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Finite Element Analysis on Combination of CA6NM Rotor and Ti 6Al 4V Blade

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Abstract-- About 80% of electricity generation in the world is by use of steam turbines. Steam Turbine is used to convert thermal energy of steam into mechanical energy, which is used to produce electrical energy. Hence steam turbine generator units are being used extensively all over the world for generation of electric power and for co-generation of steam and power. Any improvement in the design of steam turbine rotor enables more efficient use of fuel and results in reduced cost. In this present work, analysis of rotor and blade combination were carried out, in which rotor is made up of CA6NM and blade is made up of Ti 6Al 4V material. For this combination modal analysis is carried out to predict the natural frequency along with deformation at the rotational velocity of 91Hz, also Campbell diagram analysis is carried out to find out critical speed of the rotor.

Keywords-- CA6NM, Campbell diagram, Modal analysis, Natural frequency, Rotational velocity, Steam Turbine, Rotor, Ti 6Al 4V.

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1 INTRODUCTION

A steam turbine is a mechanical device that extracts thermal energy from high temperature and high pressure steam which converts it into rotary motion. Since the turbine generates rotary motion, it is suited to be used to drive an electrical generator – majority of the electricity generation in the world is generated by steam turbines. The steam turbine is a form of heat engine that derives much of its improvement in thermodynamic efficiency through the use of multiple stages in the expansion of the steam, which results in a closer approach to the ideal reversible process.

Its modern manifestation was invented by Sir Charles Parsons in 1884[1]. There are many advantages and application of steam turbine compared to other types of turbine.

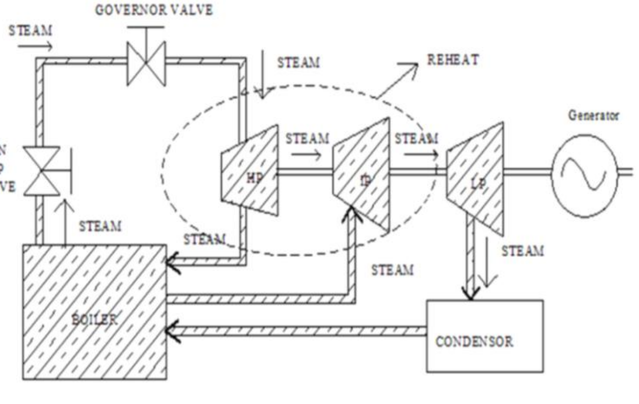


Fig.1 A schematic view of steam turbine

There are three different sections in the steam turbine, they are high pressure section, intermediate pressure section, low pressure section clearly shown in the above figure 1. The high pressure steam at 5650 C and 156 bar pressure passes through the high pressure section. The exhaust steam from this section is returned to the boiler for reheating before being used. On leaving the boiler reheater, steam enters the intermediate pressure section at 5650 C and 40.2 bar pressure. From here the steam goes straight into Low pressure section of steam turbine, expanding itself with increase in mass flow.

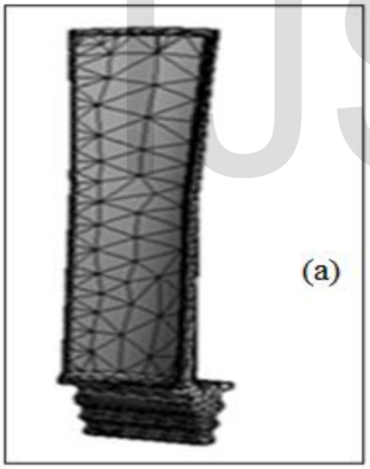
Literature Review: The manufacturing of the large capacity steam turbine at low pressure stage is difficult, hence many problems arises i.e. erosion effects, corrosion effects, corrosion cracking, abrasive & droplet impingement during the operation. But solution is discussed by V. A. Ryzhenkov et al.,[2],. Failure in even one rotor blade out of hundreds of blades fixed on the rotor leads to colossal damage to the machine is discussed by G.D. Barinberg et al., [3]. Steam turbine blades suffer from different types of loadings which lead to different types of stresses, like tensile and bending stresses due to centrifugal force and steam flow loading. For designing long blades centrifugal force is one of the major problems and it is discussed by Subramanyam Pavuluri et al.,[4]. One way to tackle this is by using twisted blades or using blades of variable cross-section area and it is discussed very clearly by Arkhan Kh. Husain Al-Taie.et al.,[5]. Another way of tackling from this is by replacing blade material with Ti6Al 4V, since this material as excellent specific strength/density ratio as stated by Sergey Zherebtsov,et al.,[6] and B saha[9] papers. Advanced FEM techniques and various vibrational modal methods with a sealed points on turbine and also modal analysis is carried out by Kadambi, et al.,[8]. Steam turbine rotors are usually manufactured by CA6NM, it's an iron, chromium, nickel and molybdenum alloy and it is hardened easily by heat treatment process and various types of CA6NM materials are available which is clearly explained in Steel Casting Handbook [10]

Objectives: Combination of rotor and blades are analyzed in this present work, in which rotor is made up of CA6NM and blade is made up of titanium alloy. Modal analysis of the rotor and blade combination is carried out to check whether the system is stable or not at rotation velocity of 10 rad/sec, 28 rad/sec, 62 rad/sec and 91 rad/sec, Campbell diagram of rotor is carried out to check the critical speed of the rotor and blade combination.

2 FINITE ELEMENT APPROACH

2.1 Geometry of Blade and Rotor

The following figure 2(a) describes the meshed view of Ti 6Al 4V blade, here we can observe 10364 nodes, 5606 elements and it is been meshed using Ansys with solid 192 elements, volume of the blade is 1.723e+005 mm^3. Figure 2(b) describes the meshed view of CA6NM rotor, here we can observe 80354 nodes, 45541 elements and it is been meshed using Ansys with solid 192 elements, volume of the rotor is 1.041e+007 mm^3.



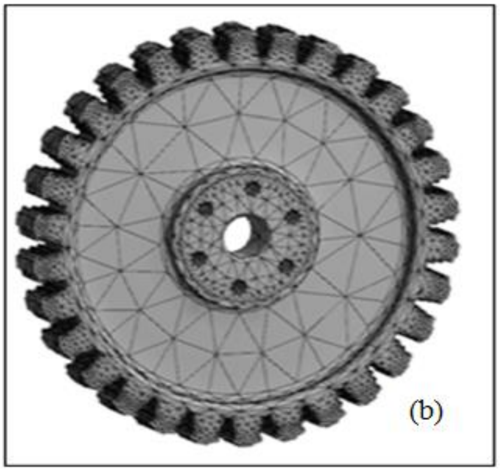


Fig. 2 Meshed view of steam turbine blade and rotor

TABLE I

PROPERTIES OF ROTOR (CA6NM) AND BLADE (TI64)

Particulars	Blade of Ti 64 alloy	Rotor of CA6NM material
Volume	1.723e+005 mm^3	1.041e+007 mm^3
Mass	0.796 kg	92.651 kg
Density	4191 kg/m^3	8073.9 kg/m^3
Young's Modulus	96 GPa	200 GPa
Poisson's Ratio	0.36	0.32
Bulk Modulus	114.29 GPa	185.19 GPa
Shear Modulus	35.294 GPa	75.758 GPa

3 RESULTS AND DISCUSSION

3.1 Analysis on combination of rotor and blade (CA6NM+Ti 64)

The figure 3 represents combination of rotor and blade, in which rotor is made up of CA6NM material and blade is made up of Ti64 alloy, mass of the rotor is 92.65kg and mass of the blade is 0.796 kg. Other properties of rotor and blade used for the present analysis are shown in table 1.

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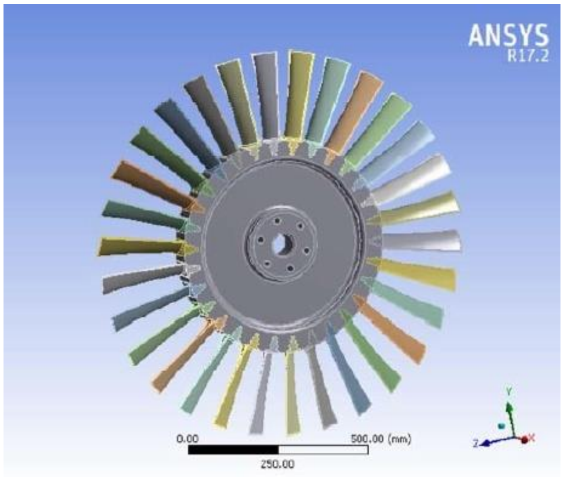


Fig. 3 A view of rotor and blade combination

Modal Analysis of rotor and blade combination

Rotating flexible structures like turbine blades are often idealized as rotating cantilever beams. Modal analysis is mainly a mathematical model to discretize the vibrational structure by using FEM [7]. The FE model was used to obtain the mode shapes and natural frequencies for the turbine blade and rotor in a stationary reference frame. The natural frequencies and obtained modes are given in the figure 4.

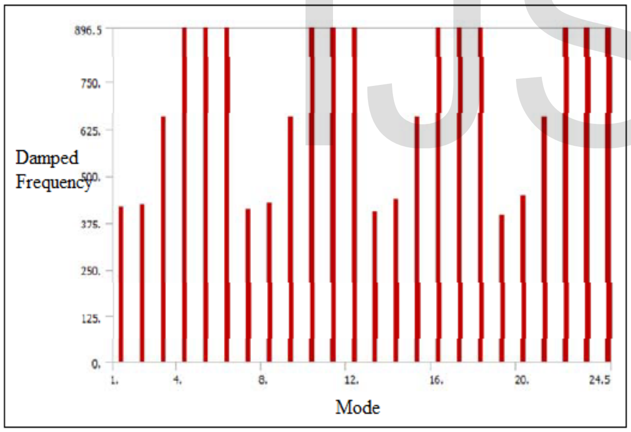
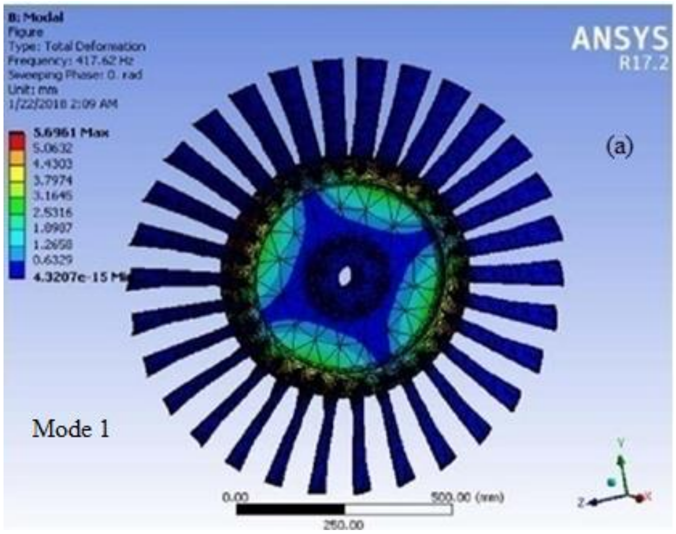
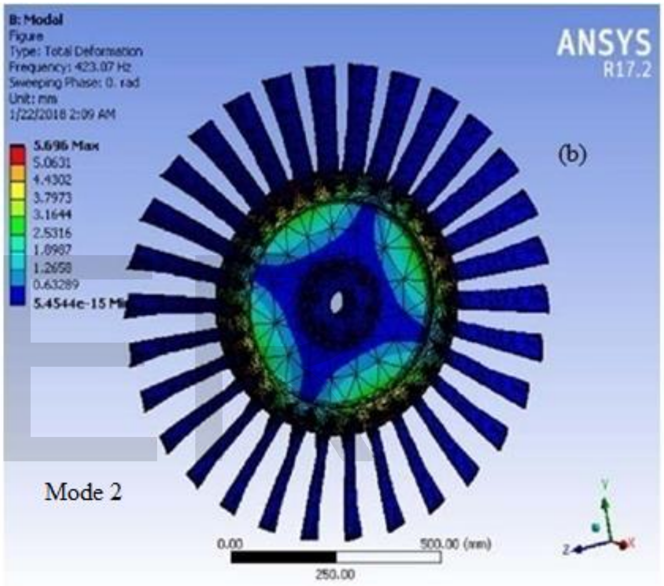
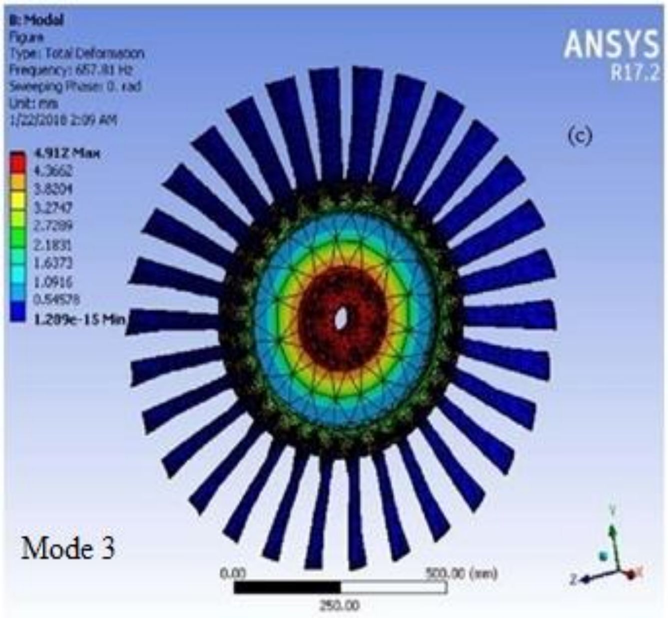


Fig. 4 Damped natural frequency v/s mode







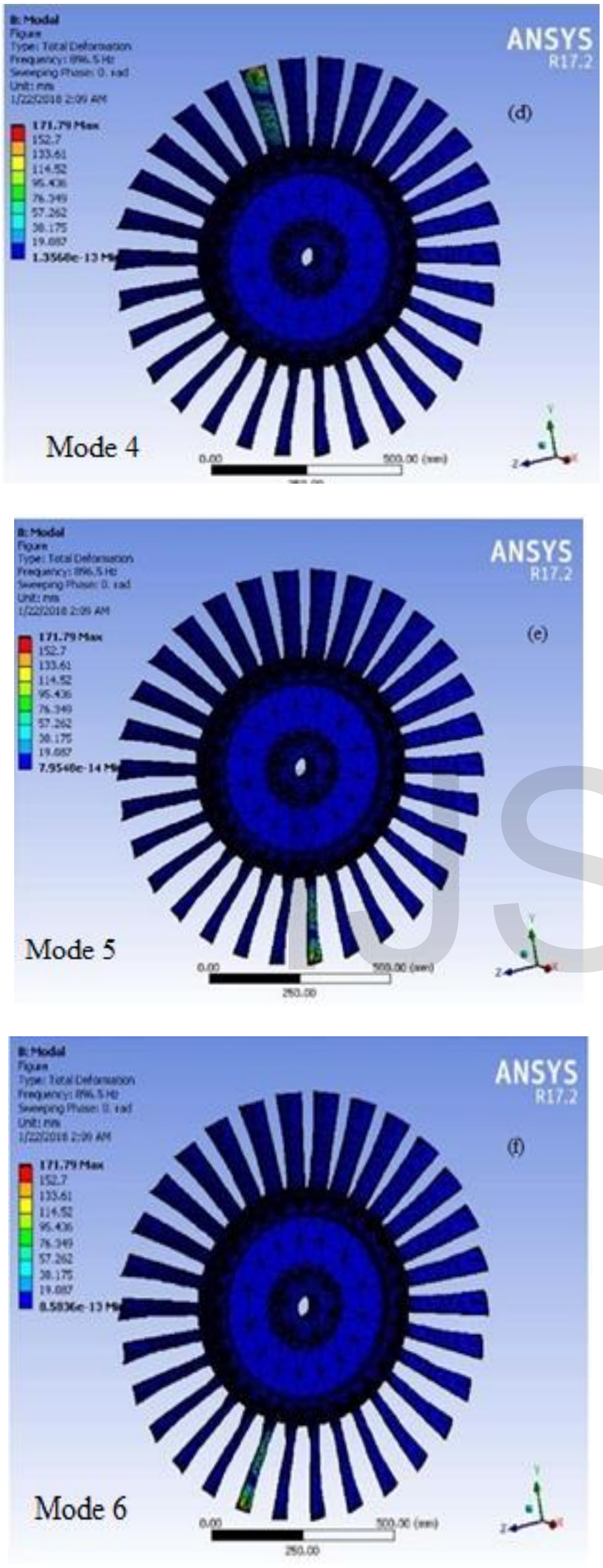


Fig. 5 Natural frequencies, Deformation at various mode shapes at operational speed of 91Hz

The above figures represents different mode shapes obtained from different frequencies. Fig 5(a) shows mode shape 1 of frequency 417.62 Hz and its minimum deformation is 4.32e-15mm and maximum deformation is 5.696mm. Fig 5(b) shows mode shape 2 of frequency 423.07 Hz and its minimum deformation is 5.45e-15mm and maximum deformation is 5.696mm. Fig 5(c) shows mode shape 3 of frequency 657Hz and its minimum deformation is 1.209e-15 mm and maximum deformation is 4.912mm. Fig 5(d) shows mode shape 4 of frequency 896Hz and its minimum deformation is 1.35e-13 and maximum deformation is 171.79mm. Fig 5(e) shows mode shape 5 of frequency 896 Hz and its minimum deformation is 7.95e-14 and maximum deformation is 171.79mm. Fig 5(f) shows mode shape 6 of frequency 896 Hz and its minimum deformation is 8.58e-13 and maximum deformation is 171.79mm.

3.2 Campbell Diagram

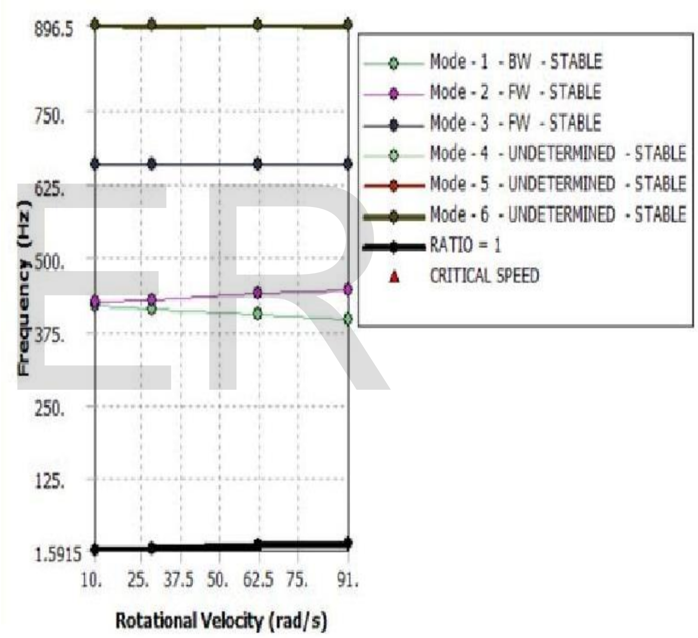


Fig. 6 Campbell diagram of rotor

TABLE 2

MODE STABILITY/ CRITICAL SPEED/ MODE V/S DIFFERENT

FREQUENCY

Mode	Whirl Direction	Mode Stability	Critical Speed	10. rad/s	28. rad/s	62. rad/s	91. rad/s
1.	BW	STABLE	NONE	417.62Hz	421.81 Hz	403.86 Hz	396.39 Hz
2.	FW	STABLE	NONE	423.07 Hz	428. Hz	437.48 Hz	445.72 Hz
3.	FW	STABLE	NONE	657.81 Hz	657.81 Hz	657.81 Hz	657.81 Hz
4.	UND	STABLE	NONE	896.5 Hz	896.5 Hz	896.5 Hz	896.5 Hz
5.	------	STABLE	NONE	896.5 Hz	896.5 Hz	896.5 Hz	896.5 Hz
6.	------	STABLE	NONE	896.5 Hz	896.5 Hz	896.5 Hz	896.5 Hz

In this present analysis Campbell diagram for combination of rotor and blade is carried out which is clearly shown in figure 6 with different rotational velocity of 10 rad/sec to 91 rad/sec. Table 2 shows the modal stability and critical speed of the rotor and blade combination in which it is clearly observed that system is stable at 91 rad/sec velocity and found no critical speed.

4 CONCLUSIONS

Present work consist of analysis on combination of rotor and blade, Six mode shapes are obtained for this combination from different frequencies, they are 417.62 Hz, 423.07 Hz, 657.81 Hz, 896.5 Hz, 896.5 Hz and 896.5 Hz. for all these natural frequencies respective mode shapes are obtained along with deformation in mm. Campbell diagram of rotor was obtained, for different mode and rotational velocity (10 rad/sec, 28 rad/sec, 62 rad/sec and 91 rad/sec) and in the analysis no critical speed found for both forward and backward rotation, so the turbine rotor is safe at running 5460 rpm of speed.

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