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# Trembling Analysis of Helical Blade Vertical Axis Wind Turbine (VAWT)

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*Abstract:* **This paper tells about the trembling analysis of vertical axis wind turbine with helical blades. The essential intent is to define the behaviour of the turbine in order to select the most preferable material, and avoid problems, such as frequent maintenance and misalignment of the turbine. For modelling and vibration analysis of the wind turbine, SOLIDWORKS 2010 software package is used. Natural frequency and mode shape of the vertical axis wind turbine are calculated by Modal analysis. Modal time-history analysis is completed for the wind turbine with damping and without damping conditions. The analysis results of stress and displacement values are plotted.**

*Keywords:* **Damping, Displacement, Frequency, Stress, Vertical axis wind turbine (VAWT), Vibration, SOLIDWORKS 2010.**

## 1. INTRODUCTION

Wind turbine is a machine, which converts the kinetic energy of wind into mechanical energy. If the mechanical energy is used directly by machine is termed as a wind mill. If the mechanical energy is then converted to electricity, the machine is called as a wind energy generator, wind turbine, or wind energy converter (WEC).Wind turbines can be classified according to its rotor axis orientation and the type of aerodynamic forces used to take energy from wind.

***Rotor axis orientation types:***

1. Horizontal Axis Wind Turbines (HAWT)
2. Vertical Axis Wind Turbines (VAWT)

The major advantage of VAWTs is that, the blades can have a constant shape along their length and, there is no need in twisting the blade to entire section of the blade, which is subjected to the same wind speed. This allows an easier design, fabrication and replication of the blade which can influence in a cost reduction.

***Aerodynamic force types:***

1. The drag type takes less energy from the wind but has a higher torque and is used for mechanical applications as pumping water. The most representative model of drag-type VAWTs is the Savonius.
2. The lift type uses an aerodynamic airfoil to create a lift force, they can move quicker than the wind flow. This kind of windmills is used for the generation of electricity. The most representative model of a lift-type VAWT is the Darrieus turbine.

***Fundamental of vibrations:***

Vibration occurs when a system is displaced from position of stable equilibrium. The system tends to return to this equilibrium position under the action of restoring forces. The system keeps moving back and forth across its position of equilibrium. A system is a combination of elements intended to act together to accomplish an objective. A static element is one whose output at any given time depends only on the input at the time while a dynamic element is one whose present output depends on past input. A static system contains all elements while a dynamic system contains at least one dynamic element.

***Natural frequency and mode shapes:***

Natural frequency is the frequency at which a system naturally vibrates once it has been set into motion of free vibration of a system. For a multiple degree-of-freedom system, the natural frequencies are the frequencies of the normal modes of vibration. Normal mode of vibration is a mode of vibration that is uncoupled from other modes of vibration of a system .When vibration of the system is defined as an Eigen value problem; the normal modes are the eigenvectors and the normal mode frequencies are the Eigen values. Each mode is entirely independent from all other modes. Hence all modes have different frequencies (with lower modes having lower frequencies) and different mode shapes.

## 2. LITERATURE SURVEY

The literature survey for this paper is taken from highly reputed papers and is summarized as follows. The Vertical axis wind turbines (VAWT) is compared with Horizontal axis wind turbines (HAWT) has a lower efficiency. However, the supporting structure of VAWT structure is relatively simple. It is suitable in poor wind conditions. Besides, VAWT also generates lower noise and vibrations [1]. But the inconsistent behavior of the wind may change the nature of the flow field around the VAWT which could decrease its life cycle. The performance of a VAWT is monitored under an accelerated and decelerated gust of the value 1.09m/s² characterized by change in velocity from 4m/sec to 10m/sec. The instantaneous torque output varies significantly when a gust of air is applied to the turbine. Furthermore the torque outputs during accelerating and decelerating flows vary, highlighting the effect of transient phenomena. This abrupt change in the instantaneous torque output of the turbine may give rise to highly transient loads on the turbine's structure which may induce heavy stresses on the turbine leading to structural failure [2].

Instead of that, special type of vertical axis wind turbine with parabolic blades called Darrieus will be focused on the vibrations of the tower. It is really important to know the tower´s behavior against them in order to choose the best material for it and to avoid problems such as frequent maintenance and even wind turbine breakage [3]. In order eradicate the problems on free vibration analysis is used to determining parameters such as natural frequencies and mode shapes of vertical axis wind turbines (VAWT) for an urban application. For further understanding of the wind turbine dynamic analysis, two vibration parameters of dynamic response have been studied, namely natural frequencies and mode shapes. Block Lanczos method has been used to analyze the natural frequency while wind turbine mode shapes have been utilized because of their accuracy and faster solution. In this problem 12 modes of structure have been extracted [4].

In this study, Finite element method is used to calculate and obtain natural Frequencies of Mechanical vibration. A simple model of Vertical Axis Wind Turbines Natural Frequencies under three conditions was used, to determine and analyze the relationship between Vibration and the shape of the Wind Turbines. This study offers a solution, that assists in analyzing the vibration of Vertical Axis Wind Turbines and also provides improvements, in order to help the design and development Vertical Axis Wind Turbines. A way to reduce the vibration of the VAWT is offered in order to increase the lifetime and efficiency of Vertical Axis Wind Turbines.

## 3. DESIGN OF VAWT MODEL

A VAWT model will be designed and created SOLIDWORKS 2010. And also the VAWT model will be analyzed by using SOLIDWORKS-simulation through finite element method. SOLIDWORKS is the 3D mechanical CAD/CAM/CAE software that runs on Microsoft Windows and is developed by Dassault Systèmes SOLIDWORKS Corp., a subsidiary of Dassault Systèmes, S. A. (Vélizy, France).

***Features of SOLIDWORKS:***

- SOLIDWORKS is a Para Solid-Based Solid Modeler
- A Parametric Modeling Software
- Feature-Based Model Approach
- Associative to Create Models and Assemblies

***Design parameters***

The design parameter involves defining geometric dimensions and material properties for VAWT model.

***1. Geometric Dimensions:***

- Diameter of the centre shaft -60mm
- Length of the centre shaft -1000mm long
- The connecting shafts are oval shaped and has a vertical diameter of 40mm with a horizontal diameter of 15mm
- The length of the turbine blade -700mm
- The diameter of the whole turbine -500mm

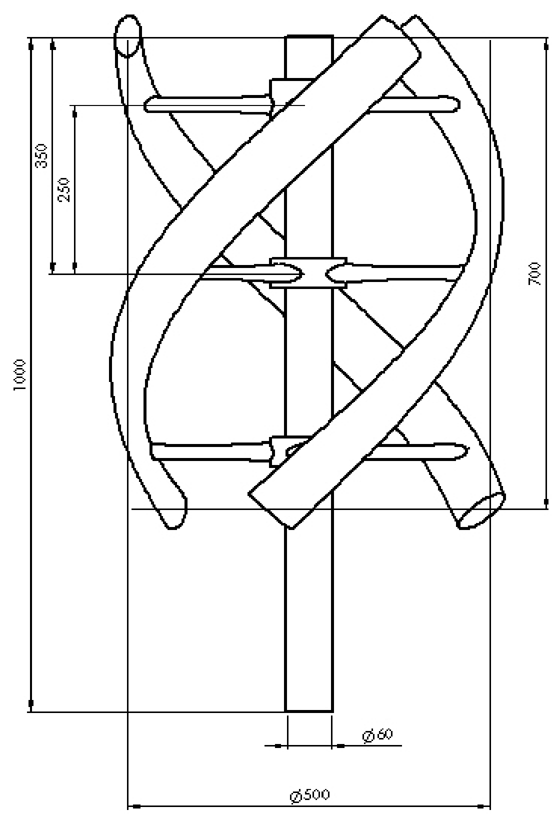



**Fig. 3.1.VAWT model with dimensions**

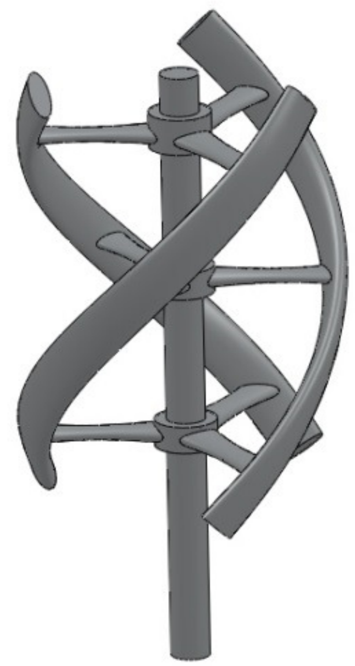


*Fig. 3.2.VAWT-3D Cad Model*

### *2. Material properties:*

The turbine was made of ALUMINIUM ALLOY 1060-H18 because of its strength and light weight compared to other material that was used before. The properties of the ALUMINIUM ALLOY 1060-H18 are given as follows,

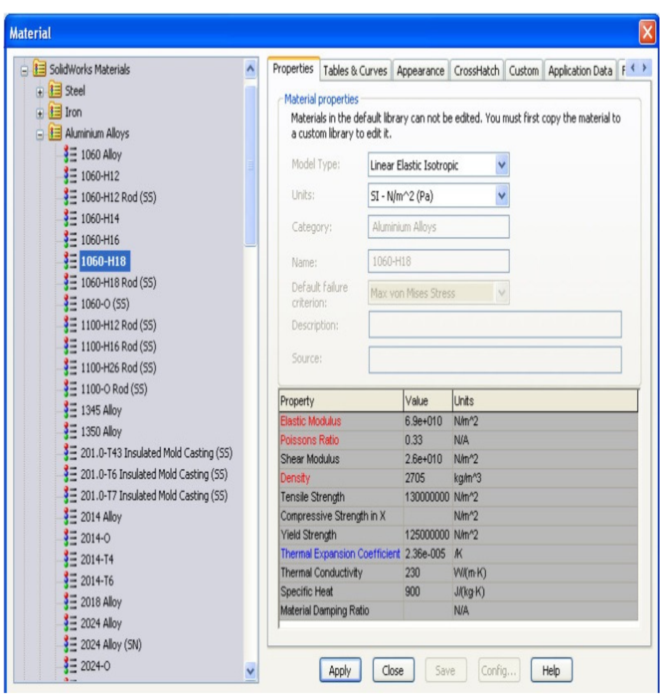



**Fig. 3.3.Material Properties of Aluminium alloy**

## 4. INPUTS GIVEN

### *1. Mesh consideration:*

***Structured Mesh:*** For this 3D model of VAWT structured mesh was used to produce good fine mesh in the near vicinity regions. This restricts the element choices to quadrilaterals in 2D or hexahedra in 3D. As we could store the mesh connectivity in a 40 by 12 array. The regularity of the connectivity allows us to conserve space since neighborhood relationships are defined by the storage arrangement.

**Fig. 4.1.VAWT model mesh by SOLIDWORKS**

### *2. Analyzing type:*

For this model, we have selected Modal analysis and Time-dependent analysis for obtaining natural frequency and stress-displacement with respect to time respectively.

### *3. Boundary conditions and loads:*

For Modal analysis, the bearing fixture is used at the centre-shaft base end. There is no load is applied for this analysis. In Time-dependent analysis, the bearing fixture is applied at the center-shaft base end. In this analysis, the torque is applied to the shaft at 24 Nm. Wind velocity is taken as 10 m/s.

## 5. RESULTS AND CONCLUSION

In this sectional part helical VAWT model is analyzed with three different thicknesses in order to obtain the vibration and frequency relative with wind energy to find a method of improvement.

1. Mode shapes of helical VAWT rotor with thickness = 2.0mm

2. Mode shapes of helical VAWT rotor with thickness = 2.25mm
3. Mode shapes of helical VAWT rotor with thickness = 2.5mm

***1. Mode shapes of helical VAWT rotor with thickness 2.0mm***

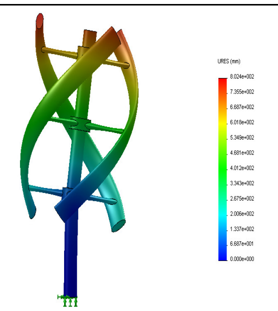
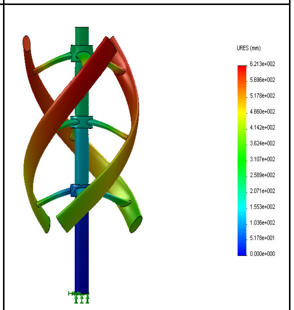
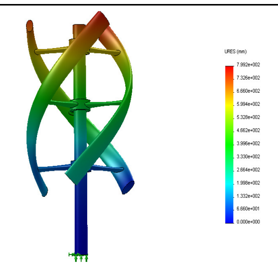
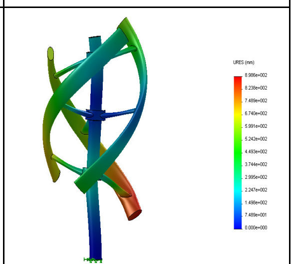
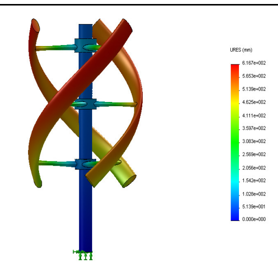
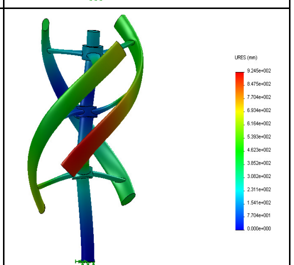
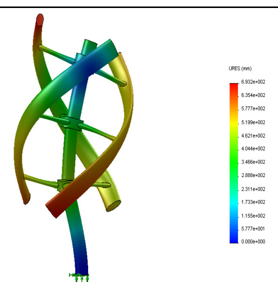
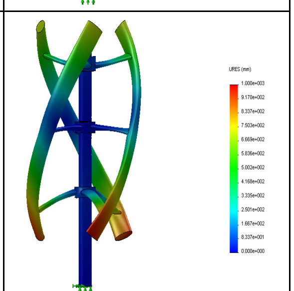
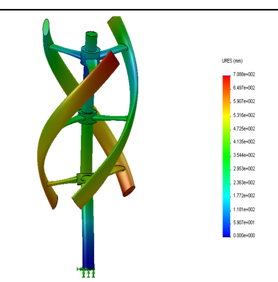
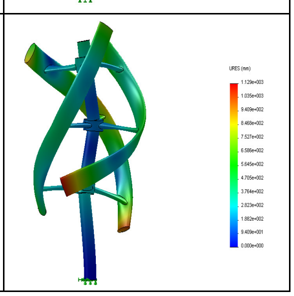
| NO | MODE SHAPES | NO | MODE SHAPES |
|---|---|---|---|
| 01 |  | 06 |  |
| 02 |  | 07 |  |
| 03 |  | 08 |  |
| 04 |  | 09 |  |
| 05 |  | 10 |  |

**Table 5.1 Mode shapes and Frequencies of thickness 2.0mm**

| LIST OF RESONANT FREQUENCIES | | | |
|---|---|---|---|
| **Mode No.** | **Frequency (Rad/sec)** | **Frequency (Hertz)** | **Period (Seconds)** |
| 1 | 95.798 | 15.247 | 0.065588 |
| 2 | 98.707 | 15.71 | 0.063655 |
| 3 | 298.6 | 47.523 | 0.021042 |
| 4 | 599.59 | 95.428 | 0.010479 |
| 5 | 600.86 | 95.63 | 0.010457 |
| 6 | 811.6 | 129.17 | 0.0077417 |
| 7 | 868.38 | 138.399 | 0.0072355 |
| 8 | 869.5 | 138.39 | 0.0072262 |
| 9 | 988.1 | 157.26 | 0.0063588 |
| 10 | 1305.6 | 207.8 | 0.0048124 |

***2. Mode shapes of helical VAWT rotor with thickness 2.25mm***

**Table 5.2 Mode shapes and Frequencies of thickness 2.25mm**

| LIST OF RESONANT FREQUENCIES | | | |
|---|---|---|---|
| **Mode No.** | **Frequency (Rad/sec)** | **Frequency (Hertz)** | **Period (Seconds)** |
| 1 | 101.46 | 16.148 | 0.061927 |
| 2 | 101.9 | 16.218 | 0.061661 |
| 3 | 302.21 | 48.099 | 0.020791 |
| 4 | 612.28 | 97.447 | 0.010262 |
| 5 | 614.87 | 97.859 | 0.010219 |
| 6 | 841.91 | 133.99 | 0.007463 |
| 7 | 897.43 | 142.83 | 0.0070013 |
| 8 | 899.32 | 143.13 | 0.0069866 |
| 9 | 1015.5 | 161.63 | 0.0061871 |
| 10 | 1347.2 | 214.42 | 0.0046638 |

***3. Mode shapes of helical VAWT rotor with thickness 2.5mm***

| NO | MODE SHAPES | NO | MODE SHAPES |
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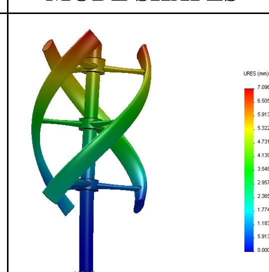
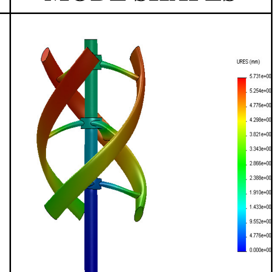
| 01 |  | 06 |  |

| | | | |
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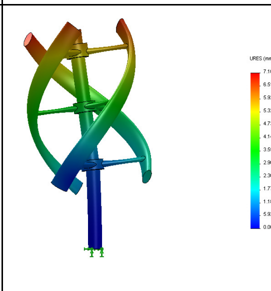
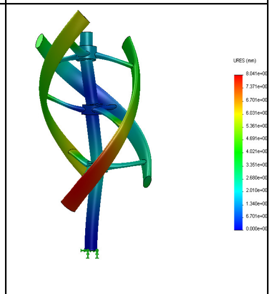
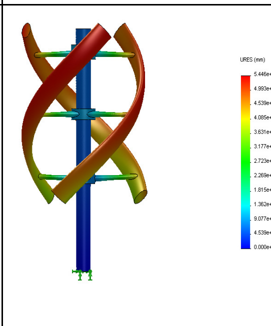
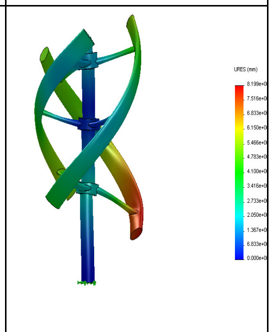
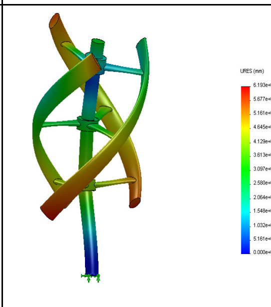
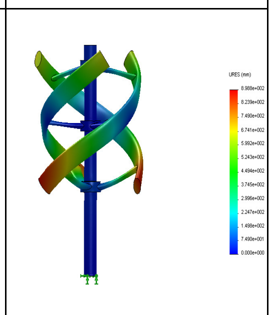
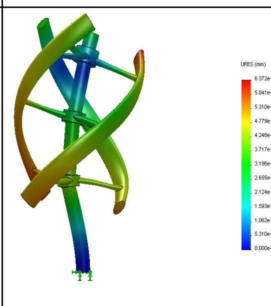
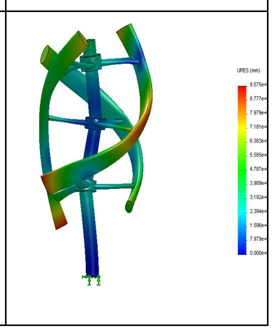
| 02 |  | 07 |  |
| 03 |  | 08 |  |
| 04 |  | 09 |  |
| 05 |  | 10 |  |

**Table 5.3 Mode shapes and Frequencies of thickness 2.5mm**

| LIST OF RESONANT FREQUENCIES | | | |
|---|---|---|---|
| **Mode No.** | **Frequency (Rad/sec)** | **Frequency (Hertz)** | **Period (Seconds)** |
| 1 | 103.93 | 16.542 | 0.060454 |
| 2 | 104.66 | 16.658 | 0.060032 |
| 3 | 304.97 | 48.538 | 0.020603 |
| 4 | 626.91 | 99.662 | 0.010034 |
| 5 | 627.91 | 99.935 | 0.010006 |
| 6 | 871.15 | 138.65 | 0.0072125 |
| 7 | 925.07 | 147.23 | 0.0067921 |
| 8 | 928.57 | 147.79 | 0.0067665 |
| 9 | 1044.3 | 166.2 | 0.0060169 |
| 10 | 1384.8 | 220.39 | 0.0045374 |

Thus from the above analysis, the helical VAWT with maximum thickness of 2.5 mm is provided a better results compared to other two models. The range of frequency and mass participation for the helical VAWT with thickness 2.5 mm is higher compared to other models.

***Time-dependent analysis for helical VAWT rotor:***

The Time-Dependent Analysis is mainly used to find the maximum displacement and stress with respect to time. The boundary condition is already specified that the bearing fixture is applied at the centre shaft. Torque for the centre shaft is 24 Nm. The wind velocity will be 10 m/s. In this analysis two cases are taken based on damping conditions.

Case.1- Time-dependent analysis without damping effect

Case.2- Time-dependent analysis with damping effect

The results will be given as follows

- Maximum Displacement
- Graph : Maximum displacement Vs Time
- Stress Distribution
- Graph : Stress Vs Time

***Case 1: Time-dependent analysis without damping***

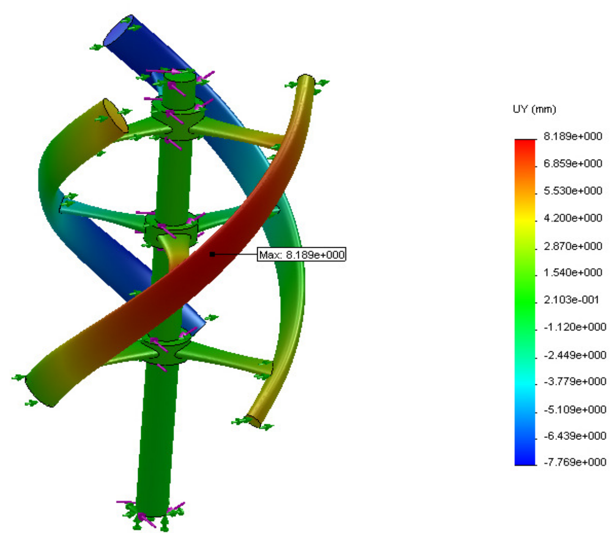
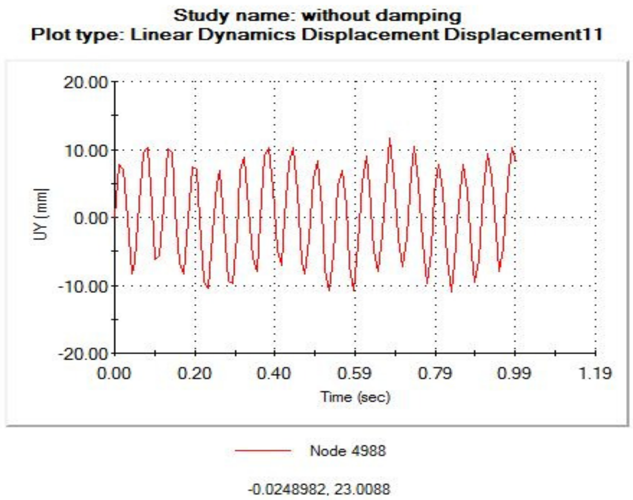



**Fig. 5.1 Maximum Displacement**




**Graph 5.1 Maximum Displacement Vs Time**

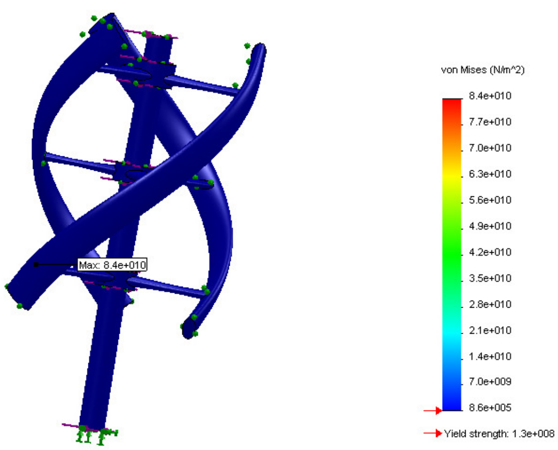
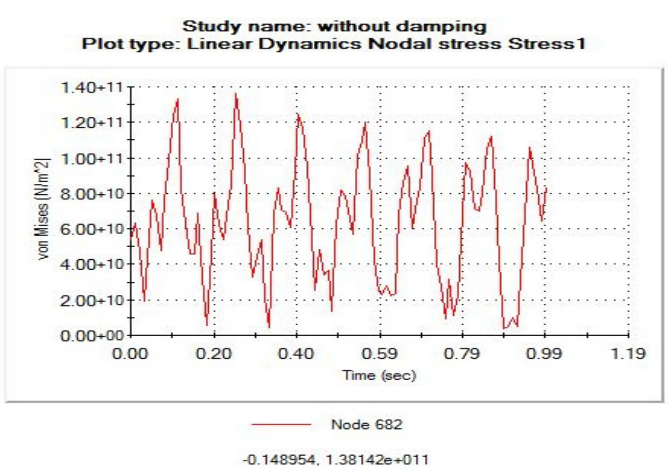



**Fig. 5.2 Stress Distribution**




**Graph 5.2 Stress Distribution Vs Time**

***Case 2: Time-dependent analysis with damping***

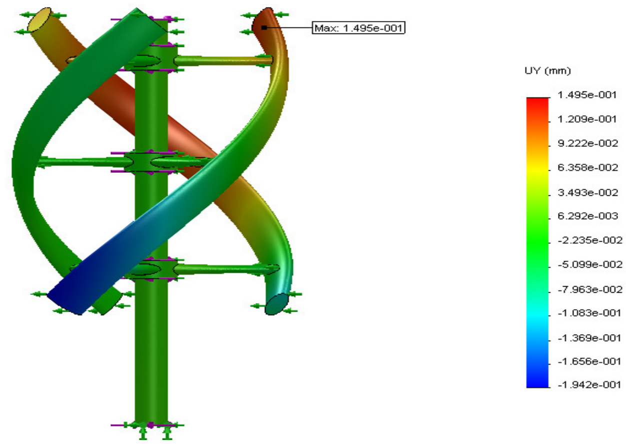
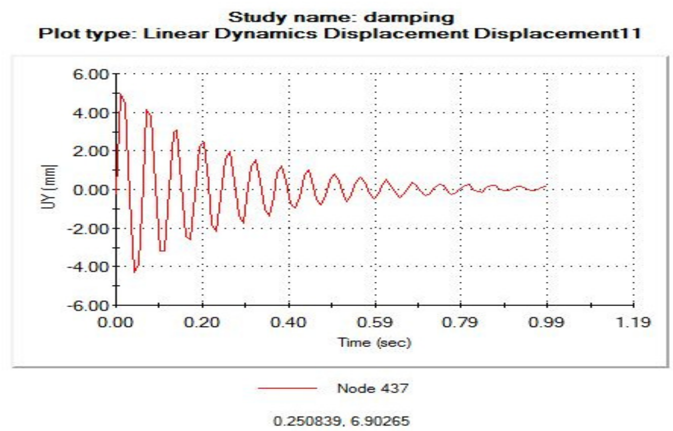



**Fig. 5.3 Maximum displacement**




**Graph 5.3 Maximum Displacement Vs Time**

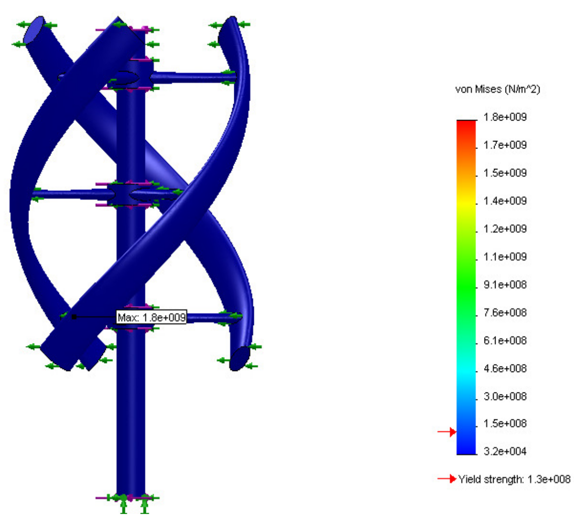
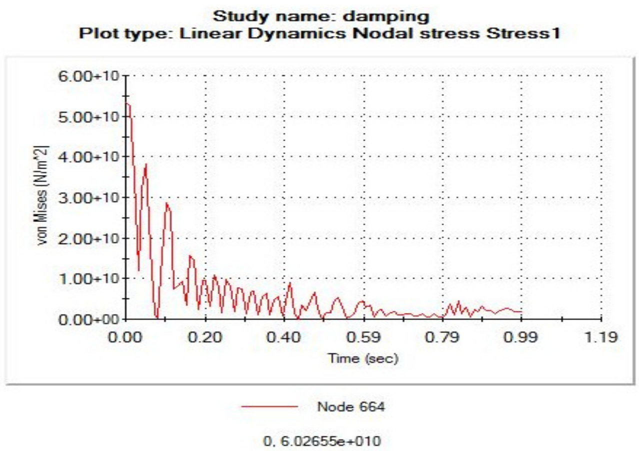



**Fig. 5.4 Stress Distribution**




**Graph 5.4 Stress Distribution Vs Time**

In the case.1, the helical VAWT rotor experienced a maximum deflection occurred due to the absence of damping condition. This results leads to uneven deflection in displacement with respect to time as shown in graph 5.1. Stress distribution also experienced the uneven deflection as like that of displacement as shown in graph 5.2. It causes reduced vibrational frequency.

It was rectified in the case.2. In this case, damping ratio (0.04) is applied which results in reduced deflection in displacement as shown in graph 5.3. The stress distribution is also converged with respect to time as shown in graph 5.4. Thus damping effect reduces the unwanted deflection caused due to rotor axial movement at certain speed.

## 6. CONCLUSION

For the three different thickness of helical VAWT were undergone with the modal analysis by sustaining boundary conditions. The main idea of this paper is to find the displacement and stress distribution values of the model at different thickness. From the plots and graphs it was understood that the helical VAWT rotor with thickness 2.5mm has effective range of frequency compared to other two models. When the helical VAWT rotor with thickness 2.5mm is subjected to time-dependent analysis, it is found that the displacement values of the model with damping effect are lesser than the model without damping effect. In the future scope of this paper grid independent study of this model could be analyzed and this model could be used for designing the purpose of urban applications etc.

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