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Design and Analysis of Vortex Bladeless Windmill for Composite Material

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Abstract

Nowadays, the non-renewable energy sources are gone to depth of the earth, so we obviously need to produce energy by using renewable energy sources. The traditional blade wind turbines are used to produce energy but its cost is very high and it have many disadvantages like as capital cost, maintenance cost, running cost, friction loss and it is also dangerous to birds and is noisy as well. Hence, there is a need to find low-priced and safe replacement to conventional windmills. The concept of bladeless windmill works on the theory of vortex shedding effect. Vortex bladeless windmills are a wind powered generator that generates electricity with minimum moving parts. It generates the electric current by using the oscillation or vibrations produced due to the wind. It's working principle of vortex-induced vibrations (VIV). Hence, the electricity is generated by using linear alternator or piezoelectric material. Generally, structures are designed to minimize vortex-induced vibrations (VIV) in order to minimize mechanical failures. But in this project work, we try to increase the vortex-induced vibrations (VIV) with maximum deflection of bladeless windmills which is used to produce electricity with experimental and geometrical approach.

Keywords: *Bladeless windmills, deflection, renewable energy source, vortex shedding effect, vortex-induced vibration*

INTRODUCTION

A windmill is a device which converts the kinetic energy of wind into electrical energy. There are two ways of producing the energy from windmill which is through rotational windmills and oscillation windmills.

Rotational windmills are nothing but the conventional windmill. In this type, the rotating turbine blades are mounted to shaft of gearbox at the center. This gearbox is used to convert the rotational energy of blades into mechanical energy and this mechanical energy is used to run the generator. The generator is used to convert mechanical energy into electrical energy in suitable form. Rotational windmills are effectively used in commercial applications because of its effectiveness and efficiency at a larger scale.

Oscillation type windmills are used to produce less amount of electrical energy that's why it is not used in commercial applications. Its main advantage is that it has less moving parts, less space is required for installation, light in weight and cost is also less because it is bladeless and gearbox is also absent. To understand the reason behind it, we have to understand the working of oscillation type windmills. This type of windmills is based on the theory of vortex induced vibrations (VIV). When body is interacting with the external flowing fluid have some velocity then the body produced the motion is nothing but the VIV. When a fluid is passed on the object then VIV is produced vibration in perpendicular direction with the object. In the oscillation type windmills, the most suitable geometrically airfoil shape is cylindrical. The cylinder produces the effect of VIV because of its symmetry along its center line. As some velocity of air is passing on cylinder which is placed vertically, it starts to oscillate in the horizontal direction due to air force or velocity of air and which is hanging by a spring or any supporting element like light rod. These oscillations are nothing but the mechanical motions due to the velocity wind flow that must be transferred into electrical energy. The oscillation windmills generate electricity with the application of VIV principle, we are required to convert linear mechanical motion into voltage. Oscillation type windmill is more suitable for small-scale.

Working Principle of Vortex Bladeless Windmills

This concept is based on fluid dynamics. In vortex-induced vibrations (VIV), the motions carry by the body due to an external fluid flow it starts to oscillate. For example, the VIV of a cylinder which is placed into air having definite velocity and these air strikes in the perpendicular direction to the center axis of a cylinder. Hence the fluids always having some viscosity, when the flow comes in contact with the cylinder then will be slowed down and forming the boundary layer. Due to excessive nature of curvature of body, the boundary layer will be separated at some point. Vortices are then formed changing the pressure distribution along the surface. When the body is not formed symmetrically around to its mid-plane then due to this reason different lift forces were developed on each side of the body, hence it tends to converts motion transverse to the flow. This motion changes the nature of the vortex formation in such a way as to lead to limited motion amplitude.

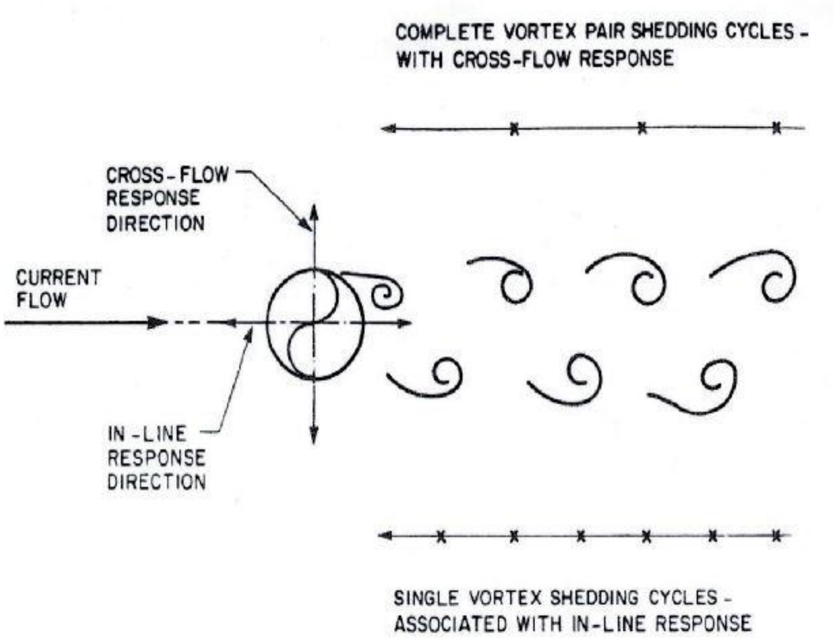

***Figure 1:** VIV of a cylinder.*

The function of VIV airfoils to the production of lift forces in two directions which is perpendicular to airflow. Due to this, the airfoil must be symmetrical with the vertical cross-section for the analysis purpose is shown in Fig. 2.

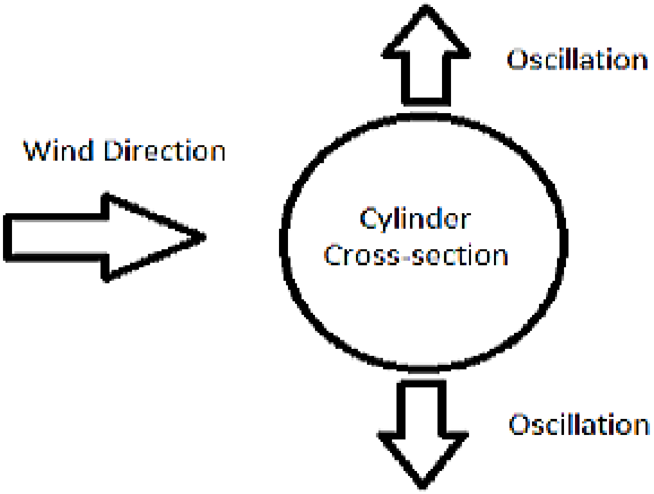

Figure 2: *Working principle.*

The most commonly used geometry shape for this application is a tapered or non-tapered cylinder. The cylinder is best way to produce the vortex shedding property of fluid flow and it produces oscillation because of its simple and aerodynamic shape. The cylindrical airfoil is also easy to manufacturing with any material and easy to design as well.

LITERATURE REVIEW

Gaurao Gohate, Abhilash Khairkar, Sameer Jadhav [1] In this paper we can study of the vortex induced vibrations for producing energy with the various methods of the wind power energy are discussed. For the generation of wind energy the various phenomenon and concepts are used is also discussed. Also the various problems in the conventional wind power harvesting are also discussed. From this paper we also understand that by using a piezoelectric material in the oscillation of wind power harvesting type model is also better way to produce electric energy [1].

Prof. Harshith K, Blayan Santosh Fernandes, Shreerama P R, Thilak Raj [2] This paper deals with the theoretical study of the bladeless wind power generation. In which various detail parts of bladeless wind power generation is discussed. In this paper the assembly of sprocket, chain and wheel is attached mast model is discussed and also history of the bladeless wind power generation is to be discussed. The different applications of the bladeless windmill and its future scope are studied [2].

Banafsheh Seyed-Aghazadeh, Daniel W. Carlson, Yahya Modarres-Sadeghi [3]. This paper deals with the study of the effect of the taper ratio on vortex-induced vibration of tapered cylinders. In this paper, they are conducted test on various types of cylinder with the effect of different taper ratios. For linearly tapered cylinders of wider range is compared with the uniform cylinders. The tests are carried out on small taper ratios [3].

Antonio Barrero-Gila, Santiago Pindadob, Sergio Avilac [4] In this study, (VIV) of a circular cylinder is analyzed as a potential source for energy harvesting. To this end, VIV is described by a one-degree-of-freedom model where fluid forces are introduced from experimental data from forced vibration tests. The influence of some influencing parameters, like the mass ratio m* or the mechanical damping ξ in the energy conversion factor is investigated [4].

PROBLEM STATEMENT AND OBJECTIVE

Problem Definition

The problems produced in the conventional windmills are discussed for the design and construction of vortex bladeless windmills is as follows:

- The conventional windmills required big investments. This is the most important problem for installation of windmills.
- It mostly installed in that places where the speed of wind is more.
- The production cost and transportation cost of heavy parts of windmill is very high.
- Designing of windmill blades is also critical task.
- The size of the assembled windmill is also very big.
- Also, they are dangerous to birds.

Objective

The main aim of this project is to effectively conduct design, analysis and experimental of vortex bladeless windmills. The study focuses on maximize the deflection of bladeless windmills which is used to produce electricity in future with experimental and geometrical approach. A 3D finite element model of system is developed in CATIA design software and to determine the required results the analysis is done by using ANSYS 16.0 software. This study is studied to provide tools that ensure better designing options for bladeless windmills with experimental results.

- To design vortex bladeless windmill with existing parameter of dimension in CATIA V5.
- To correlate existing windmill in ANSYS 16.0.
- To modify windmill for better results.
- To modified windmill design in ANSYS16.0.
- To analyse under different material and dimension of mast this is important part in windmill.
- To correlate FEA with actual experiment.

  Also apart from these, the primary objective is to maximize the deflection of bladeless windmill.

ANALYTICAL CALCULATIONS

Specified Material Properties

The material properties for the design and development of Vortex bladeless windmills are sorted in Table 1.

Table 1: *Comparison between glass fiber and carbon fiber.*

Sr. no	Material	Density (g/cm^3)	Tensile Strength (Mpa)	Compressive strength (Mpa)	Thermal Expansion (µm/m* °C)
1	Glass Fiber	1.79	3445	1480	5.4
2	Carbon Fiber	2.45	4127	1600	2.9

Glass fiber is a composite material of glass cloth and polyester resin. As the weight of Glass Fiber is less hence it required less lift force and allowing for reaching natural frequency oscillations at lower velocity. By comparing the two materials, Glass fiber have tendency to resists both compressive and tensile forces well. Additionally, fiberglass is easily available in market with low cost than carbon fiber; it also does not require any special machining process to work with it and can be manufactured into number of geometric shapes, contributing to its feasibility as an airfoil material. Due to this reason Glass Fiber material is selected for the mast design and for the material of rod we take Nylon due to flexible, light weight and easily availability.

Numerical Model

The Pune city is selected for calculating dimension of vortex mast and according to metrological conditions of Pune, getting the average yearly velocity is 3m/s. According to this data vortex tube was designed. Let we consider a Tapered cylinder.

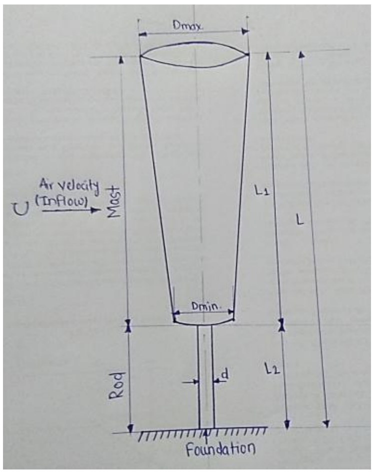

Figure 3: *Numerical model.*

Considering the notations as follows,
$D_{max.}$ = Upper Diameter
$D_{min.}$ = Lower Diameter
D = Mean Diameter
d = Rod Diameter
L1 = Length of Mast
L2 = Length of Rod
U = Air velocity

$$Mean\ Dia.(D) = \frac{(Dmax. + Dmin.)}{2}$$

$$Taper\ Ratio\ (Rt) = \frac{L1}{(Dmax. + Dmin.)}$$

Let consider the length of mast as L1=2m, i.e., 2000mm total length and from research paper study we take,

$$\frac{L1}{D} = 10$$

$$\frac{2000}{Dmax.} = 10$$

$$Dmax. = 200mm$$

Now from research paper we studied that the taper ratio lies between 14–19, so from data we consider 16 as a taper ratio (Rt) =16 and put into formula of taper ratio we get,

$$16 = \frac{2000}{(200 - Dmin.)}$$

$$Dmin. = 75mm$$

$$\approx 80mm\ approx\ for\ smooth\ taper$$

So that for initial condition we consider following dimension for CAD modelling

$D_{max.}$ = 200 mm
$D_{min.}$ = 80 mm
d = 20 mm
L1 = 2000 mm
L2 = 250 mm

FINITE ELEMENT ANALYSIS

Static Structural analysis and CFD analysis of vortex bladeless windmill is carried out by ANSYS 16.0 software to determine deflection values of the windmill. The finite element analysis includes CAD modelling, pre-processing, solution and post processing.

CAD Modelling

The dimensions for the parts were determined analytically which were later used in modelling. The CAD model is created in the CATIA V5 software. The accuracy of any FEA analysis depends on how correctly the modelling work and its meshing number have been carried out. The Part-modelling is done by CATIA V5 software using the below mentioned dimensions.

Table 2: *Dimensions for the windmill model.*

Sr. No.	Parameters	Dimension for Various Conditions (mm)		
		1	2	3
1	$D_{max.}$	200	200	200
2	$D_{min.}$	80	100	100
3	d	20	20	20
4	L1	2000	1500	1500
5	L2	250	750	1250
6	L	2250	2250	2750

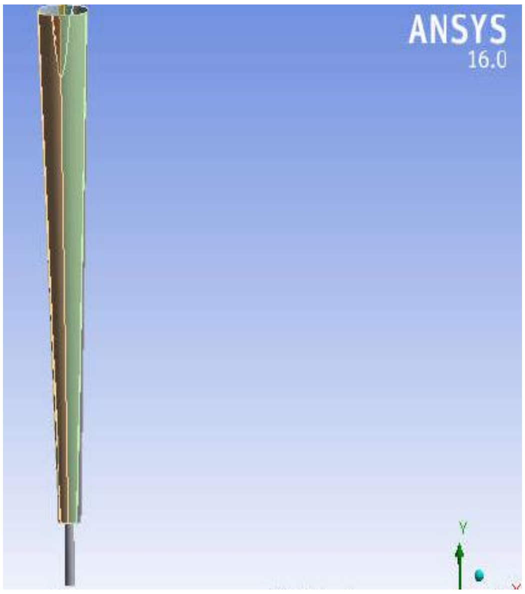

Figure 4: *Assembly drawing (condition 1).*

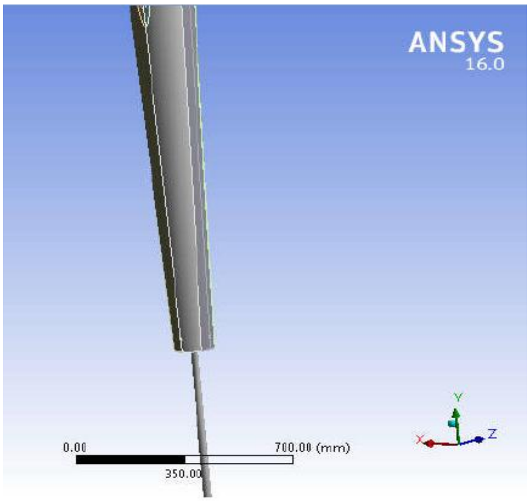

Figure 5: *Assembly drawing (condition 2).*

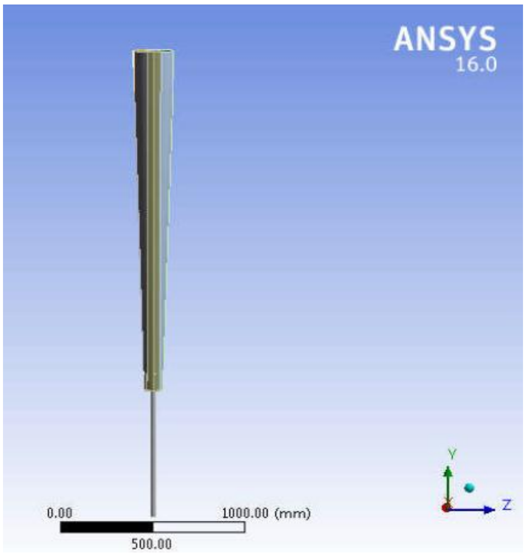

Figure 6: *Assembly drawing (condition 3).*

CFD Analysis

CFD analysis is performed by ANSYS 16.0 software to determine the pressure produced by air velocity of 3 m/s. The pressure which is getting from CFD analysis is used to applying in structural analysis for loading conditions.

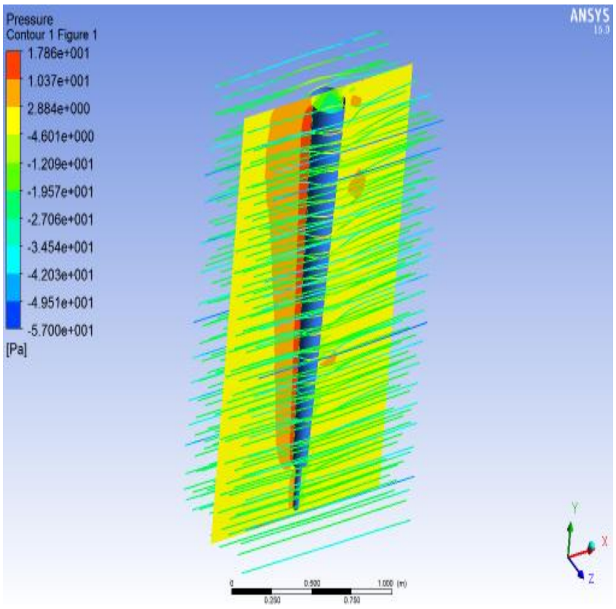

Figure 7: *CFD analysis.*

Loading and Boundary Conditions

The load is applied as a pressure from the CFD analysis on the surface of the mast and the bottom surface of rod is fixed. These are the loading and boundary conditions on the structure of Vortex bladeless windmill.

Static Structural Analysis

Condition 1

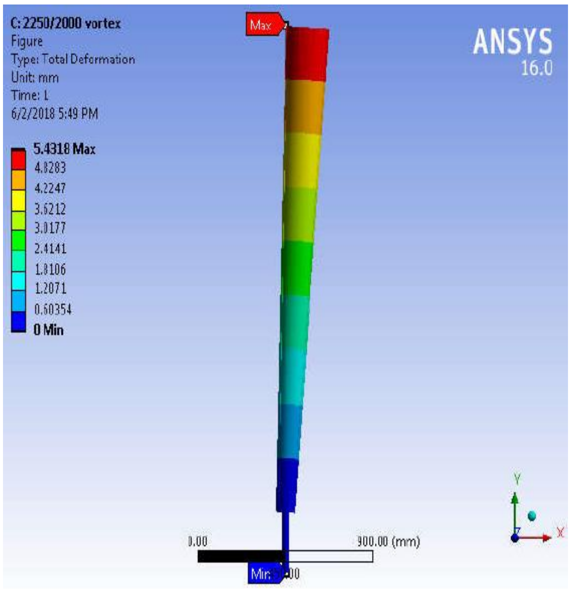

Figure 8: *Total deformation (condition 1).*

Maximum Total Deformation – 5.4318 mm
Minimum Total Deformation – 0 mm

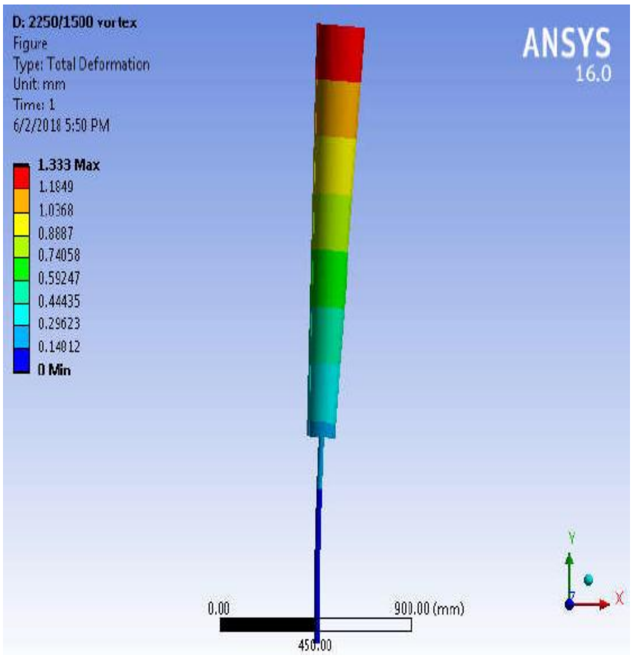

Figure 9: *Total deformation (condition 2).*

Maximum Total Deformation – 1.333 mm
Minimum Total Deformation – 0 mm

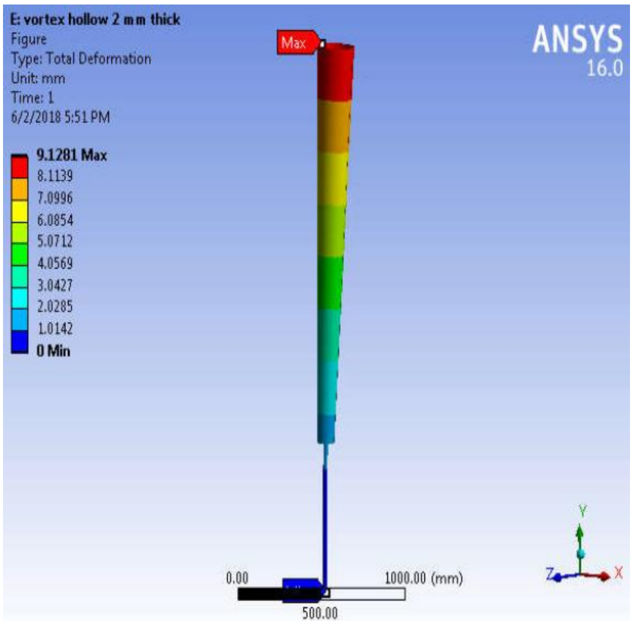

Figure 10: *Total deformation (condition 2).*

Maximum Total Deformation – 9.1281 mm
Minimum Total Deformation – 0 mm

Table 3: *Dimensions for the windmill model.*

Material	Conditions	Max. Total deflection(mm)	Min. Total deflection(mm)
Glass Fiber (Mast) and Nylon (Rod)	1	5.4318	0
	2	1.333	0
	3	9.1281	0

EXPERIMENTAL ANALYSIS

The below material is used for respective parts: According to Finite Element analysis, the maximum deflection is given by the condition consider at number three so that we consider the dimensions and material for carry out the experimentation and manufacturing of Vortex bladeless windmills is as follows:

Material for Mast – Glass Fiber
Material for Rod – Nylon

Table 4: *Dimensions for the windmill model.*

Sr. No.	Parameters	Dimension for Condition 3(mm)
1	D max.	200
2	D min.	100
3	d	20
4	L1	1500
5	L2	1250
6	L	2750

Figure 11: *Vortex bladeless windmill.*

Figure 12: *Experimental setup – Deflection testing for vortex bladeless windmill.*

Measured Parameters
Actual Deflection in cm at air velocity 3.5 m/s.

RESULT AND DISCUSSION

The samples of Vortex bladeless windmill was tested in open environmental at 10 ft. height of building to checking the maximum deflection. Firstly the windmill was mounted on the rigid fixture; it was observed that on application of air velocity the windmill began to deflect with 10-30 mm.

Table 5: *Comparison of software and experimental results.*

Parameter	FEA Result	Experimental Results
Total Deflection	9.1281 mm	10–30 mm

CONCLUSION

From the above results, the glass fiber is the most suitable material for manufacturing of Vortex tube because it gives maximum deflection. By comparing FEA analysis results and experimental results, the deflection of vortex tube is nearly same. After experimentation, it is found that the maximum deflection is more, i.e., 10–30 mm. Vortex bladeless windmill is mostly used in small application where less amount of electricity is required. It is most preferable solution as compare to conventional windmill due to it have simple in construction, easy to design, easy to manufacture and less space required. The main advantage is that it requires low maintenance cost because of less moving parts. For future use of this project work, we can use this type of windmill for home appliances or where less amount of electricity is required.

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