N/mm^2
Taking a factor of safety 6, we have,
$8 \times Π/4 \times d_b^2 \times 250/6 = 21.5 \times 10^3$
d_b = 6.93mm = 7mm (approximately)

3. Fabrication of blade

The blades are the most highly stressed component of the windmill. Gyroscopic forces are the worst threat during yawing at very high speeds because of the change in wind direction. The extra inertia of the heavier blade does not actually consume power but it may prejudice to start up during brief gusts of above average wind speeds.
The blade should be light at tip and harder at root for minimum stress.

Wood is the best choice for construction as it is light, strong, and workable and has good fatigue properties. And it is cost effective.

Materials required for fabrication include 3 pieces of teak, 150mm x 50mm x 1150mm and 2 plywood discs, 12mm thick, 300mm in diameter, exterior or margin grade.

The first step of fabrication is marking the stations on the pieces of teak, equally spaced at intervals of 230mm.

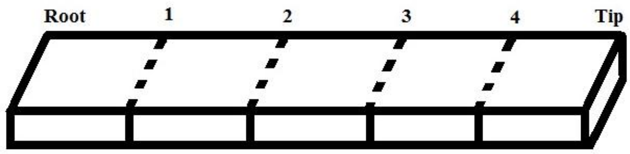


Fig 1: Marking out the stations

The second step involves tapering the blade at the sections with the given below readings.

Table 1: width at different stations of the blade

Station	Width	Drop (Step 3)	Thickness
1	145	50	25
2	131	33	20
3	117	17	18
4	104	10	15
5	90	5	11

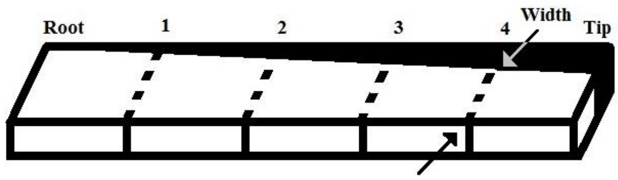


Fig 2: Tapering the blade

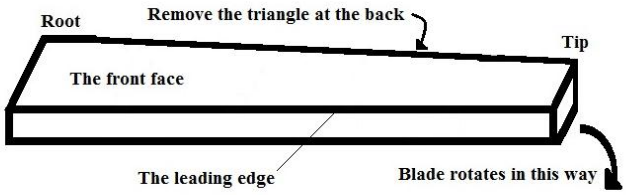


Fig 3: Leading edge and front face

In the next iteration the twist is carved by dropping the lines at stations on the newly cut face and mark the points on that lines which are represented as drop in the table 1. The root is to be left uncut, for assembly between the hub discs.

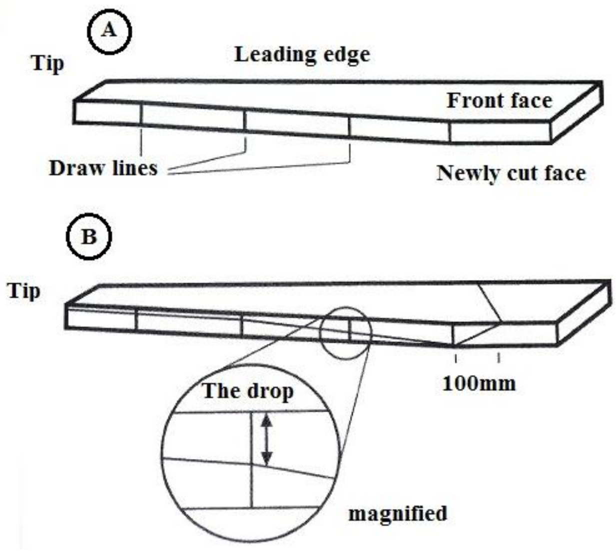


Fig 4: cutting the blade according to the drop values

After carving the twist the blade will be as given below.

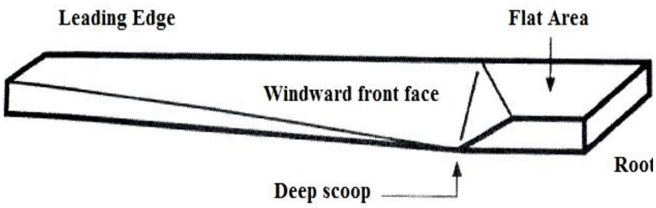


Fig 5: the blade after carving the twist

We now get a tapered piece of wood, with a twisted face hollowed out of the front. The next step is to remove wood from the back of the piece, to get the exact thickness at each station.

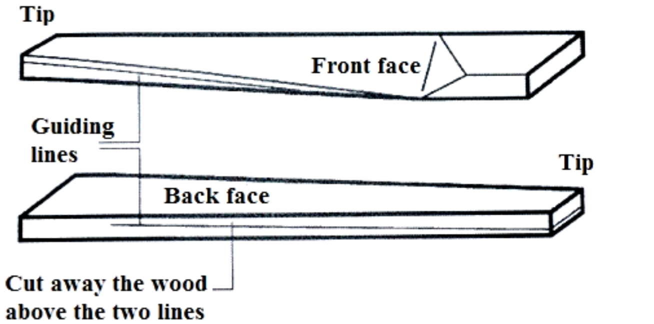
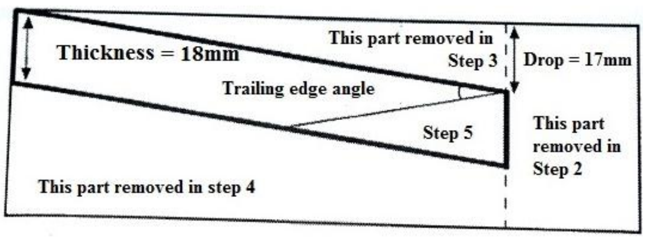


Fig 6: Twisted and tapered blade of correct thickness

The final stage of carving is to provide a streamlined aerofoil section. The wood is planned off from the back until a sharp edge, less than a millimeter wide, beveled at 20^0 angles. The finished edge should be less than 1mm wide.



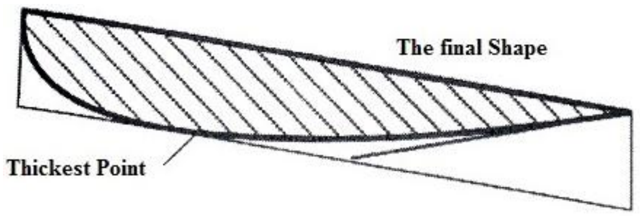
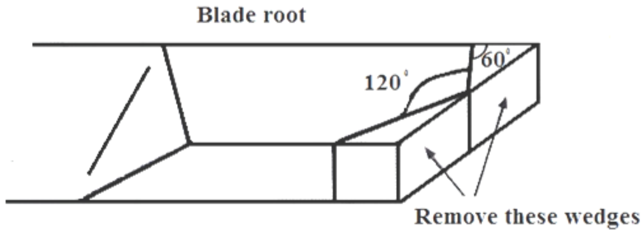


Fig 7: The finished cross section of the blade

Ensure the thickness is same all over each blade root ant it should be cut to fit snugly at the hub. The root has to be made as the given below and the number of screws is 8 on each side.



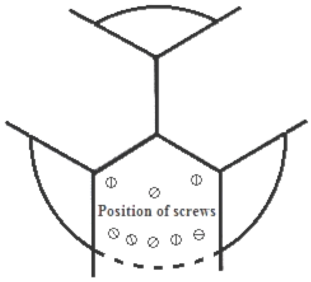


Fig 8: Root design at hub

Leading edge is protected by using an epoxy resin or leading edge tape as high tip speeds cause rapid erosion of the blade material.

A reliable, low speed generator with good efficiency in light winds is selected for conversion of mechanical to electrical energy.

Apart from blades and generator, tail vane, tower, yaw drive mechanisms, governing and shut down systems should be selected appropriately.

Fig 9: types of tale vanes

The simplest tower for the wind turbine is a guyed tube. Steel tube is considered because of light weight and ease to machine.

Conclusions

For reasons of efficiency, control and aesthetics the wind turbine market is subjugated by the horizontal axis three blade turbine, with the use of yaw and pitch. Manufacturers are also seeking increase in blade efficiency rather than increase in the blade size as this gives the advantage of easy transportation and installation.

The material of the turbine plays a very important role in design and fabrication. The teak wood which is used to make the blades of the turbine is easily available and also can be carved precisely. And the most important factor i.e. the cost effectiveness and reliability of the turbine designed is very optimum and can be used by every individual for the domestic purpose.

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