COMPARATIVE MODAL ANALYSIS STUDIES FOR MODELLING A TURBINE BLADE AS TWISTED CANTILEVER BEAM

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Abstract : The dynamic behaviour of a mechanical component is characterized by the modal parameters such as natural frequencies and mode shapes associated with each natural frequency. Many researchers spent considerable amount of time and effort in obtaining the modal parameters of the twisted cantilever beam. In this paper, comparison of modal analysis is made for twisted cantilever beam and the steam turbine blade for different angle of twists. So, parametric studies have been carried out using ANSYS software to evaluate natural frequencies and mode shapes for different angle of twists i.e. 15°, 30°, 45°, and 60° of steam turbine blade and twisted cantilever beam. From this analysis, the effects of the angle of twist on the natural frequencies of the blade and beam were studied. This analysis is believed to know the exact dynamic behavior of the turbine blades compared with twisted cantilever beam.

***IndexTerms* - Twisted cantilever beam, turbine blade, modal analysis, natural frequencies.**

I. INTRODUCTION

Fatigue is a common concern for turbo-machinery users. Faults may develop due to fatigue in the blades of a turbine and can have an adverse effect on the reliability of the turbine. Turbines are more expensive and require proper condition monitoring of their blades. Early fault detection and repair enhances the reliability as well as the durability of the machines. Vibration monitoring is one of the promising condition monitoring technique which can be carried out on the components of the machine when the defect location is not accessible. As machine components such as turbine blades (where there is a possibility of fatigue fault) can be treated as a pretwisted blade with uniform cross section, one can study the effect of fault with the dynamic response of twisted beam and it can be extended to develop online crack detection of such machine components.

Hong Hee Yoo et. al. [1] has derived equations of motion for the vibration analysis of rotating pre-twisted blades from a modeling method which employs hybrid deformation variables. Bazoune et.al [2] developed a method for dynamic response analysis of spinning tapered Timoshenko beams utilizing the finite element method. The equations of motion are derived to include the effects of Coriolis forces, shear deformation, rotary inertia, hub radius, taper ratios and angular setting of the beam. Chung and Yoo [3] presented finite element analysis for a rotating cantilever beam in their study. Based on a dynamic modeling method using the stretch deformation instead of the conventional axial deformation, three linear partial differential equations are derived from Hamilton's principle. Two of the linear differential equations are coupled through the stretch and chordwise deformations. The other equation is an uncoupled one for the flapwise deformation. Young and Gau [4] investigated stability of a pre-twisted cantilever beam spinning along its longitudinal axis with a periodically varying speed and acted upon by an axial random force at the free end. Yoo and Pieree [5] investigated modal characteristics of a rotating plate. A dynamic modeling method for rectangular plates undergoing prescribed overall motion is employed to derive the equations of motion. Yoo et al. [6] obtained certain modal characteristic requirements such as maximum or minimum slope natural frequency loci and the geometry shapes that satisfy the requirements through an optimization procedure. Lim and yoo [7] presented a modeling method for the modal analysis of cantilever plates undergoing accelerated in-plane motion. Von Karman strain measures are employed to derive the in-plane and the lateral equations of motion. In-plane strain measures of the accelerated plates are obtained from the in-plane equations and substituted into the lateral equations to obtain the linear equations for modal analysis. Sabuncu and Evran [8] presented a finite element model to study the dynamic stability of a pre-twisted Timoshenko beam having asymmetric aerofoil cross section subjected to lateral parametric excitation. Solutions referred to as combination resonance are investigated considering the effects of shear deformation and rotary inertia in the analysis. Vadiraja and Sahasrabudhe [9] presented structural modeling of rotating pre-twisted thin-walled composite beams with embedded macro fiber composite actuators and sensors using higher shear deformation theory. It is observed in the study that, gyroscopic coupling between lagging-extension motions is found to have significant effect and cannot be neglected in the analysis. Chen [10] investigated the influence of thickness to width ratio, twist angle, spinning speed and axial load on the natural frequency and buckling load of Timoshenko beams. Sinha and Turner [11] derived the governing partial differential equation of motion for the transverse deflection of a rotating pre-twisted plate. Strain-displacement relationships include the effect of warping of the cross-section due to twist-bend coupling effect introduced as a result of pre-twist in the plate of non-circular cross-section. Then the equation of motion, thus derived, is used to formulate the free vibration of a typical turbo-machinery cantilevered airfoil blade by considering it as a plate of an equivalent rectangular cross-section subjected to a quasi-static load due to centrifugal force field. The results of the eigenvalue solution are presented in a non-dimensional form for plates of varying aspect ratios and different amounts of pre-twist in the plate. The numerical results are directly applicable in determining the static and running frequencies of typical blades used in turbo machinery. Mustapha and Zhong [12] presented governing equation of motion to address the effects of the rate of twist and the material length scale on the bending wave propagation characteristics of the motion scale beam. Results are presented for the spectrum curve, the cut-off frequency, the phase speed and the group velocity of the propagating harmonic wave profile in the twisted micro scale beam.

This literature review presents an overview of the vibration response methodologies in isotropic material and orthotropic (composite) material. Identification of modal parameters pertaining to twisted beams is part of the standard methods in performance monitoring of the structure. Many procedures are proposed in this line and developed for isotropic materials. The main scientific challenge addressed in this paper is to establish a robust description of twist angle effects that can be used in more precise fatigue lifetime models and simulations of fatigue behavior of turbine blades. The industrial benefit will be access to a reliable, fast and efficient tool for the fatigue assessment of critical machine components like turbine blades.

II. PROBLEM FORMULATION

The objective of the present work is to evaluate the natural frequencies and mode shapes of a twisted cantilever beam to study the dynamic behavior of the turbine blade. Putting appropriate boundary condition for twisted cantilever beam the general eigenvalue problem will be specified for the proposed case as shown in Fig. 1. The finite element model of the twisted cantilever beam is shown in Fig. 2. To find out Eigen value and Eigen vectors finite element method (FEM) has been used. The modal analysis has been carried out by ANSYS Software. This code is a general purpose Software on finite element analysis. It contains a library of different types of elements and different types of analysis. To solve the present problem, solid brick element has been used for meshing the beam model.

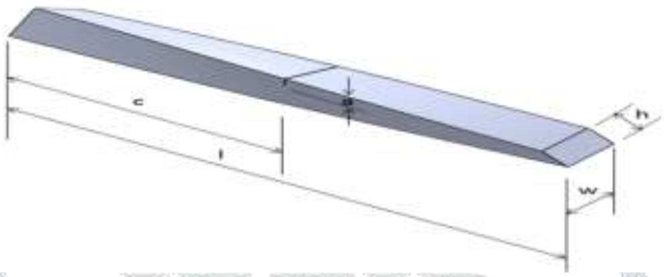

Fig. 1: Twisted cantilever beam

The last stage blade of low pressure steam turbine is modeled as twisted canitlever beam with l/h=60. Since the frequencies could be compared accurately for low modes of vibration, the present study is focused on the 1st and 2nd modes as shown in Fig. 3. Generally the first two measured frequencies and modes of vibration are sufficient to compare vibration analysis of twisted cantilever beam and turbine blade.

Fig. 2: Finite element model of twisted cantilever beam

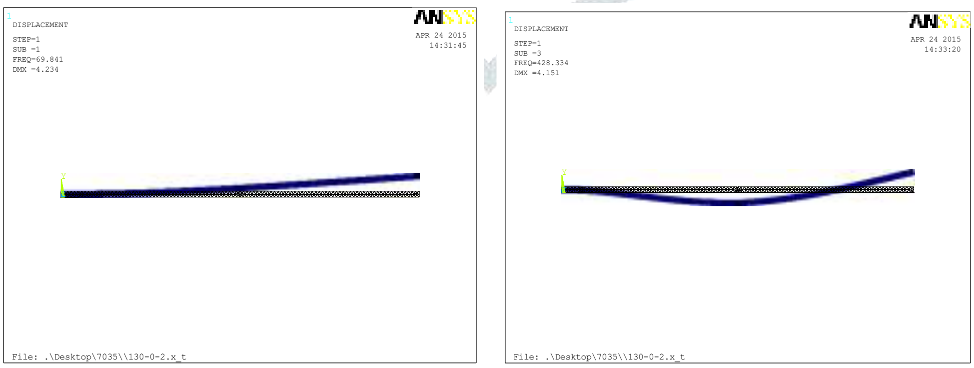

Fig. 3: First two mode shapes of twisted cantilever beam

III. RESULTS AND DISCUSSIONS

The modal analysis deals with the behaviour of mechanical structures under the dynamic excitation. The modal analysis helps to reduce the noise emitted from the system to the environment. It helps to point out the reasons of vibrations that cause damage of the integrity of system components. Using it, we can improve the overall performance of the system in certain operating conditions. We know two basic methods of the modal analysis, namely the numerical modal analysis and the experimental modal analysis. The experimental modal analysis deals with measurement input data from which a mathematical model is derived. However, it has to take different levels of analysis, from which the model is constructed.

Natural Frequency values for twisted cantilever Beam of rectangular cross section are analyzed and the 1st, 2nd and 3rd mode are given in table 1.

Table 1: Natural frequencies of twisted cantilever beam with different angles of twist

Angle of Twist	Frequency 1	Frequency 2	Frequency 3
0º	57.548	360.17	1006.3
15º	58.265	382.72	1009.6
30º	58.525	418.99	980.64
45º	58.787	461.35	939.27
60º	59.289	508.87	896.39

Later same analysis was carried out for turbine blade of low pressure steam turbine last stage blade which is modeled with airfoil cross section and tapered length. The material properties are assigned to the blade and boundary conditions are defined. The blade's root surface is constrained with all degrees of freedom. They are denoted with the blue flag Fig. 4. This condition prevents the movement of the surface in a space.

Mesh on the blade is generated automatically by ANSYS, by using the spatial element SOLID185 Fig. 5. The element is defined by 10 nodes while each node has three degrees of freedom. The SOLID185 has a quadratic shifting behaviour and is suitable for modelling of the finite element irregular mesh.

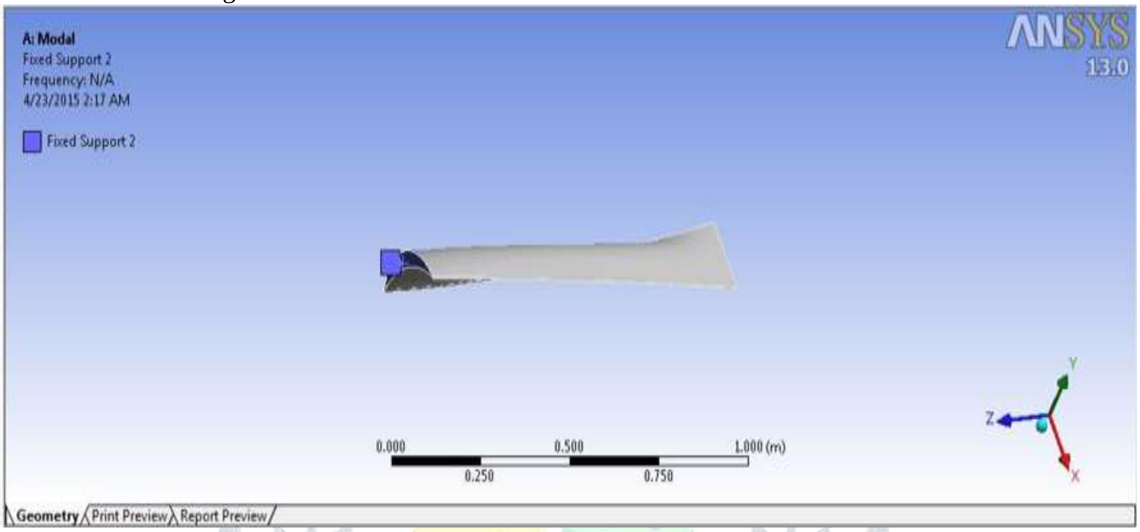

Fig. 4. Boundary condition of turbine blade in ANSYS Workbench

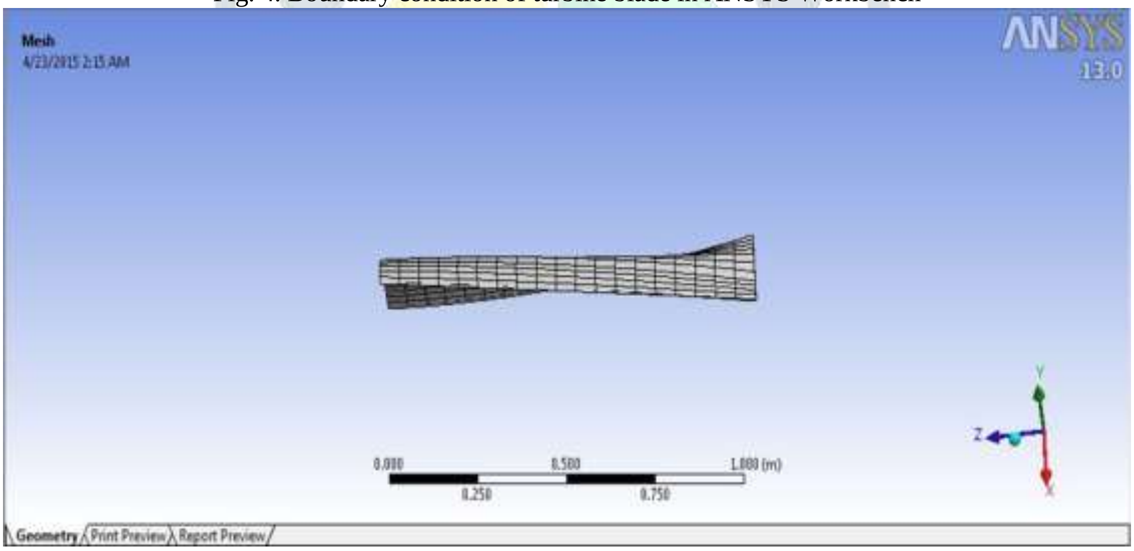

Fig. 5. Meshing of turbine blade in ANSYS Workbench

It is possible to influence the computational time of the analysis, when a range of frequencies or number of mode shapes is specified. The type of solver and the solution method inprogram ANSYS is selected automatically. For this modal analysis the direct solver including the Block Lanczos method is used. The first three natural frequencies are of the turbine blade are given in table 2 and mode shapes of angle of twist 0º, 15º, 30º, 45º and 60º are shown from Figs. 6 to 10.

Table 2: Natural frequencies of turbine blade with different angles of twist (for uncracked blade)

Angle of Twist	Frequency 1	Frequency 2	Frequency 3
0º	74.093	268.71	690.59
15º	72.775	229.47	685.18
30º	72.395	236.55	719.23
45º	72.281	269.16	690.62
60º	70.596	301.53	677.20

From the table 1 it was found that Frequency 1 is more for cantilever beam with 0° angle of twist and it is same with increased angle of twist. Frequency 2 is increasing with increased angle of twist and Frequency 3 is decreasing with increased angle of twist. The same can be observe for turbine blade as frequency values given in table 2.

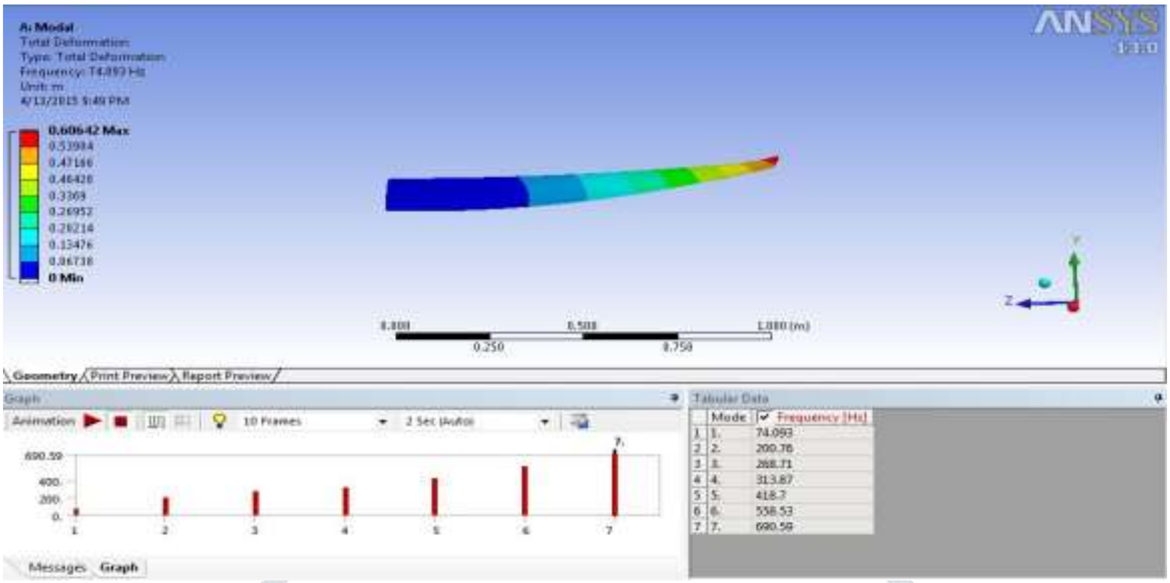

Fig. 6: First mode shape of turbine blade with 0° angle of twist

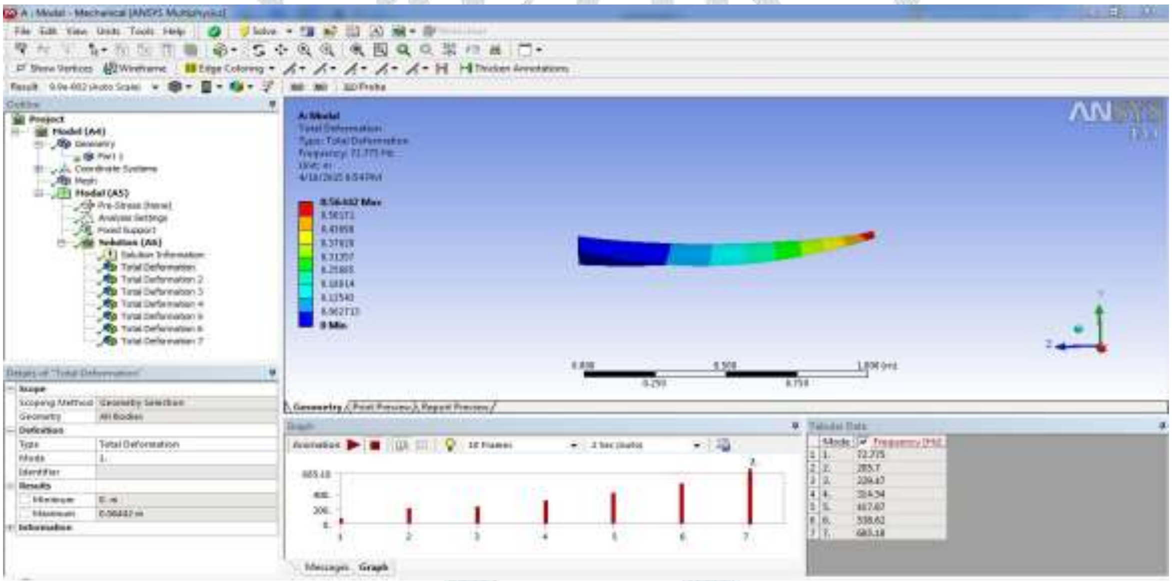

Fig. 7: First mode shape of turbine blade with 15° angle of twist

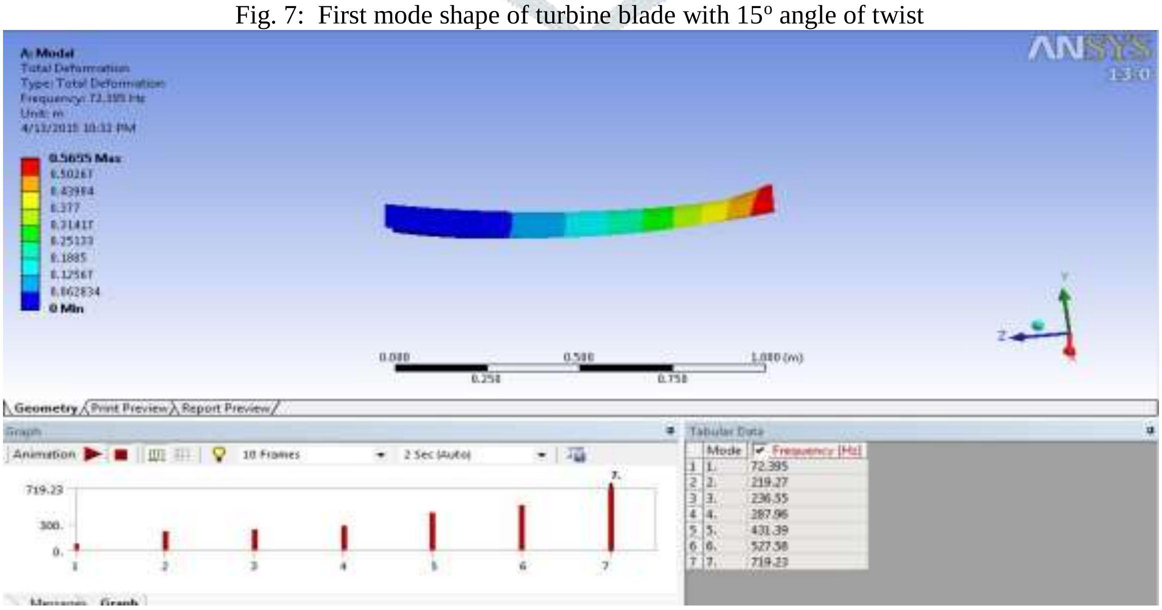

Fig. 8: First mode shape of turbine blade with 30° angle of twist

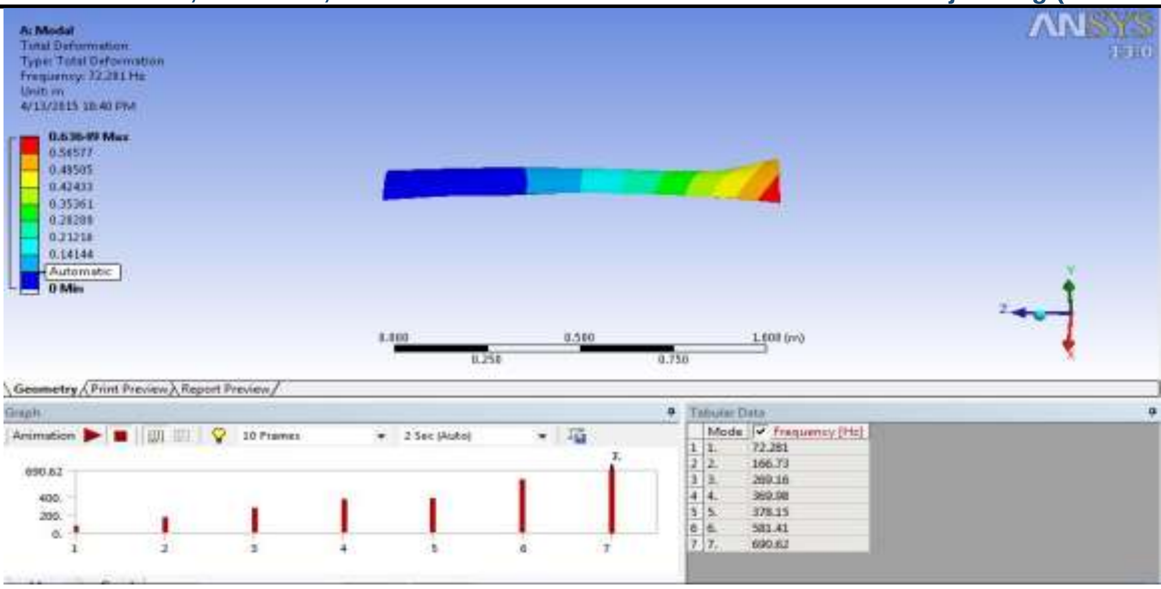

Fig. 9: First mode shape of turbine blade with 45° angle of twist

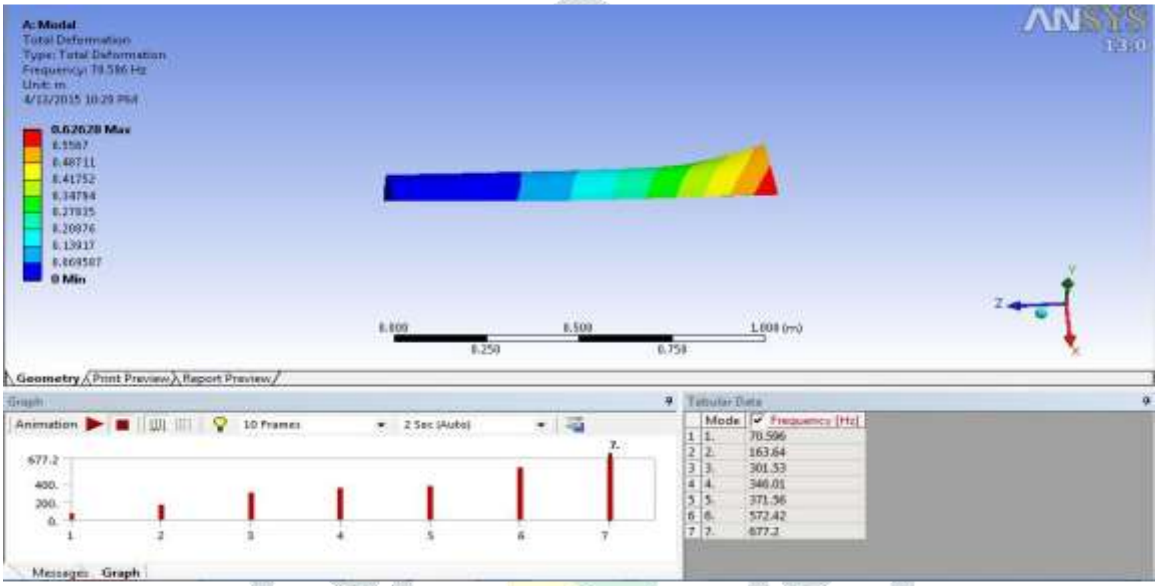

Fig. 10: First mode shape of turbine blade with 60° angle of twist

The first three measured natural frequencies and modes of vibration are compared to validate vibration analysis of twisted cantilever beam as turbine blade. From Fig. 11 it was found that Frequency 1 is more for cantilever beam with 0° angle of twist and it is same with increased angle of twist. Frequency 2 is increasing with increased angle of twist and Frequency 3 is decreasing with increased angle of twist as shown in Figs. 12 and 13 respectively.

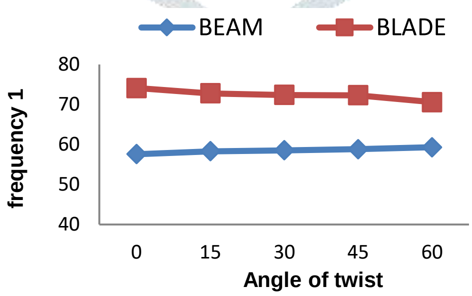

Fig. 11: Comparison of 1st mode frequencies of blade and beam for different angle of twist

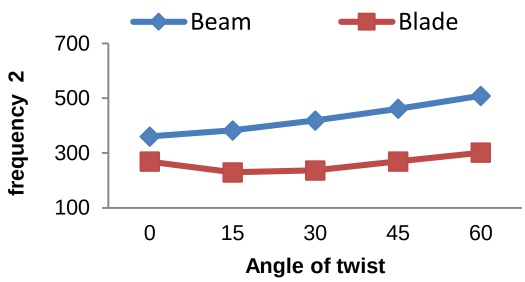

Fig. 12: Comparison of 2nd mode frequencies of blade and beam for different angle of twist

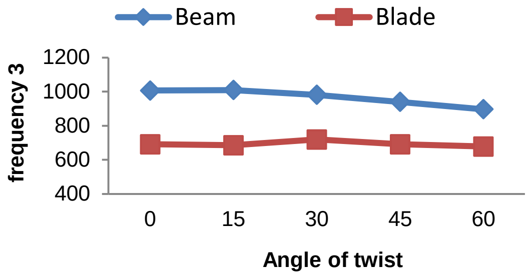

Fig. 13: Comparison of 3rd mode frequencies of blade and beam for different angle of twist

IV. CONCLUSIONS

A comparison for modal analysis of twisted cantilever beam with turbine blade has been attempted in this paper. After modeling turbine blade as a twisted cantilever beam parametric studies have been carried out using ANSYS software to evaluate modal parameters (natural frequencies) for different twist angles. From the analysis it has been observed that the trends of the natural frequencies of first three modes of vibration for both the turbine blade and twisted beams are similar for varying angle of twists. So, modal analysis results of twisted cantilever beam can be supplemented to turbine blade for predicting the faults in the turbine blades.

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