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Vibration analysis of Vertical axis wind turbine (VAWT) using Ansys

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Abstract - **Wind turbines are the most common type of equipment used to transform wind energy into mechanical energy. Understanding the vibration characteristics of wind turbines is essential for reducing blade failure caused by resonance-induced amplitude build-up. The current study investigates a vertical axis wind turbine subjected to free and forced vibration conditions using ANSYS FEA software. In the VAWT test, conventional aluminium alloy and aluminium MMC were used. Natural frequencies and mode shapes for both materials are determined using free vibration (modal) analysis, which is essential for the design of VAWT and the reduction of resonance.The Campbell diagram developed by free vibration analysis found no critical velocities for the operating ranges of 178.02 rpm, 263.89 rpm, 350.81 rpm, 413.64 rpm, 462.86 rpm, and 481.71 rpm. The spin direction and harmonic responses are also investigated using modal analysis. The harmonic response of the system revealed that using Aluminum MMC (composite material) rather than Aluminum alloy material resulted in less stress on the blades. The mode shapes and mass participation factor for both materials offered critical information on vibration properties under free vibration conditions**

Index Terms - Modal Analysis, Harmonic Analysis, vertical axis wind turbine

INTRODUCTION

There is a clear need for the development of renewable energy sources, especially in light of recent studies suggesting that fossil fuel stocks such as oil and natural gas may be depleted in the not-too-distant future. Renewable energy sources include solar, wind, and geothermal energy, to name a few. With wind energy being one of the most well-known sources of renewable energy, it stands out among the other renewable energy alternatives. To transform wind energy into mechanical energy, wind turbines are the most extensively utilised piece of equipment on the planet. Wind turbines transform wind energy into electricity via the use of rotating blades in the generator. The development of substantial technological advances has made it possible to Manuscript Click here to view linked References construct wind turbines [6] [2] that are more practical, dependable, and trustworthy sources of energy, notably for power generation. Wind turbines provide a significant amount of electricity in several countries. Wind energy production increased dramatically in the globe from 1996 to 2015. Wind turbines are devices that generate electricity by using the kinetic energy of the wind as a power source. Prior to the invention of the computer, they were more often used as a mechanical device that spun machinery. It is now possible to use turbines to generate considerable amounts of electrical energy in both onshore and offshore wind farms, and the Vertical Axis Wind Turbine is one of the options available to you (VAWT). Even though a large number of VAWTs are already being used to produce electricity, the HAWT continues to be more practical and popular than the VAWT and is considered to be the focal point of most wind turbine discussions. Wind turbines are a fantastic method to create electricity for our homes and businesses while also using a clean and sustainable resource. 1.1 Theory of Free Vibration [2]: When a mechanical system is started with an initial input and then allowed to vibrate at its own speed, it is referred to as free vibration. When a mechanical system is subjected to a different force or motion on a regular basis, it suffers forced vibration. Washing machines that shake owing to an imbalance, transportation vibration (produced by the vehicle's engine, springs, the road, and so on), and building vibration during an earthquake are all examples of this kind of vibration. The frequency of forced vibration is equal to the frequency of the applied force or motion, with the order of magnitude varying depending on the mechanical system. Once the system is begun in motion, it will inevitably oscillate at its natural frequency, which is a characteristic of the system. Figure 1: Spring-Mass System and Free-Body Diagram The basic foundation for evaluating the motion of the system is Newton's second law.

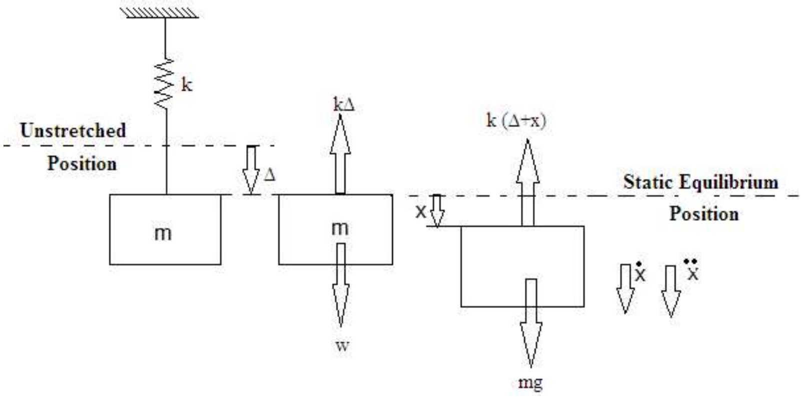


Figure 1: Spring-Mass System and Free-Body Diagram

The spring deformation in the static equilibrium position is Δ , as illustrated in Fig. 1 and the spring force kΔ is equal to the gravitational force w acting

$$k\Delta = w = mg \qquad (1.1)$$

The forces on m are $k\ (\Delta + x)$ and w when the displacement x from the static equilibrium position is measured. All numbers, including force, velocity, and acceleration, are positive in the downhill direction when x is selected to be positive.

The mass m is now subjected to Newton's second law of motion: \

$$m\ddot{x} = \sum F = w - k(\Delta - x) \qquad (1.2)$$

And because $k\Delta = w$, we obtain:

$m\ddot{x} = -kx$ (1.3)

It is evident that by utilising the static equilibrium position as a reference for x, w, the gravitational force, and the static spring force $k\Delta$ have been eliminated from the equation of motion, leaving only the spring force due to the displacement x to operate on m.

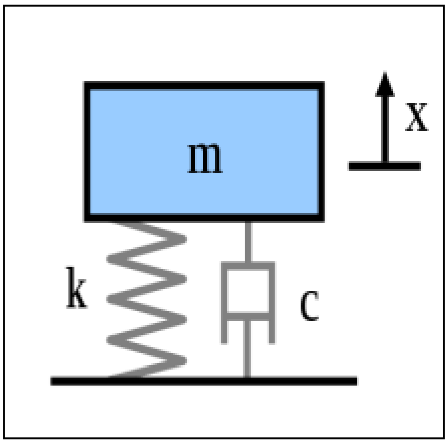


Figure 2: Spring-Mass and damper System

After adding a "viscous" damper to the model, which produces a force proportionate to the mass's velocity. Because it simulates the actions of an item inside a fluid, the damping is termed viscous. The damping coefficient, c, is a proportionality constant with velocity (lbf s/in or N s/m).

METHODOLOGY OF ANALYSIS IN ANSYS

ANSYS is a multipurpose, large-scale finite element programme that may be used to address a number of engineering problems. ANSYS can do static and dynamic structural analyses, steady-state and transient difficulties, mode frequency and buckling eigenalue problems, static or time variable magnetic analyses, and other types of field and coupled field applications. Plasticity, large strain, hyperelasticity, creep, swelling, large deflections, contact, stress, stiffening, temperature dependency, material anisotropy, and radiation are just a few of the non-linearities or secondary effects that may be integrated into the solution using this application. As the programme grew, further sophisticated capabilities such as sub structuring, sub modelling, random vibration, kinetostatics, kinetodynamics, free convection fluid analysis, acoustics, magnetic, piezoelectric, coupled field analysis, and design optimization were included. These capabilities contribute to ANSYS's versatility as an analytical tool for a wide range of engineering specialisations. ANSYS software has been extensively used in the aerospace, automotive, construction, electronics, energy services, manufacturing, nuclear plastics, oil, and steel industries since its launch in 1970. ANSYS is also utilised for analysis, research, and teaching by a huge number of consulting firms and hundreds of institutions.

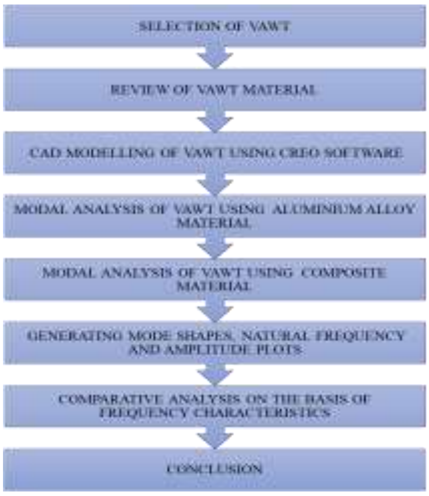


Figure 3 Flow Chart Shows the Process of Methodology

Design of Vertical Axis Wind Turbine [6]

The design of vertical axis wind turbine is taken from literature and dimensions are given in table 1 below

Table 1: Dimensions of Vertical Axis Wind Turbine

Parameter	Value (cm)
Chord length	12
Height of the blade	40
Length of the shaft	48
Diameter of the shaft	3.2
Diameter of the frame	36
Diameter of support –I	30.5
Diameter of support- II	23.6

The vertical axis wind turbine CAD model was created using PTC's Creo 2.0 software, which is a sketch-based, feature-based, parametric 3d modelling programme with parent-child relationships and bidirectional associativity. Extrude, rotate, sweep, and pattern tools are used to create the CAD model. Initially, the aerofoil is developed in accordance with the NACA 0012 standard. The sketch and extrude tool is used to create the aerofoil. To build wind turbine blades, the aerofoil profile is extruded up to 400mm. As demonstrated in Figure 3, a single blade is patterned to produce many copies in the final assembly file.

To build wind turbine blades, the aerofoil profile is extruded up to 400mm. As demonstrated in Figure 4 a single blade is patterned to produce many copies in the final assembly file.

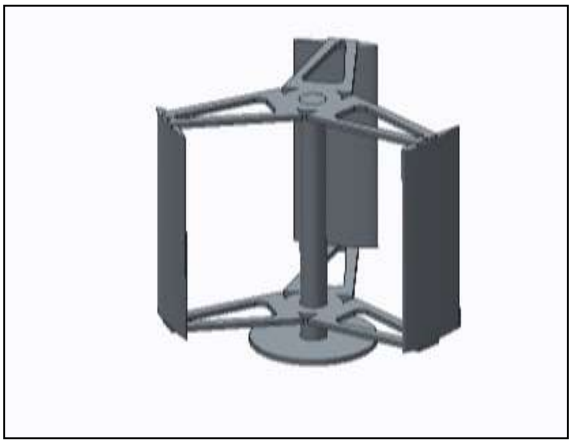


Figure 4: CAD model of vertical axis wind turbine assembly

Table 2 display the material properties of the vertical axis wind turbine used in the study, including structural, physical, and thermal properties.

Table 2: Vertical axis wind turbine material properties

Properties	Aluminium Alloy	Al MMC
Youngs Modulus (MPa)	$7.1 * 10^4$	113000
Density (Kg/m^3)	2770	2820
Poisson's ratio	.34	.33

The model is applied with moment load on top geometry after importing and meshing the CAD model. The moment load is 178.02 rpm, 263.89 rpm, 350.81 rpm, 413.64 rpm, 462.86 rpm, and 481.71 rpm, as indicated by literature [9], total deformation, and maximum primary stress are created for each loading condition.

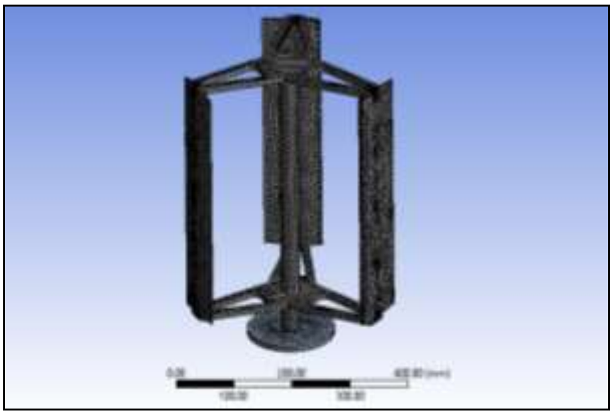
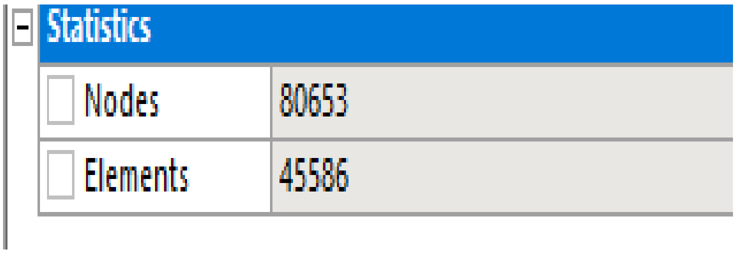


Figure 5: Meshed model of vertical axis wind turbine

During meshing conditions total 80653 nodes created and 45586 elements designed.



Statistics	
Nodes	80653
Elements	45586

Boundary conditions

For the examination of wind turbine blades, two kinds of loading circumstances were considered, one with normal speed and the other with critical speed.

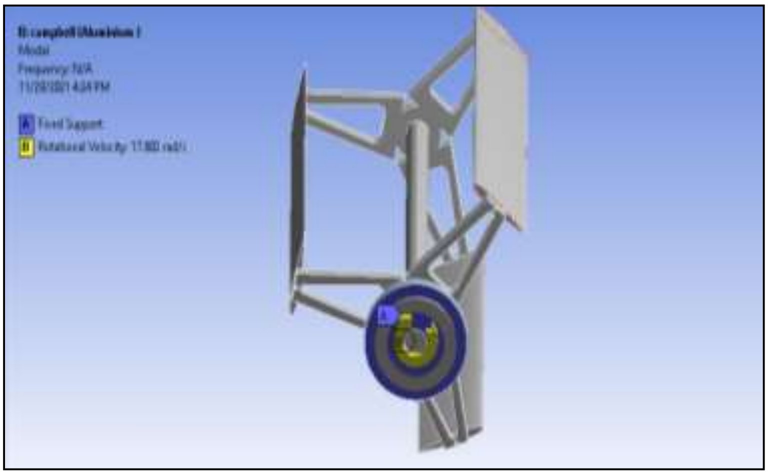


Figure 6: Moment applied on upper geometry

The simulation has now progressed to the solution step, which entails matrix formulations, multiplication, and inversions after the application of loads and boundary conditions. The results are calculated at nodes and the length of each element's edge is interpolated.

RESULT AND DISCUSSION OF ANALYSIS IN ANSYS

ANSYS software is used to calculate mode shapes, mass participation factor, campbell diagram, and 6 fundamental frequencies for a vertical axis wind turbine. This section discusses the results.

Case 1 Normal angular velocity:

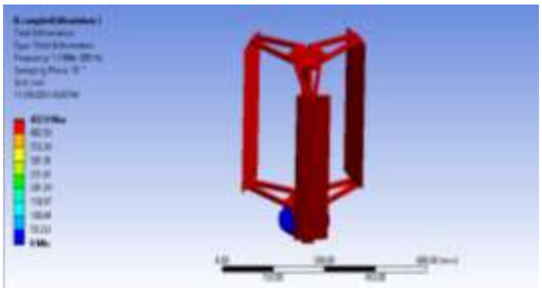


Figure 7:1st mode shape of VAWT

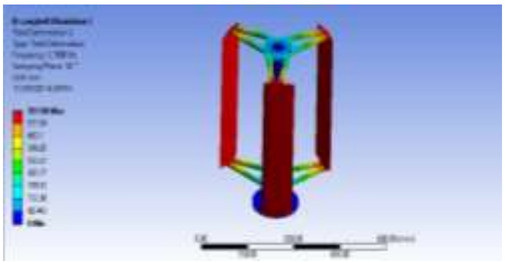


Figure 8: 2nd mode shape of VAWT

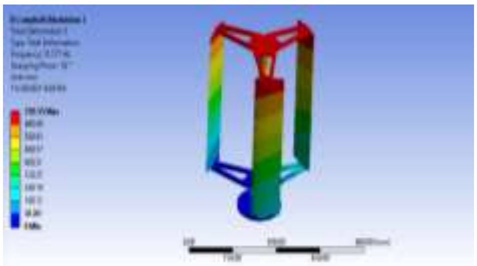


Figure 9: 3rd mode of Shape of VAWT

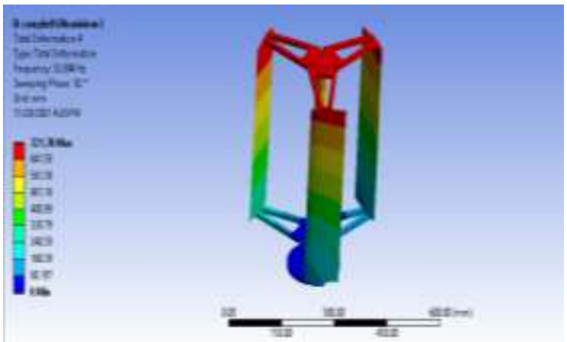


Figure 10: 4th mode shape of VAWT

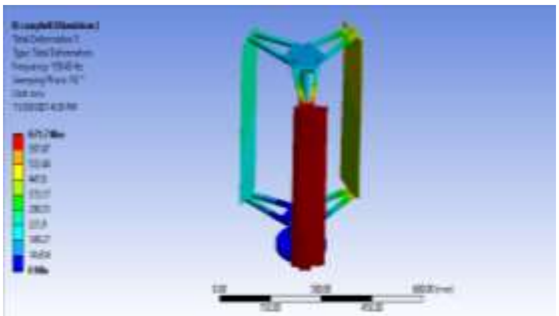


Figure 11: 5th mode Shape of VAWT

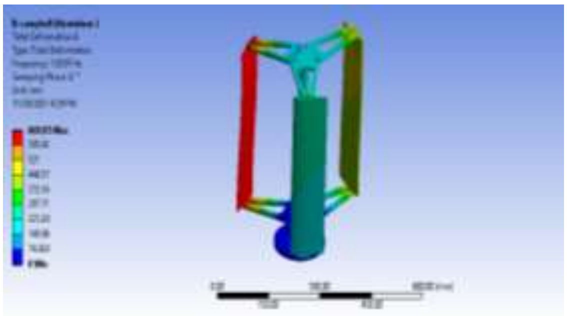


Figure 12: 6th mode shape of VAWT

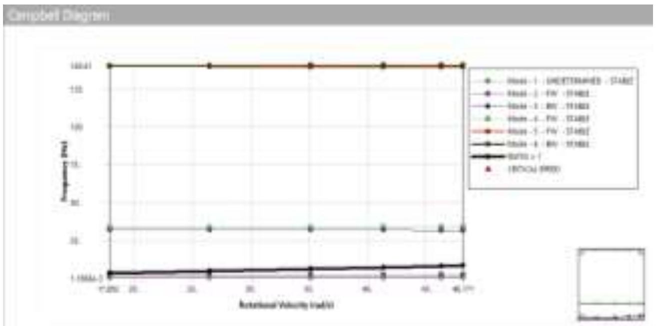
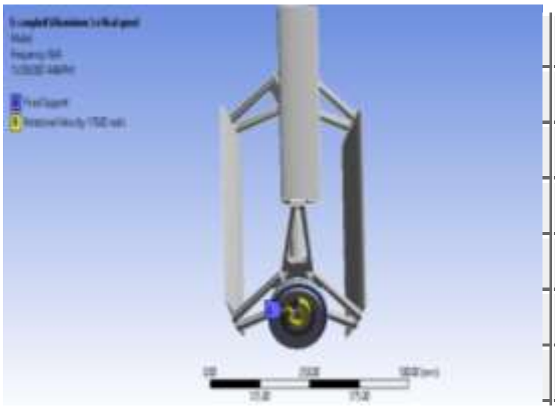


Figure 13: Cambell Diagram of Normal angular Speed

- All modes are stable
- No critical speeds are observed
- 2nd,4th and 5th mode shows forward frequency (clockwise)
- 3rd and 6th mode shows backward frequency (anti-clockwise)

Case 2: High Angular Velocity



Points	Rotational Velocity [rad/s]
1	178.02
2	263.89
3	350.81
4	413.64
5	462.86
6	481.71

Figure 14: Load and Boundary Condition

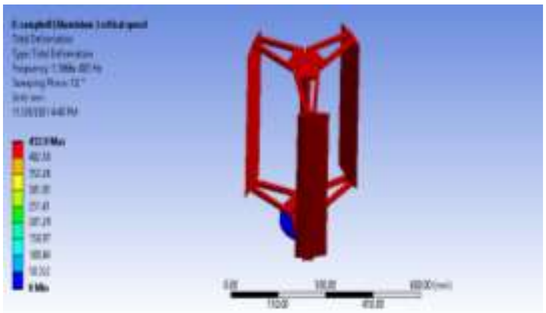


Figure 15: 1st mode Shape

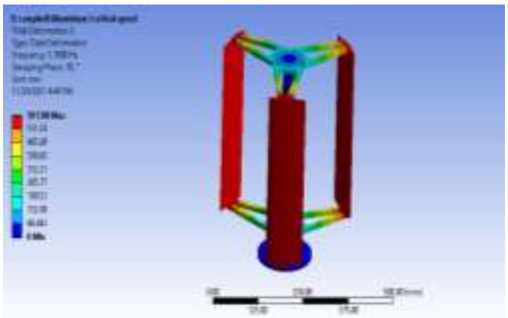


Figure 16: 2nd mode Shape

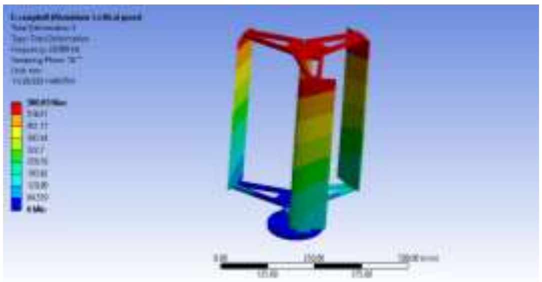


Figure 17: 3rd mode Shape

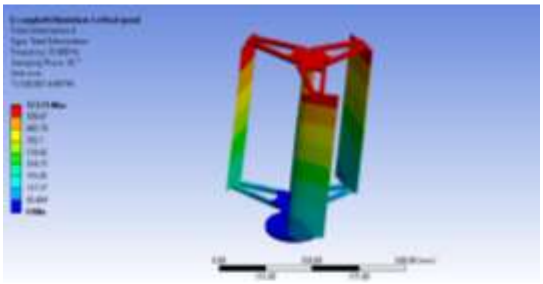


Figure 18: 4th mode Shape

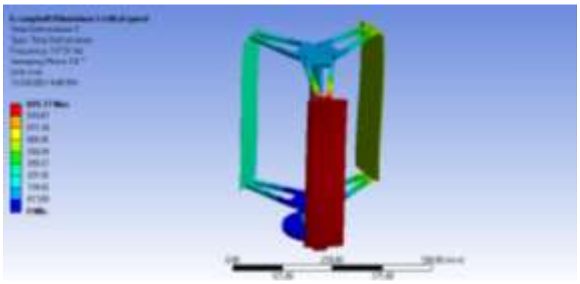


Figure 19: 5th mode Shape

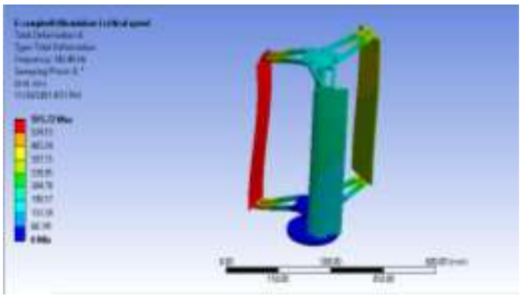


Figure 20: 6th mode shape

In dynamic analysis, two related phenomena, resonance and modal participation, must be investigated. Resonance happens when the excitation frequency of the input load matches one of the structure's intrinsic frequencies. In this circumstance, the load amplifies the mode, resulting in significant displacements. The participation factor reveals how much a certain mode influences the answer. As a result, although the stimulation may match a natural frequency (i.e., a resonance condition), the mode's participation factor is near to zero, implying that little energy will enter the mode and no dynamic response will occur. The mass participation factor for different fundamental frequencies is shown in the tables. The important observations are:

- Because the motion in 1st mode is entirely in the global Z direction, we may anticipate zero EMPF in the X and Y directions and a very big EMPF in the Z direction. In this example, 2.1744 EMPF of the system's mass is involved in the Z direction of this mode form.
- The motion is completely in the global Y direction for the 2nd fundamental frequency, with low EMPF in the X and Z directions and a comparatively big amount for EMPF in the Y direction compared to Z and Z.
- The motion is completely in the global X direction for the third fundamental frequency, with low EMPF in the Y and Z directions and a comparatively big amount for EMPF in the X direction compared to Y and Z.
- The motion for the fourth fundamental frequency is entirely in the global Y direction, with low EMPF in the X and Z directions and a comparatively significant EMPF in the Y direction compared to the X and Z directions.
- The motion is completely in the global X direction for the 5th fundamental frequency, with low EMPF in the Y and Z directions and a comparatively big value for EMPF in the X direction when compared to X and Z.
- The motion is completely in the global Y direction for the 6th fundamental frequency, with low EMPF in the X and Z directions and a comparatively big value for EMPF in the Y direction compared to X and Z.

A Campbell diagram represents the vibration frequencies of a system at various operating RPMs. The campbell diagram for aluminium alloy VAWT [4] is shown in figure 6.11 below. The plot shows description of stability of VAWT at different frequencies and rotational velocities and also enables to determine critical speed.

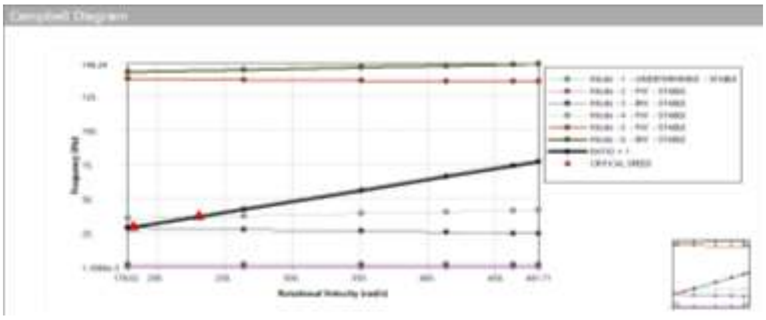


Figure 21: Cambell Diagram for High angular speed

- All modes are stable
- 2 critical speeds are observed. 1st critical speed is nearly 181.81 rad/s and 2nd critical speed is nearly 230.71 rad/s.
- 2nd,4th and 5th mode shows forward frequency (clockwise)
- 3rd and 6th mode shows backward frequency (anti-clockwise)

The variation in natural frequency of VAWT is very slightly as shown in in above figure and table below. The whirl direction is shown in 1st column of table 3 below.

Table 3: Vibration frequencies at High Angular Velocity for Aluminium Alloy Material

Mode	**Whirl Direction**	**Mode Stability**	**Critical Speed**	**178.02 rad/s**
1	Undetermined	Stable	None	1.1866e-003 Hz
2	FW	Stable	None	1.7808
3	BW	Stable	181.81 rad/s	28.999
4	FW	Stable	230.71 rad/s	35.689
5	FW	Stable	NONE	137.51
6	BW	Stable	NONE	142.46

Table 4: Vibration frequencies at Normal Angular Velocity for Aluminium Alloy Material

Mode	Whirl Direction	Mode Stability	Critical Speed	17.802 rad/s
1	Undetermined	Stable	None	1.1866e-003 Hz
2	FW	Stable	None	1.7808 Hz
3	BW	Stable	None	31.577 Hz
4	FW	Stable	None	32.894 Hz
5	FW	Stable	None	139.45 Hz
6	BW	Stable	None	139.97 Hz

Table 5: Vibration frequencies at High Angular Velocity for MMC Material

Mode	Whirl Direction	Mode Stability	Critical Speed	17.802 rad/s
1	Undetermined	Stable	None	1.0276e-003 Hz
2	FW	Stable	None	2.1687 Hz
3	BW	Stable	None	38.182 Hz
4	FW	Stable	None	39.848 Hz
5	FW	Stable	None	174.37 Hz
6	BW	Stable	None	174.9 Hz

CONCLUSION AND FUTURE SCOPE

ANSYS software is used to calculate mode shapes, mass participation factor, campbell diagram, and 6 fundamental frequencies for a vertical axis wind turbine. Under both free and forced vibration conditions, the VAWT is subjected to FEA vibration analysis. The free vibration analysis yields the mode shapes, natural frequencies, and Campbell diagram, which provide crucial information on VAWT vibration qualities. When compared to Aluminium alloy material with higher natural frequencies, the FEA findings showed that there were no critical velocities throughout the operating range for critical speeds of 178.02 rpm, 263.89 rpm, 350.81 rpm, 413.64 rpm, 462.86 rpm, and 481.71 rpm and normal speed 17.80 rpm, 26.38 rpm, 35.08 rpm, 41.36 rpm, 46.28.

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