Vibrational Analysis Of Rotating Twisted Composite Beams

K. Rajesh, P. Rajesh, Dr. J. S. Suresh

Abstract— The purpose of present study is to model the rotating composite beam with pre-twist using finite element method with the help of ANSYS© software. Numerical solutions are illustrated for a twisted rotating composite beam configuration. Effects of ply angle, twist, hub radius and speed of rotation on free and forced vibrations and optimal control of rotating beams are studied. Model verification is performed with the isotropic beam to the composite beam and compared the results, which are coherent. A 3 layer laminated model with (θ/- θ/ θ) is considered to design a rotating cantilever twisted beam with hub using a CAD software (Solid Works) later the beam so forth modelled, imported into ANSYS software for further analysis. Composite lay-up and stacking sequence is modelled in ACP pre-post module, which further utilized the model for vibration study. The beam here is a composite beam modelled with IM7_5250-4RTM a carbon fiber composite material. The element used here is shell 281 to mesh the model.

Index Terms— vibration analysis, twisted beam, composite, finite element method, hub radius, fiber angle, speed of rotation

1 INTRODUCTION

In modern engineering, the heavy metallic beams are gradually being substituted by composite beams because of their high stiffness and high modulus to weight ratios. Rotating composite beam structures generally found in engineering applications, like robotic sensors/actuators, wind turbine blades, turbomachinery blades and helicopter rotors. It is well known that beams are common types of structural components and can be classified according to their geometric configuration as uniform or tapered, and slender or thick, twisted or curved. It has been used in many engineering applications and a large number of studies can be found in literature about transverse vibration of uniform isotropic beams. But if practically analyses, the non-uniform beams may provide a better or more suitable distribution of mass and strength than uniform beams and therefore can meet special functional requirements in architecture, aeronautics, robotics, and other innovative engineering applications.

PROJECT OBJECTIVE:

The objective of this paper is to present the first known natural frequencies and mode shapes of laminated rotating cantilever beam having pre-twist. It is also the objective of this paper to study the effects of many parameters such as twist angle, lamination angle, stacking sequence, and rotational speed and hub radius ratios on the natural frequencies and mode shapes of twisted rotating cantilevered composite beams. The angle of twist, breadth and depth are assumed to vary linearly along the length of beam. The first six natural frequencies and mode shapes have been studied for rotating cantilever beams. The effects of twist, speed of rotation and fiber orientation are studied. Rotating beams are important mathematical models for structures such as helicopter rotor blades, wind turbine rotor blades, propellers, turbine blades and robotic manipulators. Therefore, the modelling and analysis of rotating beams is an important practical problem. The natural frequencies of the rotating beam should be kept away from multiples of the rotor speed. Therefore, accurate frequency prediction is important.

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2 LITERATURE REVIEW

Mohamad.S.Qatu et.al.[1] (1991), studied laminated composite twisted cantilever plates where they observed a 3-D solution to clamped edge conditions provided better results than experimental one using Ritz method applying strain energy & kinetic energy functions foe laminated twisted plates. Maximum functional frequencies had been observed when the fibers are in perpendicular to the clamped edge. Advantage of Ritz method reasonably adds to accurate results with less DOF compared to FEM but its lengthy and costly which not always required. The Ritz method was applied straight forwardly to investigate important practical problems such as studying the vibrational characteristics of laminated twisted cantilever plates. It was noticed to have reasonably - accurate results with less degrees of freedom than some other methods like the finite-element method. For fiber angles between 0 ° and 90 °, coupling between the modes exists, and the strength of the coupling increases both with increasing fiber angle and increasing twist angle. With large twist angles, it was observed that many modes where large displacements occur only in limited regions of the plate, such as in a corner, whereas most of the plate displaced very little. This was the characteristic of thin shells, and the twisted plate. Increasing the angle of twist was found to decrease the fundamental frequency, which corresponds to the first bending mode. Unlike isotropic plates, increasing the angle of twist may increase or decrease the second frequency depending on the corresponding mode shape. A careful analysis of these mode shapes were observed to show that the second mode shape was not always the first torsional mode and could be the second bending mode, especially for plates with fibers parallel to the clamped edge.

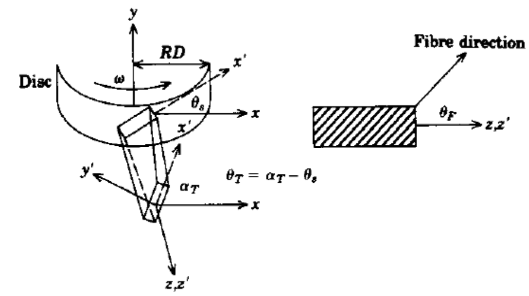
S.S.Rao and **R.S.Gupta** et.al.[2] (2001), studied the vibration analysis of rotating Timoshenko beams using finite element method. They suggested that effect of twist of beam is significant than rotation which is smooth to effect the natural frequency. They studied shear deformation which indeed reduces the values of higher natural frequencies of vibration problem of the beam. When taper is considered, breadth to depth ratio has a significant effect on the natural frequency. So for designing a vibration less beam, tapered considerations become crucial. The mass and stiffness matrices of a thick rotating beam element with taper and twist were developed for the eigenvalue analysis of rotating, doubly tapered and twisted Timoshenko beams. The element was found to give reasonably accurate results even with four finite elements. The effects of breadth and depth taper ratios, twist angle, shear deformation, offset and rotation on the natural frequencies of vibration of cantilever beams were found. The consideration of shear deformation was found to reduce the values of the higher natural frequencies of vibration of the beam. An increase in the breadth and depth taper ratios was found to increase the first two modes of vibration. The frequency ratio was found to change only slightly with rotation but appreciably with the twist of the beam.

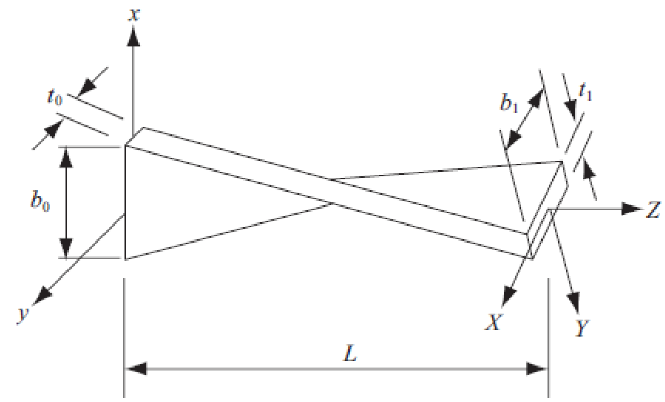
E.Ghafari & **J.Rezaeepazhand** et.al.[3] (2016), proposed a new approach called dimensional reduction method for vibration of rotating composite beams, based on polynomials and Rayleigh-Ritz method. Simple polynomial series were used to derive the essential cross sectional warping's. Natural frequencies of rotating and non-rotating beams have been obtained for isotropic, laminated composite beams and thin-walled composite box beams. A dimensional reduction method based on polynomials and Rayleigh-Ritz method is presented. A simple polynomial series have been employed to derive the necessary cross sectional warping's. Natural frequencies of rotating and non-rotating beams are obtained for isotropic, laminated composite beams and thin-walled composite box beams. The cross sectional stiffness constants and natural frequencies of the nonrotating and rotating laminated and composite box beams are in good agreement with previous experimental and theoretical results as well as the 3D finite element analysis have presented clearly. This method with high speed and precision has a capability to eliminate the costly use of 3D FEM analysis and enables researchers to optimize beam-like structures for specific behavior in different field studies. This procedure helped authors to eliminate non-straightforward process of mesh generation on beam section

L.W.Chen et.al.[4] (1993), studied the general orthotropic characteristics of pre-twisted rotating beams. Vibration of coupled-bending-bending portion of a pre-twisted rotating cantilever beam was modelled with fiber reinforced material for dynamic stability, free vibration, and rotary inertia with warping effects. Finite element method was used to study the effect of fiber orientation, twist angle and rotation of the beam and compared the results of both isometric and orthotropic materials.

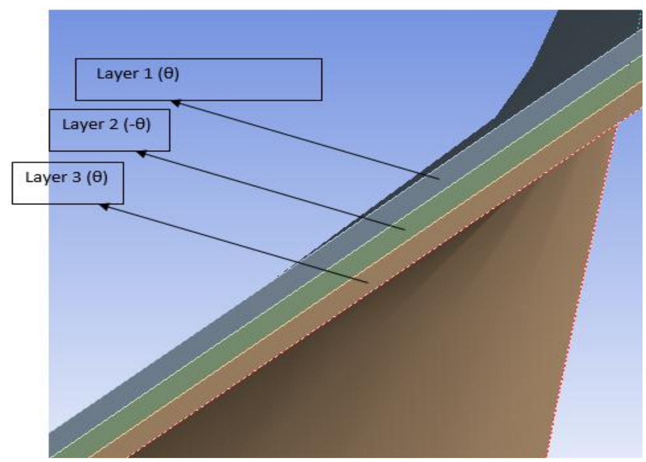
3 GEOMETRIC MODELLING

The present work deals with the vibration analysis of rotating composite twisted beams. The analysis performed on two models which are composite uniform beam and composite twisted beam. The rotating composite beam assumed to be made of carbon fiber which is a continuous, high performance, intermediate modulus, PAN based fiber. A uniformly twisted beam is modelled for vibration analysis. Beam has three layer of IM7_5250_4RTM, thickness of each layer is 0.00575m constituting to total thickness of three layers is 0.017272m and length of the beam is (L) = 0.15245m with width having 0.0254 m.





Composite layup of three layered blade is illustrated in figure, it has a layup sequence of (θ/- θ / θ) which is constructed using ACP pre-post module an inbuilt setup of ANSYS© software



4 PROBLEM STATEMENT

The present work deals with vibration analysis of rotating composite twisted beams. The analysis performed on two models which are composite uniform beam and composite twisted beam compared with non-rotating isotropic beam for validation. Analysis is carried out using finite element analysis based software ANSYS©. Vibration analysis of rotating composite twisted beam deals with the

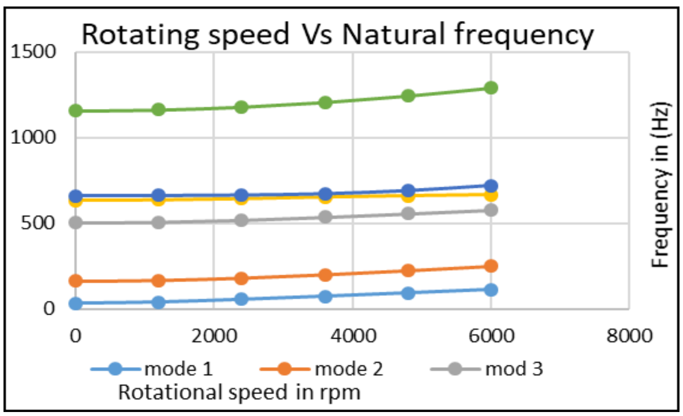
- Effect of rotating speed
- Effect of fiber angle
- Effect of hub radius ratio and

- Effect of angle of twist on natural frequency of rotating composite twisted beam.

5 Vibrational Analysis of Rotating Twisted Composite Beam

5.1 EFFECT OF ROTATING SPEED (TWISTED BEAM)

To determine the effect of rotating speed on natural frequency of rotating twisted composite beam the first six natural frequencies are obtained and illustrated in figure 27, which represents the variation of frequency with respect to rotating speed. It is observed that the natural frequencies increase with speed due to increase in centrifugal force that leads to increase in stiffness of the beam. For validating the FE model presented in this work, a comparison of current results of natural frequencies to the reference value was made and tabulated in table 1. The effect of rotation over the natural frequencies at fiber angle of 45^0 and pre-twist angle of 45^0 of the composite twisted beam has been studied. From the above Figure as the speed increases the natural frequencies and its mode shapes increases which indicates that the rotational speed has no or minimal effect on the beam. Mode 4 and 5 looks closer to each other where mode 6 is far away.



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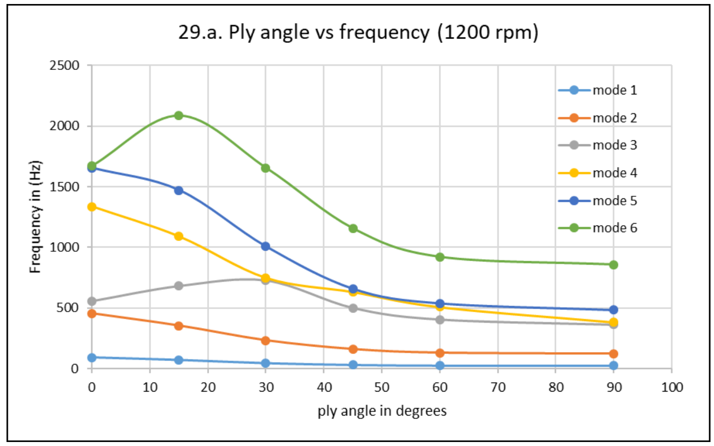
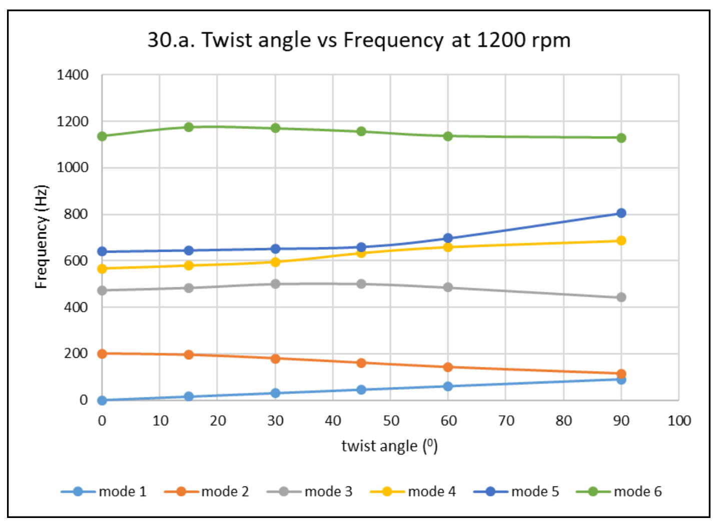
5.2 EFFECT OF FIBRE ANGLE (TWISTED BEAM)

To determine the effect of fiber angle on natural frequency of rotating composite beam the first six natural frequencies are obtained for different fiber angles at low, medium and high speeds. The first six natural frequencies are obtained for different fiber angles at different speeds are obtained and represented in figure, it shows the increment of frequencies for higher speeds.



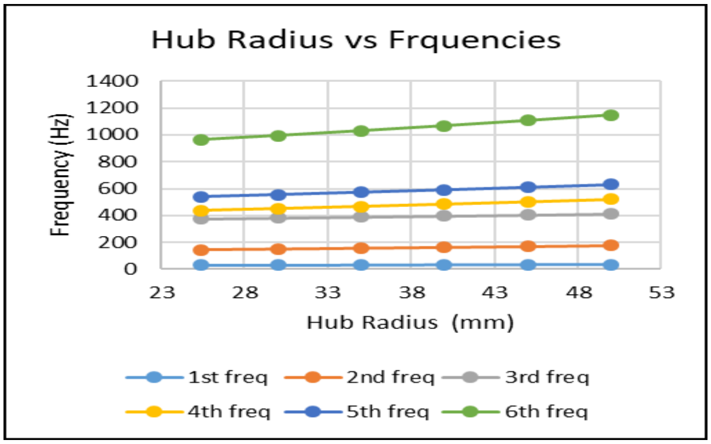
5.3 EFFECT OF TWIST ANGLE

For determining the effect of twist angle on the frequency while keeping ply angle as 45^0 at different rotational speeds, variation in values of twist angles varying from 0 to 90^0 are taken in consideration values of fundamental frequency. This is a very useful concept that can be used in rotating machine members especially turbomachinery where strength to weight ratio is important as well the frequency of the members while in rotation twisted blades forge a special case to study for such needs. Numerical results indicate that the natural frequencies of a pre-twisted beam obtained using the finite element analysis are shown to be in favorable agreement with the numerical results from literature. Results indicated that a higher first natural frequency is obtained for the beam with a higher twisted angle for $\theta < 90°$. Numerical results also indicated that the obtained second natural frequency is decreased while the twisted angle tends to $\theta < 90°$. It is evident that the third natural frequency also follows the trend of second natural frequency. The effect of twist angle on sixth mode is very evident which pitched to higher value, twist with 15^0 has the highest frequency value.

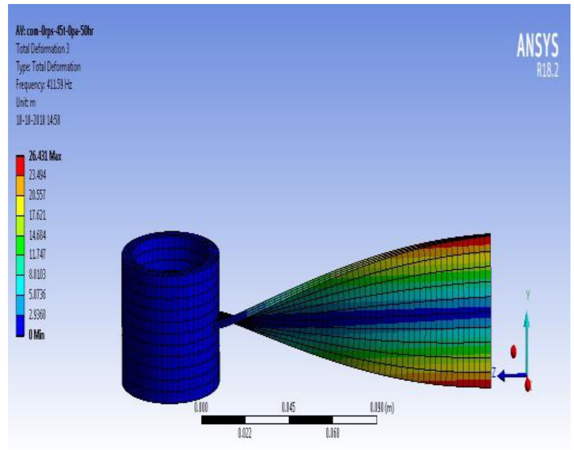


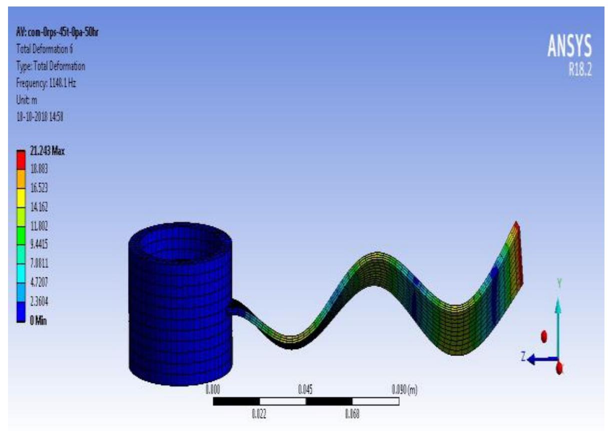
5.4 EFFECT OF HUB RADIUS (TWISTED BEAM)

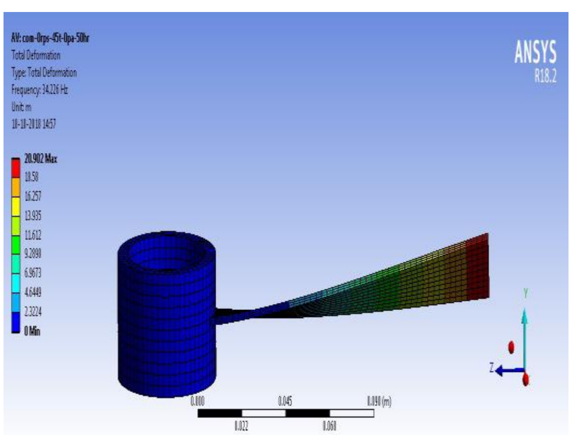
To determine the effect of hub radius on natural frequency of rotating twisted composite beam the first six natural frequencies are obtained for different hub radius ranging from 25.4mm to 50mm at zero rotational speed (i.e. stationary condition). The first six natural frequencies are obtained for different hub radius and tabulated in illustrated in a graph with figure number 32, which represents increment of frequencies for higher speeds; there is no considerable variation of speed with respect to hub radius at low speed.



First six natural frequencies of twisted composite beam are plotted in Figure. From the plotted graph it is observed that the hub radius affects the frequency in moderate manner at lower frequencies and has a significant effect on higher frequencies. From previous case; as the natural frequencies increase, the rotational speed increases and this rate of increase becomes larger with the increase in hub radius occurs. This is due to the effect of centrifugal tension force which increases as the angular velocity and the hub radius are increased. Significant effect of hub radius can be observed over natural frequencies. The mode shapes of these six cases with effect of change in hub radius have been presented case-wise from 25.4mm to 50mm. Mode shapes of rotating twisted beam for hub radius of 50mm which has highest natural frequency and had a direct effect of increase in hub radius over frequency has been presented in the figure.







6 Conclusion

The variation in natural frequencies for the twisted composite beams using the finite element method based ANSYS is investigated. The efficiency and accuracy of the method presented in the work is ascertained by comparison with reference solutions. Numerical results in different cases validated the applicability of the method for solving such an engineering problem. The pre-twisted angles influence the natural frequencies of the composite blades acting as cantilever beams. The demonstrated accuracy and simplicity of the proposed method makes it a good candidate for modelling more complicated pre-twisted beam problems. urther, the effect of rotating speed, fiber angle, hub radius ratio, twist angle on natural frequency of rotating composite twisted beam analyzed and illustrated. The following conclusions are made from the analysis

- The rotating speed affects the frequency due to variation of centrifugal force which leads variation in stiffness of the beam.
- The natural frequencies increase with the increasing rotational speed due to the stiffening effect of the centrifugal force induced from the rotation. Moreover, this effect is more significant on higher modes than on lower modes.

- The rate of increase of the natural frequencies increases as the hub radius increases. The hub radius affects the frequency at higher speeds only.
- The natural frequencies of composite twisted beam decreases as the angle of fiber orientation increases, But the natural frequency variation reaches peaks at fiber angle 15 degrees the change in all six frequencies are ascertained.
- The twist angle of the composite beam changes not only its geometric properties but also the stiffness of the oblique plies. This causes the mechanical behavior of the twisted composite beam to be different from that of the uniform beam. Therefore, it is necessary to consider the effect of the laminate stiffness of the composite beam caused by the Twist angle.
- FEA results indicates that the obtained fifth natural frequency is decreased while the pre-twisted angle increasing for $\theta < 45°$.

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