Natural Frequency Test With The Help of CAE Tool For Windmill Blade And Its Validation By Manual Calculation Method

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Abstract- *Windmills are very important source of energy which generates electricity from flowing air. Now days it comes with the best choice for generation of electricity in hilly areas where other sources become costly and non-reliable. For windmill, its blades are crucial components as it performs rotary action which causes generation of electricity. There are several reasons by which windmill blades may fail or damage hence blades need to be perfectly balanced and designed to withstand worst condition also. But still there are always chances of blade failure due to storms, heavy rainfall etc. When windmill rotates beyond its designed speed then the vibrations will generate which affects the blade performance. If such vibrations come for long period of time then it changes the shape of blade and hence the efficiency of windmill reduces. Hence it is very important to find natural frequency of windmill bade by which we may come to know about maximum deviation of blade during vibration. In this paper we have discussed modeling of windmill blade on CAD tool and perform vibration analysis on CAE Tool to know its natural frequency. Further calculation is done to validate results obtained by CAE tool.*

Keywords- windmill, natural frequency, CAD and CAE tool

I. INTRODUCTION

A wind turbine is a device that converts kinetic energy from the wind, also called wind energy, into mechanical energy; a process known as wind power. If the mechanical energy is used to produce electricity, the device may be called a wind turbine or wind power plant. If the mechanical energy is used to drive machinery, such as for grinding grain or pumping water, the device is called a windmill or wind pump. Similarly, it may be referred to as a wind charger when used for charging batteries. The working of wind mill is very simple as the air comes in the structure the working blades rotates which is connected to main rotor shaft by the supporting arms the main rotor is coupled to a generator from where we can get the output. The power in the wind can be extracted by allowing it to blow past moving wings that exert torque on a rotor. The amount of power transferred is directly proportional to the density of the air, the area swept out by the rotor, and the cube of the wind speed. The mass flow of air that travels through the swept area of a wind turbine varies with the wind speed and air density. As an example, on a cool 15°C (59°F) day at sea level, air density is about 1.22 kilograms per cubic meter (it gets less dense with higher humidity). An 8 m/s breeze blowing through a 100 meter diameter rotor would move about 76,000 kilograms of air per second through the swept area. The kinetic energy of a given mass varies with the square of its velocity.

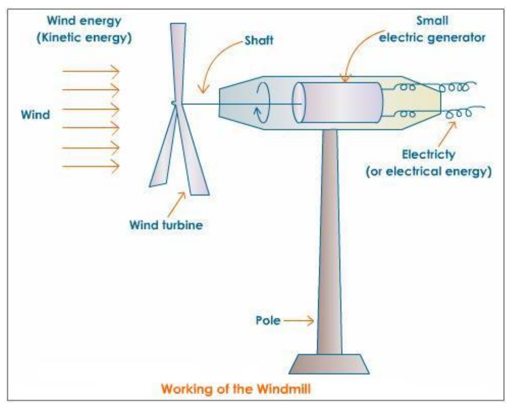


Fig. 1.1: Schematic Diagram of Windmill

II. NATURAL FREQUENCY CONCEPT

Natural frequency, also known as eigenfrequency, is the frequency at which a system tends to oscillate in the absence of any driving or damping force. The motion pattern of a system oscillating at its natural frequency is called the normal mode (if all parts of the system move sinusoidally with that same frequency). If the oscillating system is driven by an external force at the frequency at which the amplitude of its motion is greatest (close to a natural frequency of the system), this frequency is called resonant frequency.

Harmonic Frequency: For a simple harmonic oscillator, the period *r* is given by:

$$r = 2\pi\sqrt{\frac{\mu}{k}}$$

where *k* is the force constant. A molecule can absorb a photon that vibrates at the same frequency as one of its normal vibration modes. That is, if a molecule, initially in its ground vibration state, could be excited so that it vibrated at a given frequency, then that molecule could absorb a photon that vibrates at the same frequency. Although vibration frequencies are usually expressed as kilohertz or megahertz, in chemistry vibration frequencies are normally expressed in terms of the number of vibrations that would occur in the time that light travels one centimeter, i.e., $v = 1/cr$ Using this equation for simple harmonic motion, the vibration frequency can be written as:

$$\bar{\nu} = \frac{1}{2\pi c}\sqrt{\frac{k}{\mu}}.$$

In order for v to be in cm^{-1}, c, the speed of light must be in $cm.sec^{-1}$, k, the force constant in erg/cm^2, and μ the reduced mass in grams.

For a molecule, the force constants are obtained by diagonalization of the mass-weighted Hessian matrix. Most of the work in calculating vibration frequencies is spent in constructing the Hessian.

Resonance Frequency: In mechanical system, resonance is a phenomenon that occurs when the frequency at which a force is periodically applied is equal or nearly equal to one of the natural frequencies of the system on which it acts. This causes the system to oscillate with larger amplitude than when the force is applied at other frequencies. Frequencies at which the response amplitude is a relative maximum are known as resonant frequencies or resonance frequencies of the system. Near resonant frequencies, small periodic forces have the ability to produce large amplitude oscillations, due to the storage of vibration energy.

III. AIMS AND OBJECTIVES OF STUDY

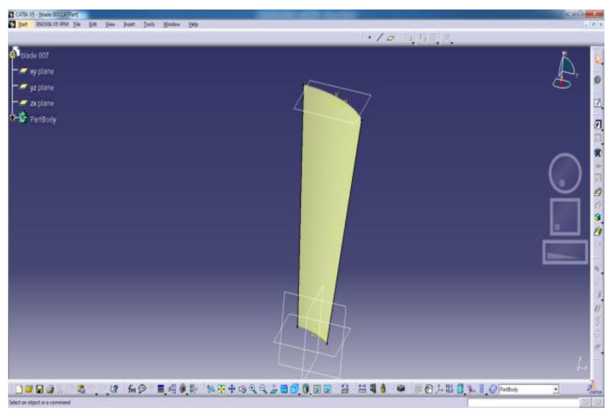
1) To understand vibration effects on windmill blade.
2) To know the natural frequency, harmonic vibrational frequency and resonant frequency of windmill blade.
3) To give conclusion which can be utilized for dynamic stability of windmill blade and hence the life of windmill blade may improve.
4) Validation of CAE results with manual calculation shows the accuracy of project and entire study, hence to learn method of validation
5) To design a windmill blade on CAD tool like CATIA.
6) Perform Vibration Analysis by using CAE Tool like ANSYS.
7) Validate the results obtained by CAE tool.
8) To reach on proper conclusion and resonant frequency.

IV. CAD MODELLING OF WINDMILL BLADE

CATIA enables the creation of 3D parts, from 2D sketches, Sheetmetal, composites, molded, forged or tooling parts up to the definition of mechanical assemblies. The software provides advanced technologies for mechanical surfacing & BIW. It provides tools to complete product definition, including functional tolerances as well as kinematics definition.

Some of the commands in CATIA used for modeling are as below

1) PAD command
2) POCKET command
3) SHAFT command
4) RIB command
5) SLOT command



V. VIBRATION ANALYSIS OF WINDMILL BLADE

A. Ansys as a CAE Tool:

Ansys software is used to design products and semiconductors, as well as to create simulations that test a product's durability, temperature distribution, fluid movements, and electromagnetic properties.

B. Material Properties Required

Poisson's Ratio:When applying a load in a certain axis direction and consequently deforming in that direction, the ratio of deformation on the opposite side is called Poisson's Ratio. Basically, it can be used at the elastic region because of the assumption of Hooke's Law, theoretically having a value less than 0.5 greater than zero.

Yield Stress:As described above, yield stress is the point at which permanent deformation is drastically increased when an external force is increased beyond the elastic limit.

Density:Since density is mass per unit volume, the density of a metal can be calculated by submerging it in a known amount of water and measuring how much the water rises. This rise is the volume of the metal. Its mass can be measured using a scale.

Property	Value
Youngs Modulus (E)	1.65e5 MPA
Poisson's Ratio	0.27
Density	

Table: Properties of Galvanized Steel Sheet for Structural Analysis.

In this study we are directly using three-dimensional model of windmill blade to perform vibration analysis.

C.Discretization (Meshing):

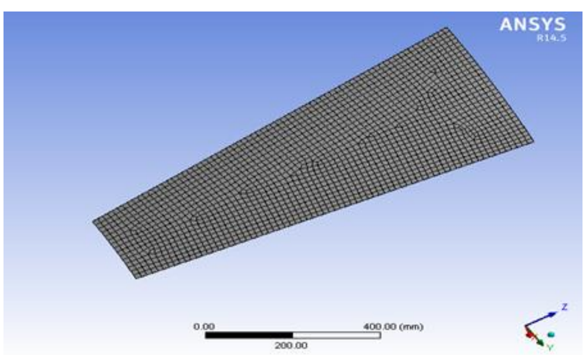


Figure. Meshing of a windmill blade.

Type of Element	2D Rectangular and Triangulate
No. of Elements	1651
No. of Nodes	1744

Table: Number of Nodes and Elements

VI. NATURAL FREQUENCY CALCULATION

A. Mass of Windmill Blade:

Consider,
A= Area of windmill blade = 0.2×1 m =0.2m^2
T= Thickness of Blade =0.5 mm = 0.5×10^{-3} m
Therefore,

Volume of Blade = 0.2 × 0.5 × 10^{-3} = 1×10^{-4} m^3…(1)
Therefore,

Mass of Blade = m = Volume × Density

m = V × ρ …(Density of GI sheet= 7.85×10^3 kg/m^3)
m = 1×10^{-4}×7.85×10^3
m = 0.785 kg

B. Natural Frequency of Windmill Blade:

To obtain natural frequency of windmill blade we have formula.

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \quad \ldots(2)$$

Where,

f_n = Natural Frequency of Blade (Hz)
k = Young's Modulus/Stiffness of Windmill Blade (MPA) = 1.65×10^5 MPA
m = Mass of Windmill Blade

Therefore,

Eq.^{n} (2) can be written as,

$$f_n = \frac{1}{2\pi}\sqrt{\frac{1.65 \times 10\ 5}{0.785}}$$

f_n = 72.9967 Hz

C. Displacement due to vibrations at mode shapes.

1) Displacement at mode shape 1.

Displacement at various mode shapes can be obtained

$$f_n = \frac{1}{2\pi}\sqrt{\frac{G}{D}} \quad \ldots(3)$$

Where,

G = Load on Windmill Blade generating Natural Frequency.
D = Static Deflection of windmill Blade.
To know the value of G, we have
G = Weight of Windmill blade / Angular displacement

G = W / α

$$G = \frac{0.785 \times 9.81}{0.0006}$$

G = 12834 N

Therefore,

Eq.^{n} (3) can be written as,

$$72.648 = \frac{1}{2\pi}\sqrt{\frac{12834}{D}}$$

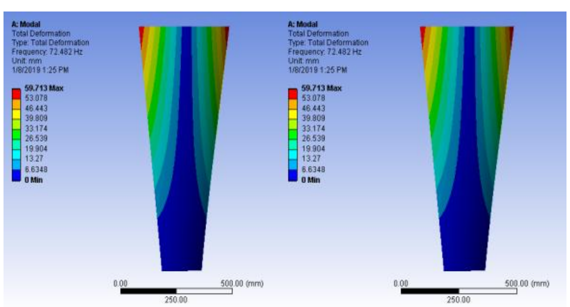
D = 0.0599 m
D = 59.9 mm

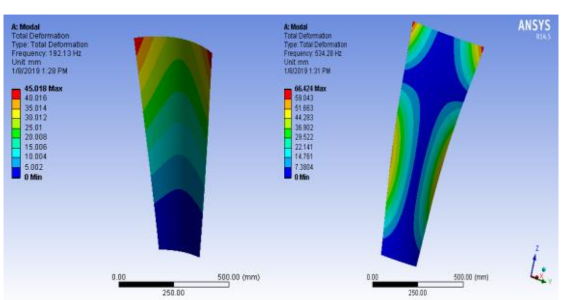
VII. RESULTS OBTAINED BY ANSYS

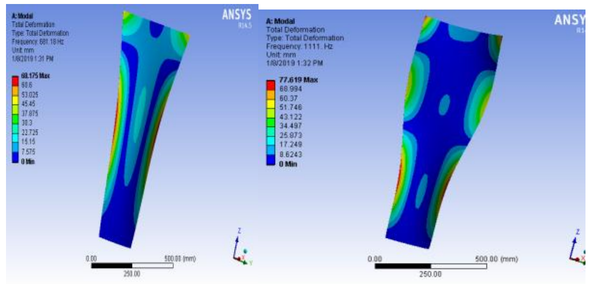
Table: Modes, frequency and displacement obtained

Sr. No.	Mode	Frequency (Hz)	Displacement (mm)
1	Mode 1	72.482	59.71
2	Mode 2	192.13	45.018
3	Mode 3	456.68	88.90
4	Mode 4	534.28	66.424
5	Mode 5	681.18	68.175
6	Mode 6	1111	77.619

A. Actual Displacement of windmill blade with ANSYS software:







VIII. CONCLUSION

By performing virtual test on windmill blade at vibrating condition for six different modes we can predict following conclusions.

1) Vibrations of windmill blade affect the performance of windmill.
2) Dynamic balancing of windmill blade may affect due to vibration of windmill blade at resonant frequency.
3) Resonance frequency of windmill blade is sufficiently high but continuous impact of such frequency range affects the blade performance. Hence the life of windmill blade is less.
4) Stability of blade can be improved by providing more support at the top, which may reduce the vibrations.

REFERENCES

[1] Yang W, Lang Z, Tian W. "Condition Monitoring and Damage Location of Wind Turbine Blades by Frequency Response Transmissibility Analysis." *IEEE Transactions on Industrial Electronics* 2015, 62(10), 6558-6564.
[2] Jihoon Jeong1, "Design optimization of a wind turbine blade to reduce the fluctuating unsteady aerodynamic load in turbulent wind" *Journal of Mechanical Science and Technology 26 (3) (2012) 827~838, www.springerlink.com/content/1738-494x,* DOI 10.1007/s12206-011-1106-
[3] M. EL-Shimy, "Steady State Modeling and Analysis of DFIG for Variable-Speed Variable-Pitch Wind Turbines", Ain Shams Journal of Electrical Engineering, (A S J E E), Vol. 2. June 2010. ISSN: 1687-8582
[4] Koji FUKAMI+1, Kai KARIKOMI+1, Akihiro HONDA, "*Aeroelastic Stability Analysis Of Offshore Wind Turbine Blades At Standstill Condition Considering Unsteady Aerodynamics*
[5] V. A. Riziotis' "Stability analysis of parked wind turbine blades using a vortex model" https://www.researchgate.net/publication/280527933
[6] Jess, Graduate Engineer, npower renewable, "Wind Turbine Power Calculations RWE npower renewable", Mechanical and Electrical Engineering Power Industry

[7] Qiyue Song, " Design, Fabrication, and Testing of a New Small Wind Turbine Blade", A Thesis presented to The University of Guelph

[8] SAMBIT SARANGI, " Dynamic Analysis Of A Wind Turbine Blade" A Thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Technology In Mechanical Engineering.

[9] S. Derakhshan and A. Tavaziani, "Study of Wind Turbine Aerodynamic Performance Using Numerical Methods", Journal of Clean Energy Technologies, Vol. 3, No. 2, March 2015

[10] Dan PREDICĂ1, PetruCristinel IRIMIA1, Nicolae VASILIU2, "Innovative Cae/Testing Solutions For Wind Turbines", SecţiuneaEnergiedurabilă

[11] John Arrigan1, Vikram Pakrashi1, BiswajitBasu, "Control of flapwise vibrations in wind turbine blades using semi-active tuned mass dampers", Structural Control and Health Monitoring Struct. Control Health Monit. (2010), View this article online at wileyonlinelibrary.com. DOI: 10.1002/stc.404

[12] Bo ZHOU, Tian-chang MA* and Fang-ai YU, "Finite Element Analysis of Wind Turbine Blades", 2016 International Conference on Artificial Intelligence and Computer Science (AICS 2016), ISBN: 978-1-60595-411-0

[13] Gunjit S. Bir Alan D. Wright C.P. (Sandy) Butterfield, "Stability Analysis of a Variable-Speed Wind Turbine", NREL/CP-440-21679 • UC Category: 1211 • DE97000075

[14] KunduruAkhil Reddy1, KalyanDagamoori2, "A Brief Research, Study, Design and Analysis on Wind turbine", International Journal of Modern Engineering Research (IJMER).

[15] E. Muljadi, V. Gevorgian, and M. Singh, "Understanding Inertial and Frequency Response of Wind Power Plants", *IEEE Symposium on Power Electronics and Machines in Wind Applications Denver, Colorado July 16-18, 2012*