Material Optimization and Dynamic Approach for performance criteria in application to Gas Turbine Blade to overcome resonance

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Abstract – Gas turbine is the most important component producing mechanical power. In order to meet the present day power requirements, high speed turbine machines are used in the power plants. At higher speeds, the stability of the turbine blades is reduced and the resonance condition may occur. When natural frequency of the blade coincides with excitation frequency high amplitude vibrations occur resulting in blade failure. In the present research work Modal analysis of the turbine blade is performed using ANSYS V-14 to find the natural frequency and Campbell diagram is plotted from which resonance speeds can be found out.

Keywords* — *Natural frequency, Resonance, Campbell diagram, Turbine blade, Ansysv-14,ExcitationFrequency

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1. Introduction

Gas turbine blade design procedure gives some idea of interrelationships between thermodynamic, aerodynamic, mechanical, control system design and emphasizes the need for feedback among the various specialists. A gas turbine, utilizes combustible gas as its working fluid. When the working fluid acts on the turbine blades the turbine gets rotated and shaft work is produced, which is converted to electric power. During the operation of gas turbine, the turbine blades are subjected to high temperatures and stresses. Hence the selection of suitable blade material is essential for better performance of the turbine system.

Vibration induced blade fatigue is one of the greatest causes of failures in gas turbines, reported to be up to 42% of total gas turbine failures. Blade vibration in a rotor assembly is unavoidable and inherent in operation of any gas turbine engine. Therefore the blade design should cater for such excitation forces present, without which vibrations could be a cause of concern leading to blade failure.

In the present work we consider Nickel-Chromium Alloy, Titanium alloy and Stainless Steel as blade materials and analyse them.

1.1 Nickel-Chromium Alloy - is used both for its high strength and outstanding aqueous corrosion resistance. Its outstanding strength and toughness is due to the addition of niobium which acts with the molybdenum to stiffen the alloy’s matrix. This Nickel Chromium Alloy has low moisture sensitivity and low wear rate.

1.2 Titanium alloy - The high strength, low weight ratio and outstanding corrosion resistance inherent to titanium and its alloys has led to a wide and diversified range of successful applications which demand high levels of reliable performance in aerospace, automotive, chemical plant, power generation, oil and gas extraction, sports, and other major industries.

1.3 Stainless Steel - is a corrosion resistant steel alloy with a minimum of 10.5% chromium. There are different grades and surface finishes of stainless steel produced to accommodate the environment in which the material will be implemented. Unlike carbon steel, stainless steel does not rust when exposed to air and moisture due to the sufficient amount of chromium.

S.NO	Property	Stainless Steel	Titanium Alloy	Nickel Chromium Alloy
1	Density	7860	4540	8000
2	Youngs Modulus Gpa	200	120	150
3	Poisson Ratio	0.30	0.31	0.32
4	Melting Point Celcius	1450	1700	1300

Table 1 - Material Properties of the three materials considered

2. Literature Survey

Shraan [1], described the effect of blade thickness and blade length on the performance of turbine system. As the blade thickness reduces fatigue strength reduces which is not desirable. As the blade length reduces angular speed gets reduced, hence shorter blades are better. The

Lee chuang [2], proposed the techniques for mounting the blade on the hub, presently arc welding and forging are being used in the industry.

Ganeshan [3], examined the methods in which blade failure occurs. Fatigue, environmental attack, corrosion, sulphidation, creep, embrittlement and thermal aging are the main ones.

Thomas [4], worked up on the torsional vibration of turbine blades of unequal width and taper he concluded that by increasing the mode order, the vibration becomes concentrated towards the tip.

Aflobi [5], worked on the various blade profiles like tapered, circular, aerofoil and found out the turbine output using each of them. The advantages of twisted aerofoil profile is explained in the work.

Cranch [6], mentioned the advantages of Nickel alloy as blade material when compared with Titanium alloy. Titanium is costly and scarce, when used in hydrogen environment it causes embritttlement, also with titanium there is oxidation problem. Nickel alloy is easily available, no embrittlement problem, highly resistant to corrosion and oxidation.

Mohammad [7], studied on torsional stiffness of rotating members the ability of material to withstand loads during rotation is called torsional stiffness. The effect of blade geometry on the blade performance were discussed in the work.

Maroco Ferioli [8], formulated the interference diagram to predict the resonant behavior in rotating turbo machinery components. The natural frequency is plotted on y-axis and rotational speed is plotted on x-axis. The region where the natural frequency lines intersect the excitation frequency is the critical region.

Povishera [9], described the design optimization study of an under platform damper to mitigate high vibration problem of a gas turbine rotor blade under resonance condition. This damper model showed significant drop in blade amplitudes and increase in the fatigue strength oh the blade.

Gladicheva [10], depicted the use of ansys software for designing the turbine blade, the coordinate date for twisted aerofoil profile was taken from naca

3. Modelling & Analysis of Turbine blade

3.1 Problem Approach

In the present study a twisted aerofoil section of a turbine blade is chosen for frequency and rotational vibration analysis. The blade is of uniform configuration along its length. It is held fixed to one end and hangs freely at other end. The blade is solid and material properties are constant throughout the section. Blade is homogenous and isotropic. The data used for the blade geometry is given below,

Length	Top Width	Bottom Width	Thickness	Base Height
200 mm	60 mm	80 mm	5 mm	50 mm

Figure 1- Geometric model of the turbine blade

The blade geometry design process generally plays a significant role in the development and verification of a new gas turbine or aero engine. The turbine blade is designed with a twisted aerofoil profile. The twisted aerofoil profile helps in reducing the drag and provides better cooling to the blades. In the present work the modelling of gas turbine blade is done using CATIA V5 software. The Twisted aerofoil profile is created using specifications available in NACA.

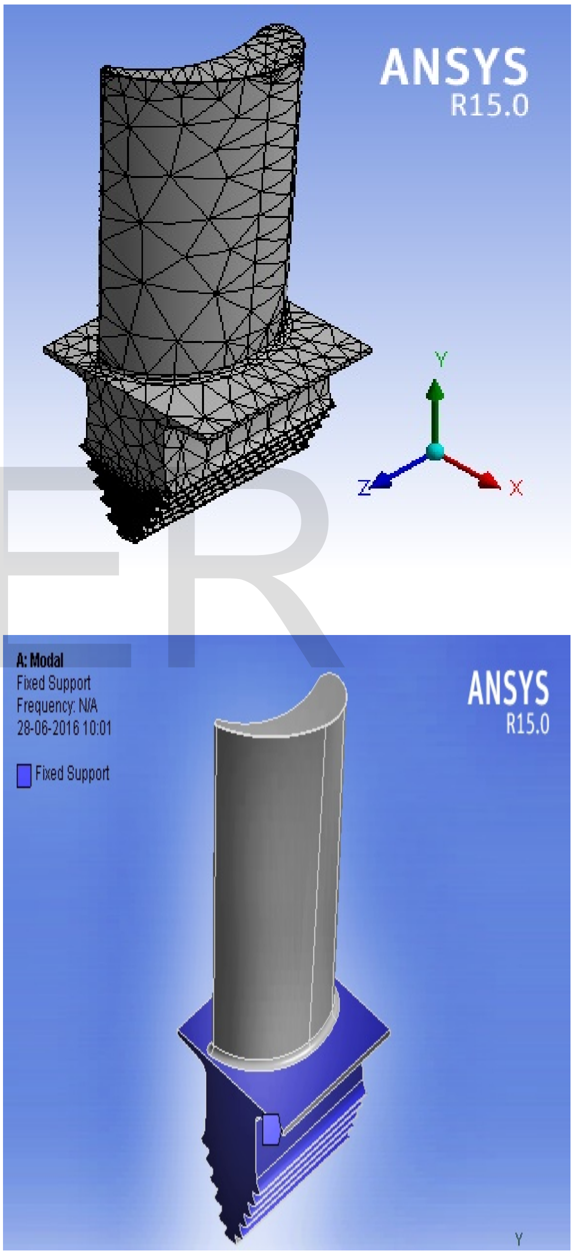


Figure 2–Meshed model of the turbine blade

The rotodynamic behaviour of the blade is analyzed using ANSYS V14 workbench. First we perform the meshing of the geometry where the model is divided into small elements. Next, we apply the boundary conditions, the turbine blades are fixed to the hub where the base part is inserted in to the groove provided in the hub. As the base part of the blade is fixed inside the hub all its degrees of freedom are constrained. Finally the model is solved and if all the settings are perfectly aligned without any errors the model gets solves successfully.

In the post processing stage, we can observe the natural frequencies and mode shapes for all the three materials namely Nickel-Chromium Alloy, Titanium Alloy and Steel alloy. The frequency values are obtained for different rotational speeds ie; 0Hz, 10Hz, 20Hz, 30Hz, 40Hz, 50Hz and the corresponding values are tabulated.

The Campbell diagram is plotted, with natural frequency on Y-axis and rotational speed on X-axis. The excitation frequencies are represented as straight lines in Campbell diagram. For example synchronous excitation 1x is represented as straight line with unit slope. The point where natural frequency line intersects the excitation frequency line is the critical point. At that point resonance occurs and the corresponding speed is taken as critical speed.

4. Results and Discussion

4.1 Mode shape of Nickel Chromium Alloy

The deformed mode shape of Nickel Chromium Alloy blade can be conceived in the post processor. On the top left corner the natural frequency value 1900 Hz is obtained. Similarly the frequency at different rotational speeds is found, the values are tabulated below.

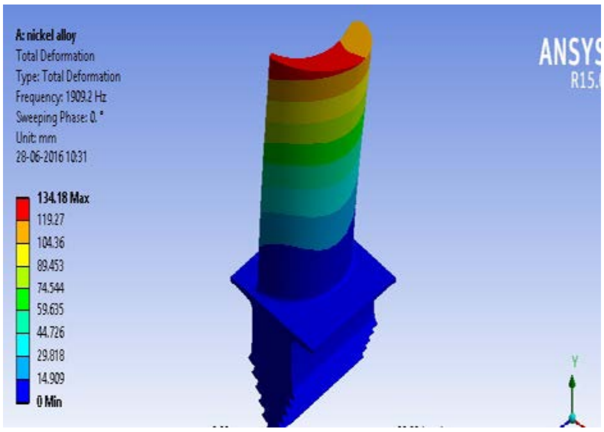
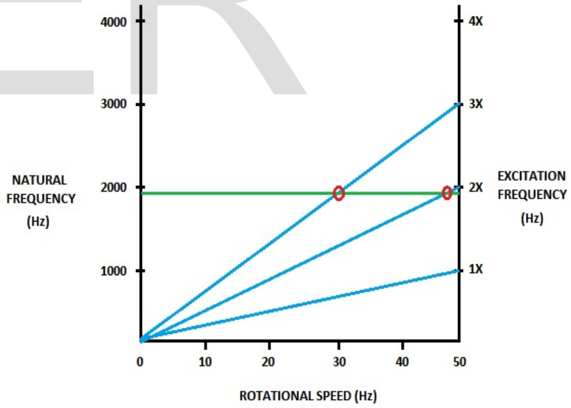


Figure 4.1- Mode shape of Nickel Chromium Alloy

Rotational speed (Hz)	Frequency (Hz)
0	1909
10	1910
20	1915
30	1918
40	1921
50	1924

Table 4.1 – Rotational Speed v/s Frequency

Now Campbell diagram is plotted, with natural frequency on Y-axis and rotational speed on X-axis. From the above natural frequency for each speed is obtained and as per those values the graph is plotted. The intersection of natural frequency with excitation frequency is indicated with the circle. The Critical speed values corresponding to the excitation frequencies are tabulated below.



Graph 4.1- Campbell diagram for Nickel –Chromium alloy

Excitation	Critical speed (Hz)	Critical speed (Rpm)
1x	-NO-	-NO-
2x	48	2880
3x	31	1860

Table 4.2 -Table showing Critical speed values

4.2 Mode shape of Titanium Alloy (Ti-6242)

The deformed mode shape of Titanium alloy blade can be viewed in the post processor. On the top left corner the natural frequency value 2127 Hz is obtained. Similarly the frequency at different speeds is found, the values are tabulated below.

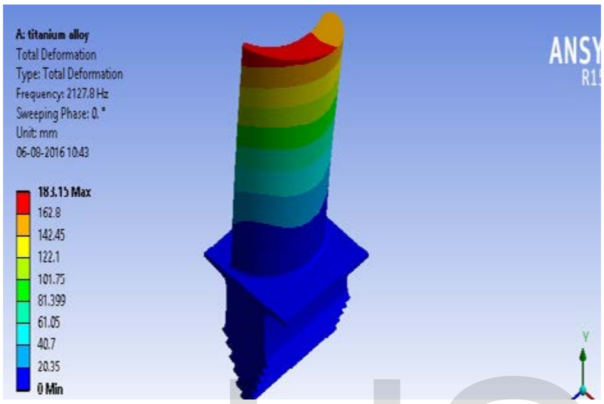
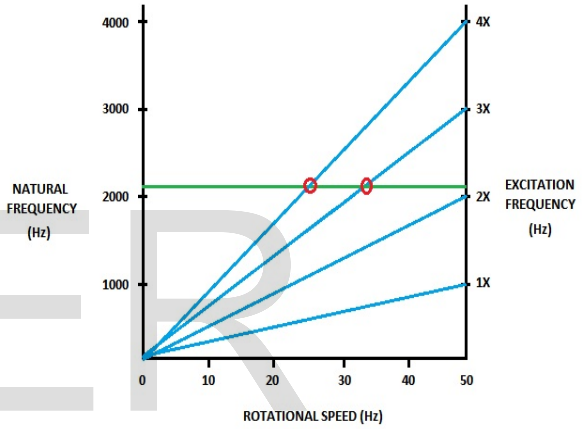


Figure 4.2- Mode shape of Titanium alloy blade.

Now Campbell diagram is plotted, with natural frequency on Y-axis and rotational speed on X-axis. From the above natural frequency for each speed is obtained and as per those values the graph is plotted. The intersection of natural frequency with excitation frequency is indicated with the circle. The Critical speed values corresponding to the excitation frequencies are tabulated below.

Rotational speed (Hz)	Frequency (Hz)
0	2127
10	2128
20	2129
30	2130
40	2134
50	2135

Table – Rotational Speed v/s Frequency



Graph 4.1- Campbell diagram for Titanium alloy .

Excitation	Critical speed (Hz)	Critical speed(Rpm)
2x	-NO-	-NO-
3x	33	1980
4x	24	1440

Table 4.1 -Table showing Critical speed values

4.3 For Stainless steel

The deformed mode shape of Stainless steel blade can be viewed in the post processor. On the top left corner the natural frequency value is also indicated. The Natural frequency obtained is 2127 Hz. Similarly the frequency at different speeds is found, the values are tabulated below.

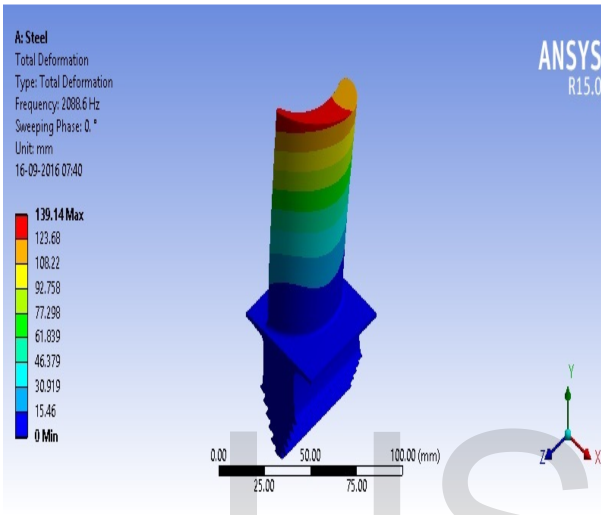
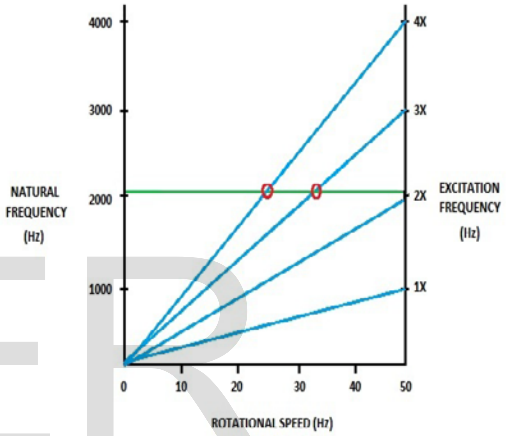


Figure 4.3 - Mode shape of Stainless Steel blade.

Now Campbell diagram is plotted, with natural frequency on Y-axis and rotational speed on X-axis. From the above table the value of natural frequency for each speed is obtained and as per those values the graph is plotted. The point where natural frequency line intersects the excitation frequency line is the critical point. At that point resonance occurs and the corresponding speed is taken as critical speed.

Rotational speed (Hz)	Frequency (Hz)
0	2127
10	2128
20	2129
30	2130
40	2132
50	2136

Table – Rotational Speed v/s Frequency



Graph 4.3 - Campbell diagram for Stainless Steel blade

Excitation	**Critical speed (Hz)**	**Critical speed(Rpm)**
2x	-NO-	-NO-
3x	31	1860
4x	23	1380

Table 4.3 -Table showing Critical speed values

5. Conclusion and Scope for Future Work

5.1 Conclusion

This research work has presented several results concerning the determination of natural frequency and critical speeds for three different blade materials. Following conclusion are drawn from the results.

1. For Optimum performance of the blade, value of aspect ratio (length/width) should be between 3 and 4.
2. Bottom base width should be greater than Top base width which is suitable for effective twisting.
3. Twisted aerofoil profile is considered for the turbine blade to minimize the drag force and improve the lift force.
4. Based on the operating conditions like high temperature withstanding capability, low moisture sensitivity, high toughness, corrosion resistance etc, when compared to other materials Nickel-Chromium Alloy gives best results.

5.2 Future Scope

Evaluating the performance measures to minimize drag and improve lift force for considerable blade geometry as well as blade material. Design Algorithms for calculating frequencies can also be developed.

REFERENCES

1. Shran, “Flutter and Resonant Vibration Characteristics of Engine Blades,” Journal of Engineering for Gas Turbines and Power, vol. 119, no. 4, pp. 742-775, 2015.

2. Lee chaung, “Recent Blade mounting Techniques,” Journal of Engineering for Gas Turbines and Power, vol. 89, no. 3, pp. 437-444, 2015.

3. Ganeshan, “Reasons of failures in aero engines and rotating machinery - An overview, International Journal of Pressure Vessels and Piping. vol. 87, no. 9, pp. 504-510, 2014.

4. Thomas, “Force Vibration Response of a Twisted Non-uniform Rotating Blade,” Computers & Structures, vol. 41, no. 2, pp. 207-212, 2013.

5. Aflobi, “Investigation of turbine blade failure in a thermal power plant," Case Studies in Engineering Failure Analysis., vol. 1, no. 3, pp. 192-199, 2013.

6. Cranch, “Study of gas turbine blade material”, International journal of Engineering Education and technology, Vol.2, No.3, Nov 2012.

7. Mohammed, “Vibration analysis of gas turbine blade”, International Journal of Advanced Research and Studies, Vol. 2, No.1, Dec 2012.

8. Morocco Ferioli, “Design and coupled field analysis of first stage gas turbine rotor blades”, International journal of Mathematics and Engineering, Vol 13, No.2, Jan 2011.

9. Povishera, “Modal analysis of t gas turbine blade using ansys”, International journal of Engineering Education and technology, Vol.2, No.3, Nov 2010.

10. Gladicheva, “The design and analysis of gas turbine blade”, International Journal of Advanced Research and Studies, Vol 2, No.1, Dec 2010.