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Comparative Analysis of Various Types of Mast Used in Bladeless Vortex Turbine

Shlok Jhunjhunwala
BIS Mumbai, India shlok.3075@bis.edu.i

Vinay Vishwakarma
On My Own Technology Mumbai, India
vinay.vishwakarma@onmyowntechnology.com

Abstract- This study presents a vortex-bladeless wind turbine run using vortex shielding frequency. In the present study, we perform a comparative analysis of two different types of masts model using fusion360; these masts are circular and conical. The height of each mast is 500 mm of PLA material. To analyze the mast, we used SIMSCALE software to generate the masts' accurate eigen frequencies. Two different types of masts are compared with each other for validation purposes and each mast generates natural frequencies of 10 nodes. For drag and lift coefficient simulation purposes ANSYS Fluent was used, and the conical mast with diameters 40mm and 50mm vibrates at a very high frequency as compared to other types of conical and circular masts.

Keywords- Wind Turbine, Mast, Frequency, CFD, SIMSCALE

I. INTRODUCTION

A groundbreaking approach to renewable energy, known as Vortex Bladeless, has revolutionized the industry and it promises to transform wind power by offering an increased total output at a reduced overall cost. This includes monetary cost, the cost to wildlife like birds, and a longer lifespan per turbine. Renewable energy sources, such as Vortex Bladeless wind energy, alongside unconventional sources like unlined coal and gas, are advantageous to society as they produce no carbon emissions while posing minimal harm to wildlife at a negligible cost. A bladeless wind turbine also generates significantly less minor noise as compared to a conventional turbine, this feature enables bladeless turbines to be installed in closer proximity to residential areas, resulting in reduced transportation costs associated with cabling. This design is also scalable and, used in smaller sizes for domestic purposes, or even at the scale of wind energy farms.

These wind turbines generate energy on the principle of Vortex-induced vibrations that are produced by vortex shedding. This phenomenon developed because of pressure difference generated due to air vortices in the wake of a body. Initially, the frequency of vortex shedding is equal to the resonant frequency of the Mast, which causes periodic oscillations as the body tends to move toward the area of lower pressure. These vibrations are further used to convert mechanical energy into electrical energy with the help of electrical components.

II. LITERATURE REVIEW

Bladeless vortex generators were developed by Ghode et al. [1] to attain an efficiency of up to 45% compared to other wind turbines. A 3D-printed turbine was tested for output voltage vs incoming wind velocity.

The experimental investigation of oscillatory power producers presented by Manukonda and Rao [2] involves different winds, different charging states of the battery, and load ON and OFF conditions for the power producer. Power producers reduce the disadvantages of conventional wind turbines like noise, higher investment, and higher maintenance. Samy et al. [3]studied the vortex bladeless turbines' circular and conical mast shapes. Circular and conical vortex bladeless turbine design based on safety, and cost; were performing mast, base, generator, and road taken into consideration.

A vortex bladeless turbine changes various parameters such as height, and the minimum and maximum diameter of the conical mast designed by Sudarshan et al.[4]. Furthermore, FEA and CFD simulations were performed on different types of mast for maximum power out generated by using a vortex bladeless turbine. Mechanical energy (vibrations) to electric energy converts using VIV (vortex-induced vibrations) wind energy–harvesting device developed by Younis et al. [5]. Increasing the inlet wind velocity increases the maximum magnitude of the lift coefficient and time required to reach pseudo-steady situations. Changing the geometry of the cylinder enhanced the maximum lift force applied to vortex generators and boosted the efficiency of VIV energy harvesting showing that the numerical and experimental results are close to each other.

Efficiently analyzed and designed bladeless vortex turbine by Francis et al. [6]. 3D model created in solid works and analysis perform in ANSYS software to maximize the deflection of the bladeless" "turbine. Wulandana et al. [7] presented optimal design conditions for energy harvesting from vortex- induced oscillations. Power production and rpm of this model increase the Reynolds number, and the upstream obstacle increases the turbine response. These bladeless designs examined the turbine to be applicable in both air and water and independent flow directions.

El-Shahat et al. [8] proposed wind generators used as a reliable power source in the nano grid. A vortex wind generator is designed with a hollow, conical- shaped bluff body to be placed vertically on the ground. Airflow interacts with the bluff body, it undergoes vortex shedding, resulting in vortex- induced vibrations within the body. This vibration energy of the body is converted into electrical energy. Mane et al. [9] presented a vortex wind turbine without blades that were constructed and tested, and an e-generator driven by gyro-action to generate electricity. This prototype combines a vortex turbine and an e-generator to produce electricity using a 3-D printing model. This model observed wind speed affected the speed of the turbine, the voltage, the current, as well as the power generated by it.

Khaled et al. [10] carried out a novel approach toward bladeless wind turbines. This bladeless wind turbine has been designed, developed, simulated, and tested. This numerical investigation was carried out to simulate the fluid-structure interaction (FSI) under various air-flow conditions to analyze the correct dynamic response of the bladeless wind turbine. Schmidt [11]developed a wind generator based on piezoelectric polymers. These piezoelectric equations employ bimorphs set into mechanical oscillation by the wind.

Villarreal [12] presented a synopsis of the most general aspects of an alternative technology based on VIV fluid-structure interaction that avoids the use of gears or shafts. A wind generator with a thin, circular cross-section and a diameter that varied with height device based on aeroelastic resonance is feasible.

Bahadur [13] studied the motion of a 3-DOF variable mechanism vortex bladeless wind turbine. The mechanisms are based on a progressive rate spring located between the turbine's body mast and an oscillating permanent magnet. Spring stiffness to tune the fundamental frequency of the turbine to match the vortex-shedding frequency over a range of wind speeds. at high wind speeds, the electromechanical coupling factors significantly modified the turbine's dynamics, causing it to have just one fundamental frequency. The present research investigation aims to compare various mast designs suitable for Vortex Bladeless wind turbines to determine the most optimal design for different scales, including domestic and larger applications. The analysis was conducted using simulation techniques, specifically SIMSCALE and FLUENT, to evaluate the performance of different mast shapes in terms of high mechanical energy production.

III. METHODOLOGY

First, two types of masts were created using Fusion 360: circular and conical masts. The height of each mast was set at 500 mm and used PLA materials. PLA (Polylactic Acid) materials are a form of biodegradable thermoplastic that is derived from renewable sources like corn starch or sugarcane. These materials have become increasingly popular due to their eco-friendly nature and their ability to be used in a wide range of applications.

Subsequently, the masts were imported into SIMSCALE for natural frequency analysis. In SIMSCALE, the first step involved assigning the materials, with PLA being used in this case. The second step entailed fixing the support at the specified location on the mast. Once the support was securely fixed, the simulation was performed to determine the eigenfrequencies of the mast.

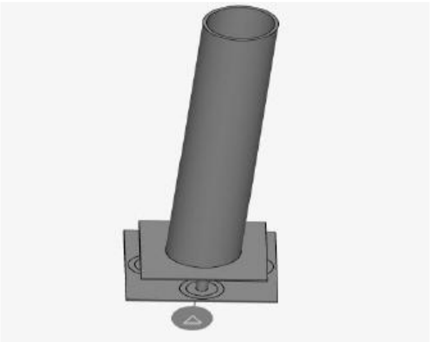


Fig. 1 Circular Mast" "

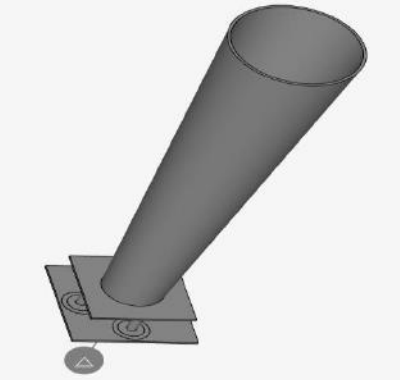


Fig. 2 Conical Mast

Simultaneously, the model was prepared for CFD simulation. Initially, this model was imported into the geometry section of Fluent in STEP file format. This model had been prepared to replicate wind tunnel testing, so the wind tunnel was designed around the model by defining the inside material as air. Later that, the mesh was generated, with the minimum element size set to 1mm and the element type set as quadratic. An inflation layer was created to capture the pressure gradient near the mast. After achieving the optimized aspect ratio and orthogonal quality of the mesh, this model was imported into the setup module of Fluent.

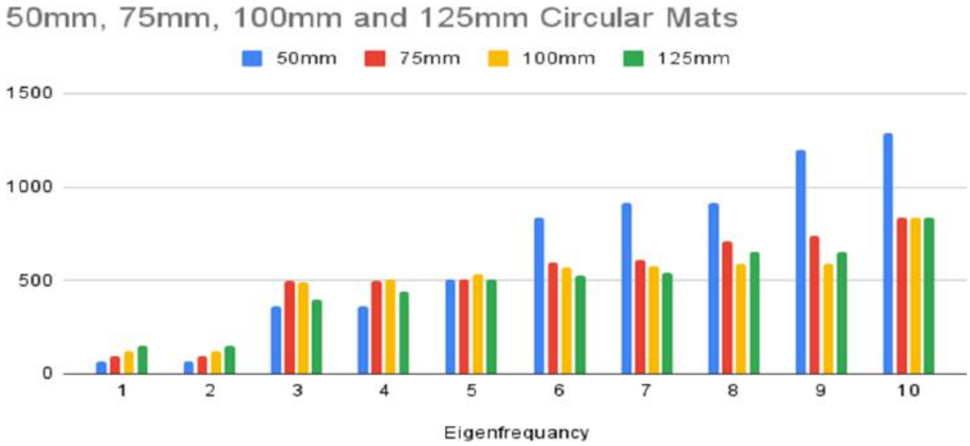
Solver Type	Pressure Based	Due to incompressible flow
Velocity Formulations	Absolute	Flow is not rotational in the Domain.
Time	Transient	To capture vortices in Real-time.
Viscous Model	K-epsilon (2eqn.), Realizable, Non-Equilibrium wall Function	It was used to determine boundary layers, separation, and recirculation under adverse pressure gradients.
Material	Air	It was used to replicate experimental wind tunnel testing.
Boundary Conditions	Inlet	Velocity inlet with initial velocity as 4m/s.
Boundary Conditions	Outlet	Pressure outlet and set as gauge pressure at zero pascal.
Solution Method	Least squares, cell based, Second order	To minimize the residuals of linear approximation
Monitors	Drag and Lift	To determine the lift and drag coefficients.

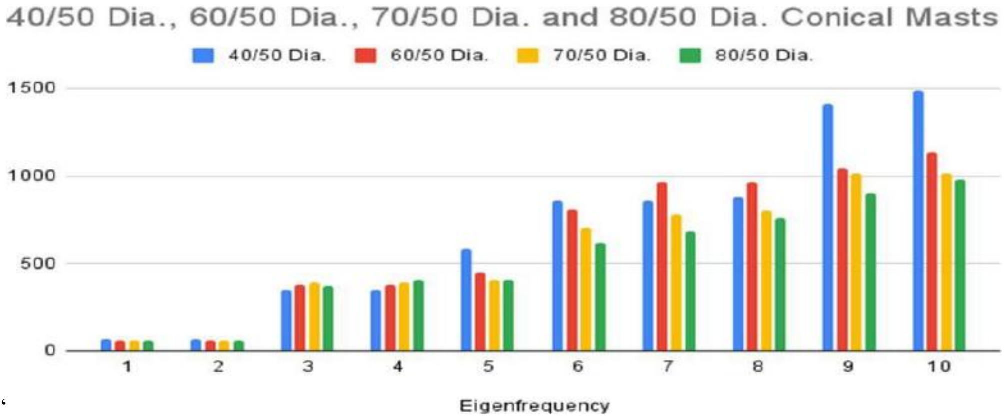
Later, the execution of the above setup in ANSYS Fluent was done, by running the simulation until the solution converged. Drag and lift coefficients were recorded during the simulation in ANSYS.

Also, the velocity and pressure contours were captured. Which is further discussed in the next section.” “

IV. RESULTS AND DISCUSSIONS

Using SIMSCALE, the eigenfrequencies are shown in the graph below.





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The above figure shows the ten eigenfrequencies of various types of masts. From the above graph, we can see that a conical type of mast with 40/50 Dia. vibrates at high frequencies as compared to another conical and circular type of mast.” “

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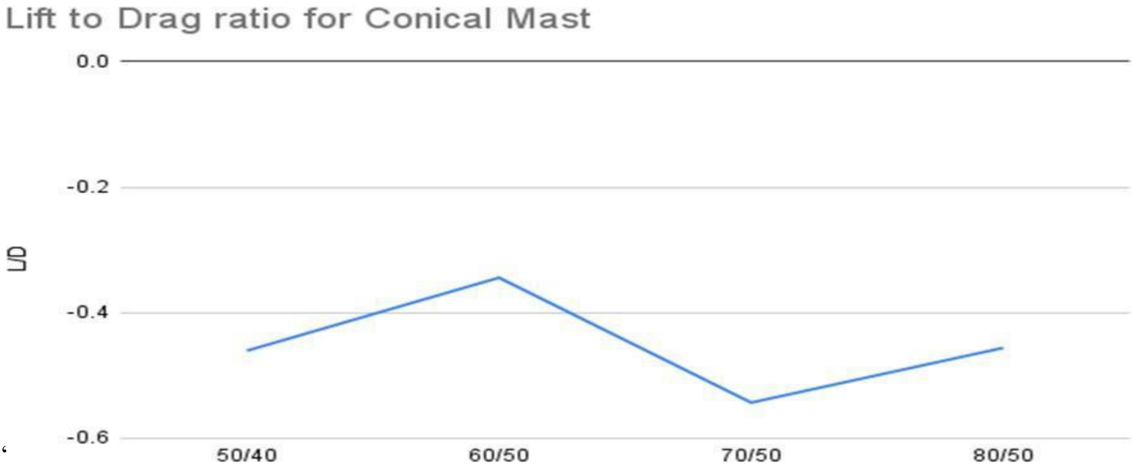

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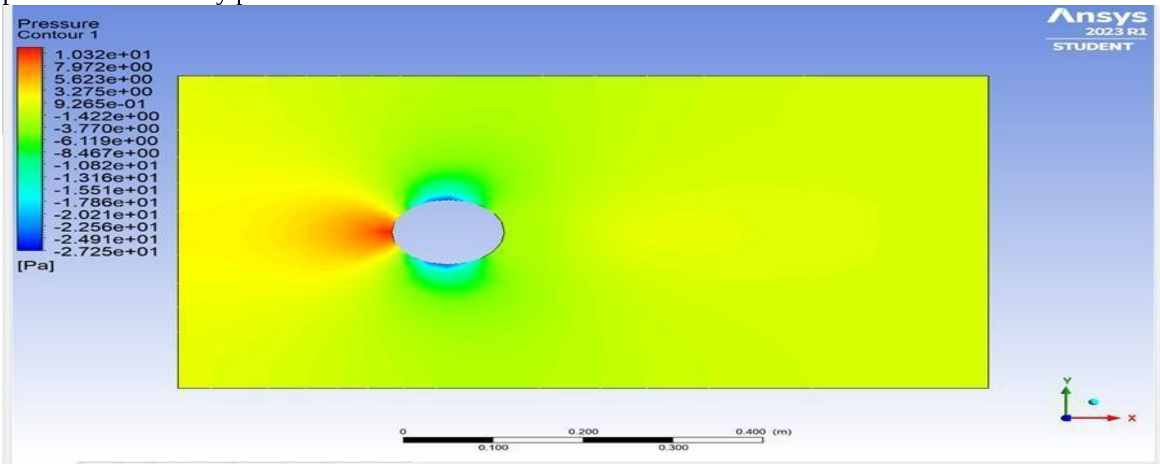
The figure above shows the Lift to drag ratio for various types of circular and conical type of masts.

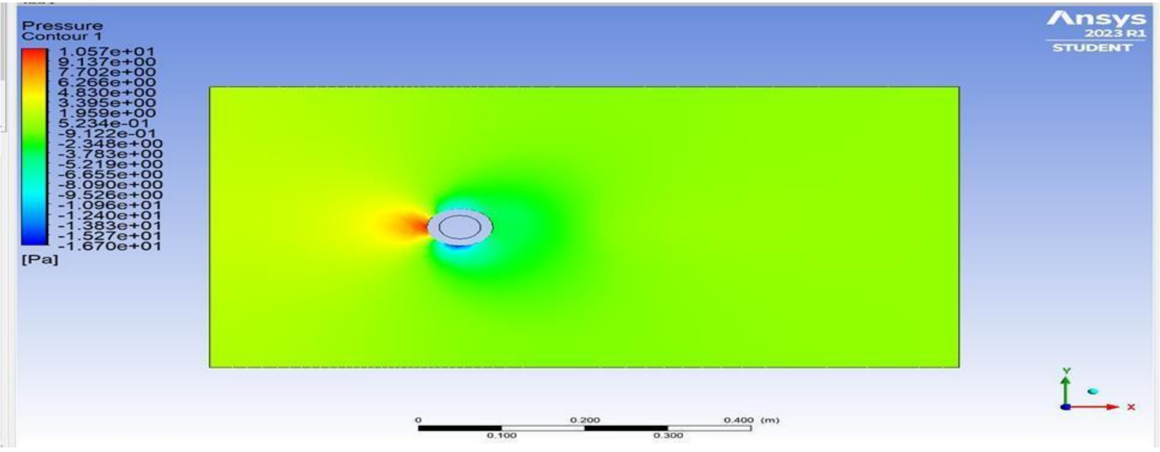
Only the Dia. 75mm Circular Mast have a positive Lift to Drag ratio other all types have negative ratios. The pressure and velocity profiles for various masts are shown below.” “



“ “Pressure contour for Circular Mast.

Above figure shows the pressure contour of the circular mast. The pressure value is equal to the atmospheric pressure when air collides with the inlet side of the mast.

However, as the air separates from the mast, the pressure decreases in the negative direction. The same trend can be observed in the Figure, show the pressure contour for the conical type of mast. When the air strikes the mast, a positive pressure is evident in the figure. However, as soon as the air separates from the flap, a negative pressure gradient becomes apparent.



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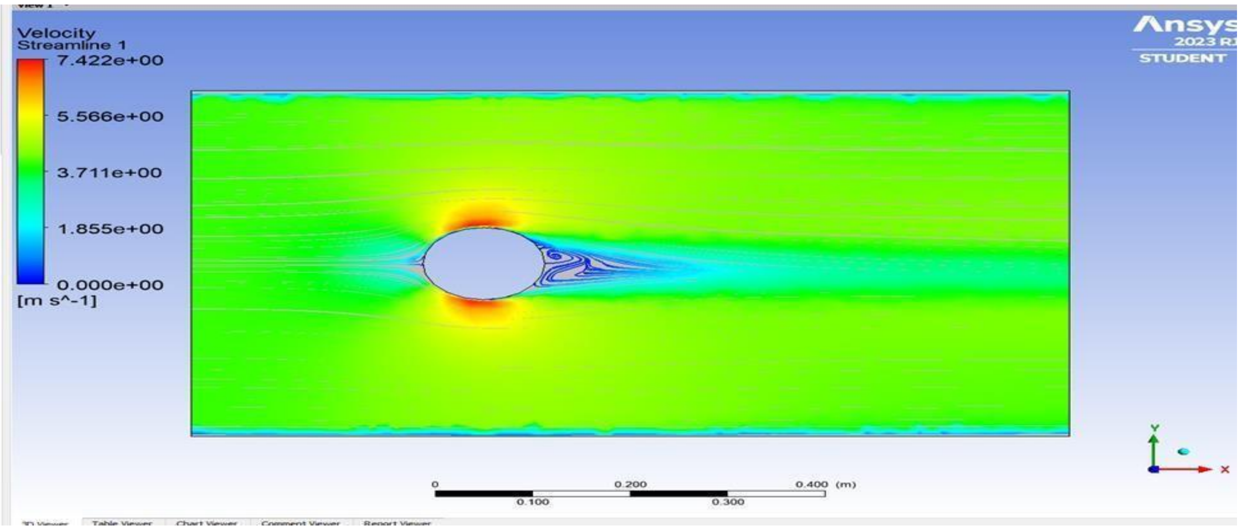
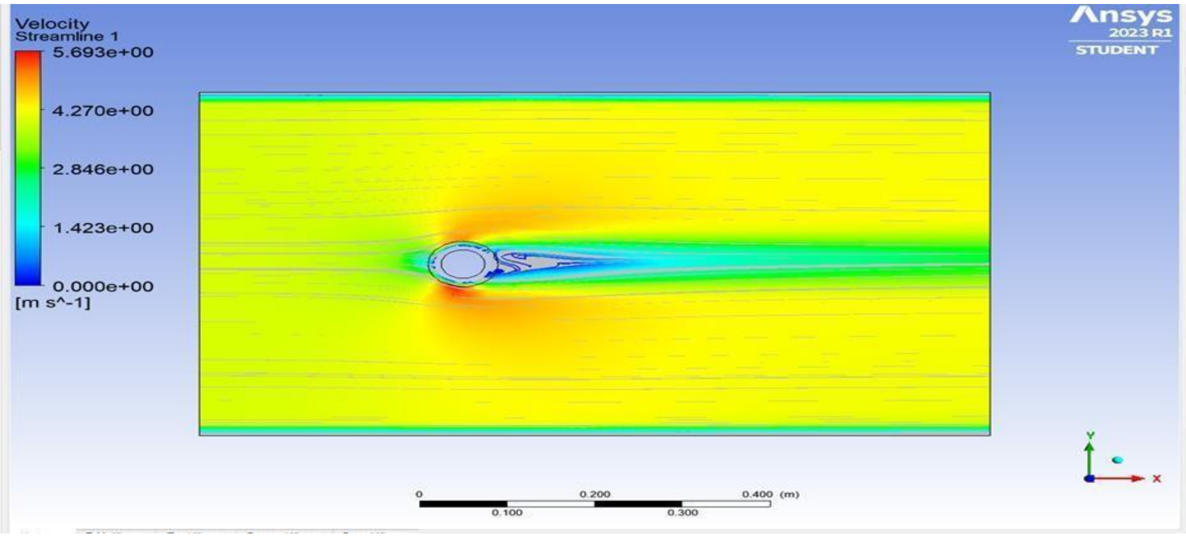
Pressure Contour for Conical type of Mast.



Velocity Streamlines for Circular Mast.

In Figure below, shows that the velocity profile along the circular mast is depicted, with the inlet velocity as 4 m/s. As the air strikes the mast, the velocity decreases significantly, and when the air separates from the mast, the pressure drops while the velocity increases. Above figure shows shows that the velocity streamlines for the Conical type of mast. Once the air leaves the mast, the flow becomes turbulent and starts generating a vortex.



Velocity streamlines for the conical type of Mast.

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V. CONCLUSION

The present study shows that the bladeless vortex wind turbines play a vital role due to the high demand for electrical energy. The mast serves as the heart of any bladeless vortex turbine, vibrating at the vortex-shedding frequency and generating electrical power. In this present research, various types of masts have been considered and analyzed for their eigenfrequency to determine the mechanical power output. Based on this research, the circular mast with Dia. 75mm has a positive lift to Drag ratio, whereas the Dia. 80/50 Conical mast vibrates at low vibration frequency. In a further study, the use of different materials for the mast could be explored. Additionally, considering the inclusion of electrical components in the analysis plays a vital role in enhancing electrical power generation.

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