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MODEL ANALYSIS OF STEAM TURBINE BLADE

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ABSTRACT

The objective of this research is to study the influence of various blade geometric parameters on its modal properties. In this line, first of all the effect of pre-twist angle has been investigated on the modal properties of the blade. Secondly, modal analysis results of a blade have also been found out by modelling the blade including all the geometric properties. It is important to design steam turbine blades in such a way that the natural frequencies of the blades remain away from the harmonics of the excitations forces. This can be ensured by carrying out the modal analysis of the steam turbine blades.

KEYWORDS: ANSYS, Workbench, Cre-o.

INTRODUCTION

The work in this paper is about the numerical simulation of steam turbine blades for modal analysis. this work introduces the applications of steam power and gives an introduction to the theory of steam turbines. the theory for analysis of steam turbine blades is also introduced.

Steam turbine steam turbine is a mechanical device where thermal energy of pressurized steam is converted into mechanical work. sir charles parsons invented the modern form of steam turbine in 1884. the steam turbine ranks with the internal-combustion engine as one of the major achievements of mechanical engineering in the 19th century. steadily increased in size, reliability and efficiency, steam turbines now account for more than 75 percent of the electric power generated in the world (most of the rest is hydroelectric) and propel most of the biggest and fastest ships. between 15 and 20percent of the fossil fuel consumed in the u.s. and western europe - and essentially all the fuel now consumed in nuclear power plants - has only one purpose: to evaporate and superheat water that then passes through a steam turbine. hossli (1969) the steam turbine is a prime mover which converts the kinetic energy of steam heat-energy into mechanical work. unlike reciprocation steam engines, in case of steam turbines the power of steam is directly converted into mechanical work

EFFECT OF TWIST ANGLE ON MODAL CHARACTERISTICS OF A CANTILEVER BEAM

Turbine blades are subjected to very strenuous environments inside a steam turbine. they are subjected to high temperatures, high stresses, and high speed. all these factors can lead to blade failure like cracking, bulging, twisting, bending and breaking of blades. the damage or failure of turbine blades will affect the performance of the steam turbine engine hence early detection of blade problems is necessary to ensure the availability, reliability and good performance of steam turbine . turbine blades are twisted to provide a better dial distribution of angle of attack, due to rotation's problem. it is a built-in angle that it is provided when the blade is built. although there is not an absolute rule, the twist axis is radial, and most of the times it is coincident to the feathering axis. most of the times, the axis passes by the quarter of chord which for thin symmetrical air foils is the aerodynamic centre. when the blade is not straight but curved, we can find the twist angle given either around the curved axis, or around a straight radial axis coincident or parallel to the feathering axis, depending on how the blade is built. we have to realise that there is static twist, i.e. the twist which is built into the blade before any aerodynamic loading. the further twisting depends on the structural stiffness of the blade. it may not be about the same axis as the initial twist built into the blade.

EFFECT OF TWISTING IN CANTILEVER BEAM WITH DIFFERENT TWISTING ANGLE

In this study, the effect of variation in twist angle has been investigated on the natural frequencies and mode shapes of a rectangular cantilever beam. the results are validated first by analytical results and further more detailed analysis has been carried out.

MODELLING OF THE CANTILEVER BEAM (without twist)

The solid model of cantilever blade as created in pro-e has been shown in **Error! Reference source not found.** the solid model as developed in pro-e has been converted into iges format for transferring it in ansys workbench for the analysis.

Model of a cantilever beam a detailed analysis has been carried out to select the optimum number of elements to be used in the finite element model. the results of convergence after convergence check to ensure the required number of elements, detailed modal analysis of the cantilever blade (without twist) has been carried out

Figure 1 A simple beam without twist

MODAL ANALYSIS OF TWISTED CANTILEVER BEAM

Modal analysis of twisted cantilever beam has been carried out. twist angles of 30, 60 and 90 have been considered. for each twist angle, first of all the required number of elements has been found out by convergence check. the convergence check has been imposed for initial six modes, for which the further results are given.

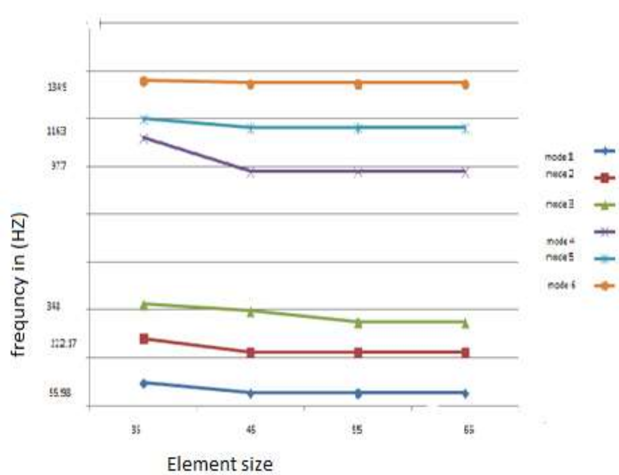

Figure 2 Convergence Graph of cantilever beam without twist.

It is seen that the initial six natural frequencies converge for 70, 80 and 90 number of elements for 30^0, 60^0 and 90^o twist angles respectively. further, mode shapes of the twisted cantilever beam have been studied. the results for mode shapes are reported for 60^o and 90^o twist angle. such a study helps us in identifying the locations of maximum and minimum displacement for the turbine blades when it vibrates at or near any of its modes.

COMPARISON OF SIMULATION RESULTS FOR NATURAL FREQUENCIES OF TWISTED BEAM WITH REFERENCE RESULTS

	At 0^o			At 30^0			At 60^0			At 90^0		
TWIST ANGLE→ Natural frequency (Hz)	Present work	Experimental work Rao (1988)	% error	present work	Rao	% error	present work	Rao	% error	present work	Rao	% error
Mode 1	55.98	56.22	-0.4	54.874	54.95	0.13	52.80	52	1.5	45.635	50	-8.73
Mode 2	222.17	220.23	0.8	204.21	204.21	0	172.41	172	0.4	116.66	120	-2.7
Mode 3	350.12	348.68	0.41	366.84	365.48	0.37	399.09	405	-1.4	438.75	470	-6.8
Mode 4	977.59	980	0.2	908.27	923.48	-0.16	786.19	800	-1.7	573.85	605	-5.3
Mode 5	1063.6 (T)	-	-	1148	-	-	1119.6 (T)	-	-	1028 (T)	-	-
Mode 6	1348.9	1348.25	-0.12	1395	1405	-0.7	1468.8	1500	-2.08	1335.6	1502	-11.07

CONCLUSION

Flexible structures like turbine blades are often idealized as cantilever beams. the procedure followed in ansys to perform modal analysis for cantilever beam has been explained. the results of modal analysis for twisted cantilever beams as obtained by finite element method matched very closely with the experimental results (as available in literature). the results thus obtained are also in agreement with the results of rao (1991), where analytical approach has been used to estimate the natural frequencies in bending model. however, the method as adopted in this work has the advantage that other effects like that of angular and axial degrees of freedom can also be simulated. the results in this work also reported natural frequencies in torsion mode, which were not reported in the work of rao (1991**).**

MODAL ANALYSIS OF TURBINE BLADE

In ansys workbench solid 3d model of the turbine blade was developed in cre-o, figure shows the modeled turbine blade. the above model was imported in ansys to develop fe model as shown in geometric model of the turbine blade. the solid model as developed in cre-o has been converted into iges format to import it in ansys workbench. after importing it in ansys, modal analysis of the turbine blade has been carried out. all degrees of freedom present in the bottom surfaces are constrained as they are attached to rigid rotor disk. the fe model was used to obtain the mode shapes and natural frequencies for the turbine blade in a stationary reference frame.

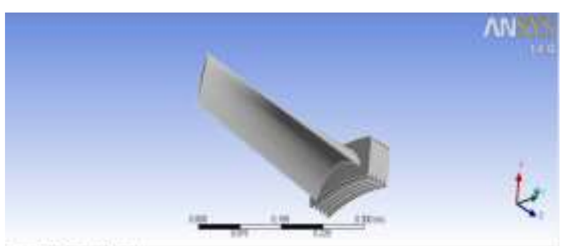

Figure 3 Geometric model of the turbine blade

Convergence graph for turbine blade

Before carrying out the detailed modal analysis, the finite element model has been checked for convergence. for this the element size of 550, 650 and 750 has been considered and the convergence check has been imposed for initial six modes, for which the further results are given. it is seen that the initial six natural frequencies converge with 750 numbers of elements. the results of convergence have been checked for the natural frequency and are plotted in it has been seen that the results are converging as the element size is reduced and finally it converges.

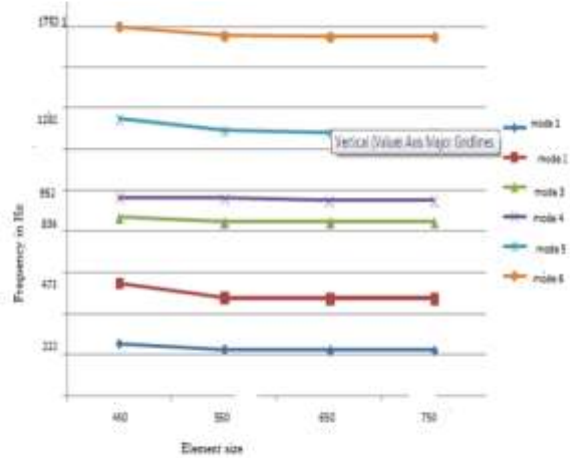

Figure 4 Final convergence graph of turbine blade for all mode shapes

Meshing of turbine blade

Meshed model of turbine blade is shown below**:**

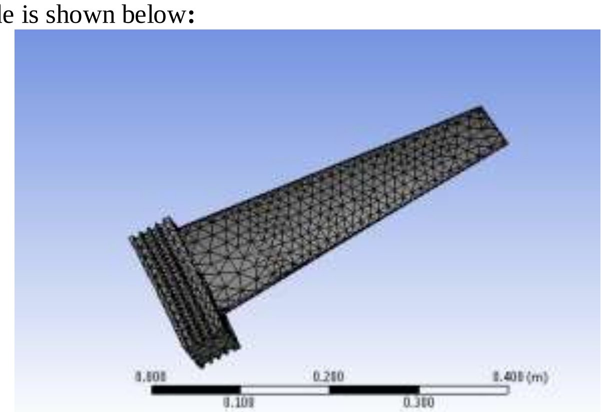

Figure 5 Meshed model of the turbine blade

RESULT

Rotating flexible structures like turbine blades are often idealized as rotating cantilever beams. this section reports the results of the modal analysis of the turbine blade in the initial six modes.

NATURAL FREQUENCIES OF THE TURBINE BLADE

table shows the natural frequencies of the turbine blade in the initial six modes. it may be noted that to see the possible resonance regions of turbine blade with excitation frequencies, campbell diagram can be plotted

Natural frequencies of the turbine blade in initial six modes

S.NO	MODE	FREQUENCY (HZ)
1	1	228.88
2	2	473.96
3	3	836.11

4	4	952.72
5	5	1282.1
6	6	1750.1

the procedure followed in ansys to perform modal analysis. result is given below in shows the first mode shape of turbine blade at frequency at 228.88 hz. this is a fundamental natural frequency.

Mode shapes of the turbine blade

Detailed analysis of mode shapes of a turbine blade is important to know the type of vibration mode. it can be found out with the help of animation about the type of mode, i.e. bending, axial or torsional mode. such analysis has been conducted in the present work. the mode shapes observed of stationary turbine blades are flexural (f), axial or edge bending (eb) and torsion modes (t). Figure 6 and Figure 7 show the initial two flexural (bending mode) of the turbine blade at a frequency of 228.88 hz and 473.96 hz respectively. in these modes, the maximum deflection is at the tip of the blade as can be seen in the figures. Figure 8 shows the third mode which is actually edge bending mode (eb) at a frequency of 863.11 Figure 9 and Figure 10 are the torsion modes at frequencies of 952.72 hz and 1282.1 hz respectively. comparing the initial four modes, the difference of variation of displacements in the bending and torsion modes can be seen clearly.it is seen that the fifth mode is again a bending mode, whereas the sixth mode is a torsion mode as can be seen the Figure 11 and 1750.1hz respectively.

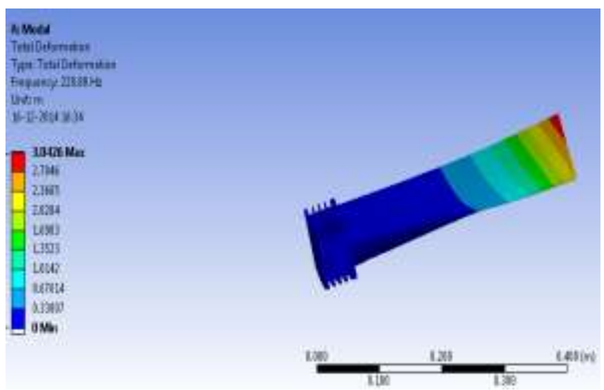

Figure 6 First mode shape

In second mode shape we are observe second natural frequency at 473.96HZ.

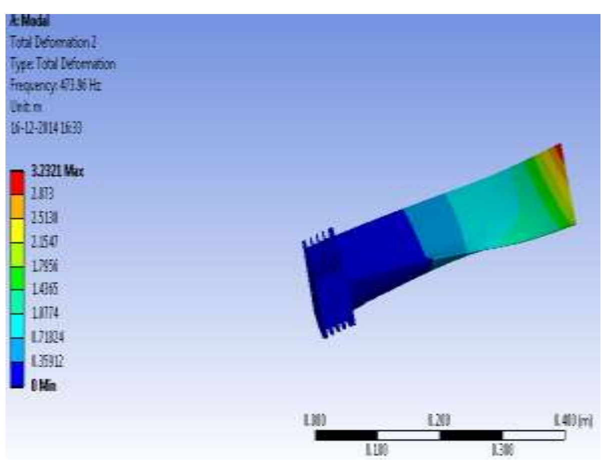

Figure 7 Second mode shape

In third mode shape we are observe third natural frequency 836.11HZ

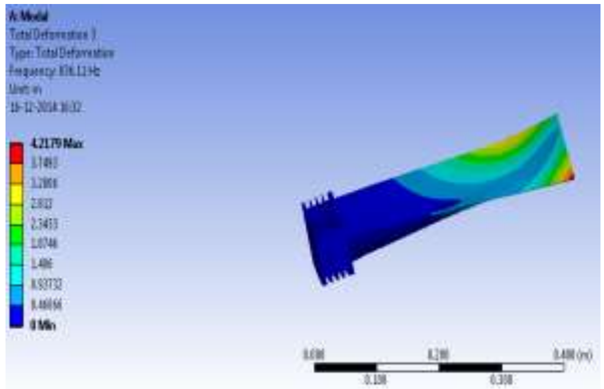

Figure 8 Third mode shape

This is a torsion mode and the natural frequency is 952.72HZ.

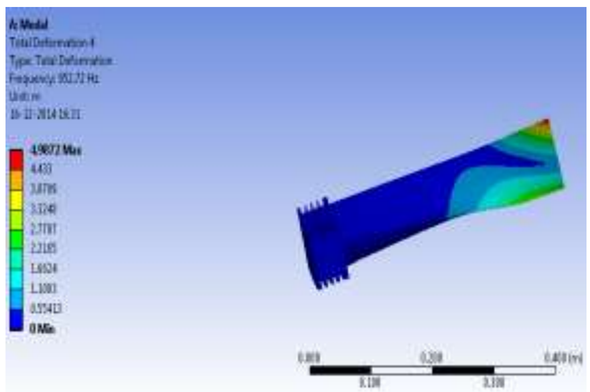

Figure 9 Forth mode shape (Torsion mode)

In fifth mode shape we are observe fifth natural frequency1282.1HZ.

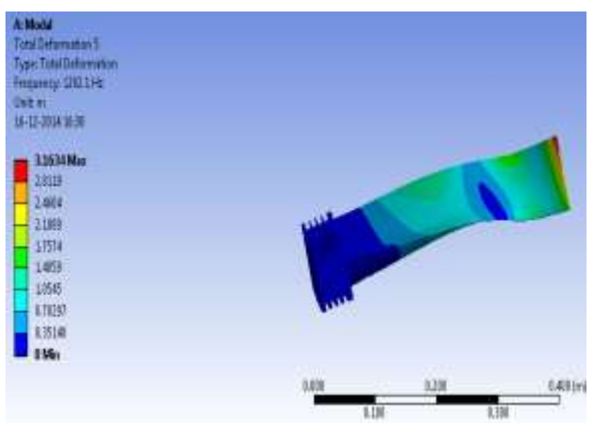

Figure 10 Fifth mode shape

In sixth mode shape we are observe sixed natural frequency1750.9HZ.

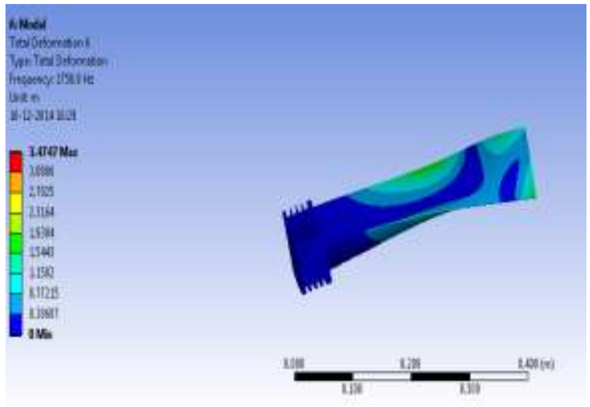

Figure 11 Sixth mode shape

Campbell diagram for the turbine blade

It is important to find out possible resonance regions for rotating machines with sub-synchronous, synchronous and super-synchronous frequencies. for solving vibration problems of turbine wheel, frequency speed diagrams were extensively used by wilfred campbell, after whose name such diagrams are called “campbell diagram” (campbell (1924)). several other names like whirl speed map, natural frequency-speed map, damped natural frequency map, interference map, and frequency interference diagram are also used in literature in place of campbell diagram.

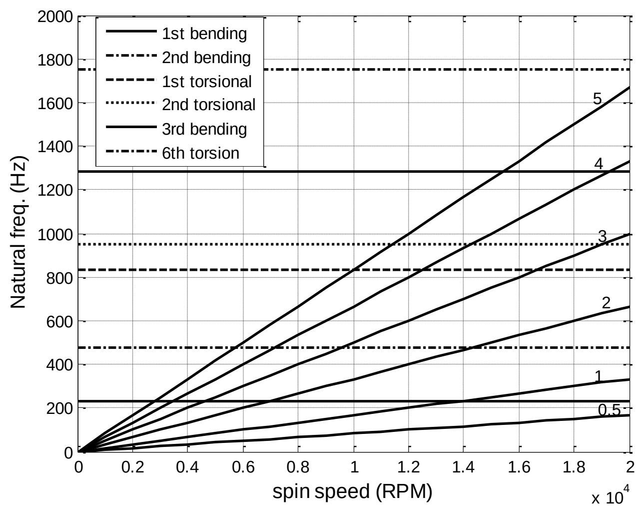

Figure 12 Campbell diagram for steam turbine blade

Figure 12**Error! Reference source not found.** shows the campbell diagram for the turbine blade. initial six natural frequencies are plotted in the figure. excitation order lines with slope values of 0.5, 1, 2, 3, 4 and 5 are plotted. such analysis helps in identifying possible resonance regions of the turbine blade with sub-synchronous, synchronous and super-synchronous frequencies. for example it can be seen that at a spin speed of 3000 rpm there is no resonance with any of the excitation frequencies plotted. at spin speed of 8000 rpm, there is no resonance at this particular speed with any of the natural frequencies. however, it can be seen from the plot that if this is the operating speed then the turbine blade will pass through resonant state during transient state. it can be noted under such a condition the vibration control is due to the damping

CONCLUSION

This work presents computational studies in modal analysis of steam turbine blades. turbine blades have complex geometry and include many features like that of asymmetry, taper and twist to improve the performance of the turbine.

turbine blades are often idealized as cantilever beams. actual turbine blades are asymmetric, twisted and tapered. turbine blades are twisted to provide a better dial distribution of angle of attack, due to rotation's problem. it is a built-in angle that it is provided when the blade is built in this work, initially, modal analysis of twisted cantilever beam has been carried out to see the effect of twist on the natural frequencies and mode shapes. ansys workbench software is used for the modal analysis, and step by step procedure required for such an analysis is explained. the results of modal analysis for twisted cantilever beams as obtained by finite element method matched very closely with the experimental results (as available in literature). the results thus obtained are also in agreement with the results of rao (1991), where analytical approach has been used to estimate the natural frequencies in bending model. however, the method as adopted in this work has the advantage that other effects like that of angular and axial degrees of freedom can also be simulated. the results in this work also reported natural frequencies in torsion mode, which were not reported in the work of rao (1991). further, the work included the detailed design procedure for and actual steam turbine blade. various aspects of design like aero dynamics; material properties etc have been explained. detailed analysis to find out the type of mode has been carried out and the bending and torsion modes are identified. natural resonant frequency for a rotating blade must be tuned to avoid frequencies, when a new steam turbine is designed. the blade designer must ensure that there is no resonance of the turbine blade at the operating speed. such resonances should also be avoided during transient state of operation. however, it may not always be possible to avoid resonance under transient state of operation. such analysis as has been carried out in this work help in designing a new steam turbine. it also helps in operating a steam turbine safely. tuning of the turbine blades can also be carried out for small turbines so that none of the resonant frequencies for any of the modes of vibration coincide with the frequencies associated with the harmonies of running speed. sometimes, tuning requires a trade-off with turbine performance or efficiency.

FUTURE SCOPE

Future scope has been identified out this thesis work and is listed point-wise below:

1 modal analysis studies by considering various features like asymmetry, taper etc can be performed.

2 modal analysis of turbine blades of low pressure, intermediate pressure and high pressure stages can perform and results can be checked to know the possible resonance regions.

3 stress analysis of the turbine blade can be performed under dynamic loading conditions.

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