Analysis of Critical Speed of Shaft With Rotor In Multi – Crack Conditions Using FEM

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Abstract- *The effective uses of a shaft are limited at its maximum operational junction frequency. The study was conducted by using the Finite element method. The shafts are used with flow of with rotation such as compresses, turbine and industrial applications. The major study was done on shaft by using different materials with different shaft profile of Solid and Hollow with two and Three Cracks. A natural frequency was analyzed and critical speed was predicted by using Campbell diagram and analysis was also performed for validation.*

In our analysis, ANSYS is used and the model is developed on CREO 5.0. In order to verify the present ANSYS model, the Natural frequency with their modes by using two types of materials are compared with the available experimental results present in the literature. And the design of shaft with solid and hollow with Two and three Cracks. In this study, the simulations of different profile shaft and two types of materials i.e. Gray cast iron, alloy 6061 and is analyzed for critical speed and natural frequency the configurations of shaft design are proposed.

The results show that solid shaft and material like Gray cast iron of shaft decreases the critical speed with increase in a RPM simultaneously. The natural frequency of shaft is compared by using two types of materials and is predicted that at solid and hollow with two and three cracks of shaft profile a alloy 6061 gives better frequencies in different modes.

Keywords- Critical Speed, Campbell Diagram, Rotor Dynamics

I. INTRODUCTION

A shaft could be a mechanical element that is employed for power transmission in cars and additionally utilized in industrial purpose like power homes, in turbines, compressors, shafts are used to transmit power from supply to system it is a rotating member. The mutual piston engine is composed crank shaft that is adjoined to convert reciprocatory movement into rotary movement with the help of connecting rod set up on a shaft for a number of electricity and torsion shaft has large used on various motive of power transmission and business programs. Shafts are horizontal individuals of rotating factors like generators, compressors and plenty of other rotating elements used for energy transmission, In case of mills kinetic energy of fluid is transformed into rotating movement with the help of turbine and power is transmitted to electric powered generator with the assist of shaft. In diesel locomotives diesel engine, compressor, traction generator are related with same shaft for electricity transmission as well as wheels of locomotives and bogies were additionally connected every different with solid shaft. In vehicles shaft transmits power from gearbox to differential the force shaft sooner or later transmits energy to wheels, so shaft has its major gain and application in transmission of energy on various applications.

II. CRITICAL SPEED EFFECTS

When the natural frequency of the system coincides with the external forcing frequency, it is called resonance. The speeds at which resonance occurs are known as the critical speed. These speeds are also termed as whirling speeds or whipping. At these speeds the amplitudes of vibration of rotor is excessively large and the large amount of force is transmitted to the foundations or bearing. In the region of critical speed the system may fail because of violent nature of vibrations in the transverse direction. Therefore, it is very important to find the natural frequency of the shaft to avoid the occurrence of critical speed which may result in excessive noise and its breakage into pieces. The critical speed may occur because of eccentric mounting of the rotor, non-uniform distribution of rotor material, bending of shaft.

Secondary Critical Speed

We have seen that main or primary speed occurring in horizontal shaft is because of centrifugal force due to unbalanced masses but besides this some amount of vibration is also observed at half the critical speed. This speed known as secondary critical speed.

Natural Frequency

When no external force acts on the system after giving it an initial displacement the body vibrates, these vibrations are called free vibration and their frequency as natural frequency. It is expressed in rad/s or Hz.

III. MATERIALS USED

- Most of shaft is formed from steel, either medium or low carbon. However, top Strength steel, typically heat treated, is additionally selected for powerful applications.
- Metals, like brass, stainless steel or aluminum are used where Corrosion may be a disadvantage or lightness is required.
- Small, light duty shafts, like in family appliances, is additionally injection shaped.
- In a plastic material for shaft are considered like nylon or carbon fiber reinforced plastics..

IV. APPLICATIONS

- Stainless steel shaft and structural steel shafts used as gear shaft and propeller shafts in automotive applications.
- Gray cast iron shafts shows stiffness in their nature and are also used in crankshafts to bear high amount of whipping load.
- Titanium alloy shafts are also used in automotive applications they are highly stiffness and opposes the property of elasticity this material shaft have various functions, there transmissions are used in differential gearbox, these shaft could be operated at variable power and torque transmission.

Objective of the Work

The main objective of the current work is

- Validation of the ANSYS models by comparing the present simulated results with the Experimental result by Hamid Khorrami et al.
- To predict natural frequency and critical speed effects for different shaft (solid and hollow with two and three cracks) on the shaft.
- To simulate the shaft of the different material having for variable modes and same RPM.
- Parameter sensitivity study of shaft.
- To define natural frequency effects and critical speed effects for the shaft of different diameter profile and different material and constant angular velocity of 25000 rpm.
- To predict frequency distribution along the shaft

Problem Formulation

The study of various literatures we find the natural frequency is lower as compared to present study. The purpose of this study is to predict critical speed and natural frequency with different material at constant angular velocity of 25000 rpm, thus to solve a problem of shaft with balanced support condition with multi crack conditions to improve the vibration characteristics at constant speed.

V. LITERATURE REVIEW

Hamid Khorrami(2017) **-** a rotor disc-bearing system with one and two cracks are analytically investigated using a modified harmonic balance method. The ana- lytical model is formulated considering rigid-short bearing supports to study the effects of cracks' characteristics such as depth, location and relative angular position on selected vibrational properties, namely, critical speeds, harmonic and super-harmonic components of the unbalance lateral response and the shaft center orbit. Each crack is initially de- scribed by a breathing function proposed by Mayes and Davies, which is subsequently modified as a softly-clipped cosine function to accurately describe saturation in breath- ing phenomenon

Dumitru et al. (2009) **-** The investigation had been done on this paper is that of building up a machine method of the Campbell outline of rotors. These papers influence bowing inside the field of mono-rotors, proportionate to in compressors and turbines. The presentation is contemplations the work of the Campbell outline and highlights some particular instances of its utilization.

Elsevier Huichun peng et al. **-** proposed that the damping results with the distinction of stationary damping and the anisotropic rotating damping at the dynamic stability of the rotating rotor with an open crack on the surface of the shaft is studied. The motion equations of the cracked rotor system are fashioned by using Lagranges primary. Different from previous studies, the anisotropic system with the multi periodical numerous coefficients is simplified by using the shifting frame approach such that the stableness evaluation based on the foundation locus technique can be applied

R. Tamrakar et al. **-**] proposed that the, vibrational response of a cracked rotor in static and rotating circumstance through Campbell diagram. An open crack in the rotor adjustments its stiffness. The effect of that's visible on the herbal frequency of the system. The natural frequency of the cracked rotor will increase in contrast to un-cracked rotor. Experimental and simulation work is achieved in the static condition to examine the herbal frequency of the rotor. Campbell diagram is generated via Simulation in ANSYS to study the crucial pace version at the start (I) and second (II) Engine order (EO) line for cracked and un-cracked rotor

Zhiwei Huang et al. - presented that the Rub-impact and fatigue crack are vital rotor faults. Based on the crack idea, an progressed switching crack model is supplied. Dynamic traits of a rotor-bearing system with imbalance, rub-impact and transverse crack are tried. Various nonlinear dynamic phenomena are analyzed using numerical technique. The outcomes screen that volatile shape of the rotor device with coupling faults is extremely complex as the rotating velocity increases and there are a few low frequencies with massive amplitude.

Anuj Kumar Jain et al - In this proposed article, the dynamic behavior and diagnostic of cracked rotor have been gained momentum. In literature, numerous studies are to be had for cracked rotor structures, but only a few authors have addressed the issue of multi-cracked rotor gadget.

M. Serier et al :- proposed that the design of test method is used to analyze and provide an explanation for the results of the rotor parameters on crack respiration and propagation in the shaft. Three elements are considered that have an influence on the behaviour and the propagation of the crack: the rotational velocity, the length of the rotor and the diameter of the shaft.

Raghava M. Et al. - proposed the overall rotating machines have extensive programs in structures, vegetation, cars, and industries. Every rotating device uses shaft as strength reworking unit. It could be very risky to operate the gadget with the presence of crack within the shaft. The growth of the crack is risky to perform and can result in catastrophic failure. It is to be detected at in advance ranges. In this paper relation among vibration amplitude and on the crack depth changed into evolved, this allows in decide the depth of the crack by means of measuring the vibration amplitudes.

Guangming Dong et al. - proposed that the A finite detail model is used for flexural vibration analysis of a static (non-rotating) rotor with open cracks; the stiffness matrices of the cracked elements are acquired using switch matrix analysis and local flexibility theorem. Through numerical simulation, the outcomes of the slenderness ratio and the crack depth at the mode shapes and the changes in the eigen frequencies of the cracked rotor are investigated; the variations of the adjustments in eigen frequencies with crack area are studied; and the ratios of the modifications inside the first two eigen frequencies are mentioned for rotors with cracks

VI. MODELING AND ANALYSIS

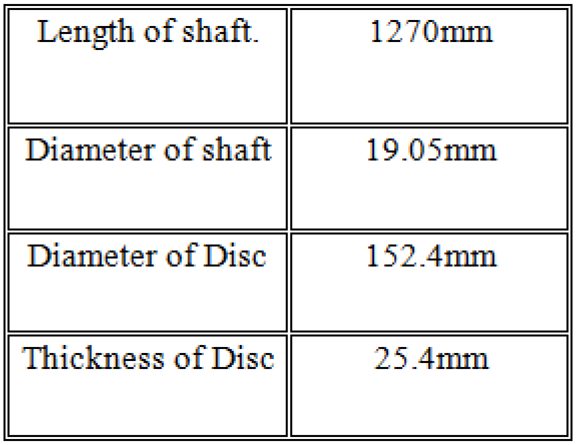
The procedure for solving the problem is:

Create the geometry.
Mesh the domain.
Set the material properties and boundary conditions.
Obtaining the solution
Finite Element Analysis of Steel Shaft
Analysis Type- Modal analysis

Preprocessing

Preprocessing include CAD model, meshing and defining boundary conditions.

Table :5.1 Dimension of Shaft.



Length of shaft.	1270mm
Diameter of shaft	19.05mm
Diameter of Disc	152.4mm
Thickness of Disc	25.4mm

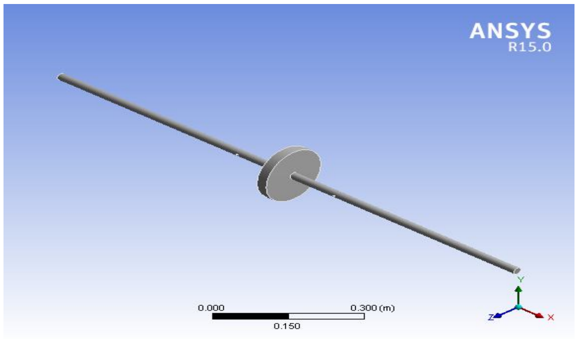


Figure: 5.1 Model of Solid shaft with Two Crack

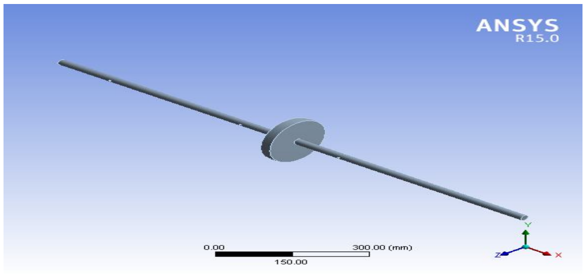


Figure 5.2 Mode of Solid Shaft with Three Crack

VII. RESULT AND DISCUSSION

7.1 Critical Speed Frequency and Stiffness along the Shaft with Different Materials

A Modal - analysis was carried out to analyze critical speed of shaft with different material by using Campbell diagram and relation between natural frequencies and spin speed and two types of materials of Alloy 6061 and Gray cast iron with different types of shaft model to determine the frequency distribution along the Shaft of the different types of shaft. Frequency distribution contours in case of different diameter for the two different profiles are shown in Figure, and the effect of different shaft profiles on the frequency and modes distribution for various different diameter and materials are represented in the Figure.

7.2 Analysis of Solid Shaft with two Crack and Different Materials

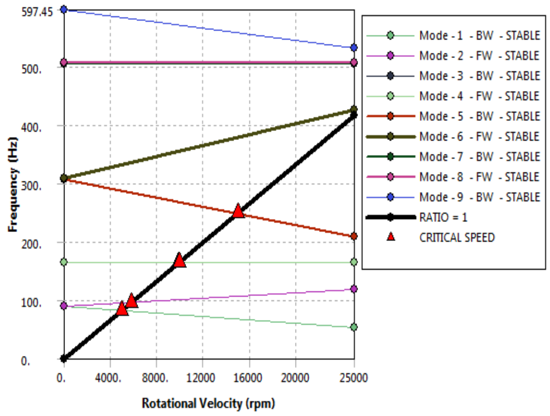


Figure No.:7.1 Result of Campbell diagram of frequency and rotational velocity distributions along the Alloy6061solid shaft with two Cracks

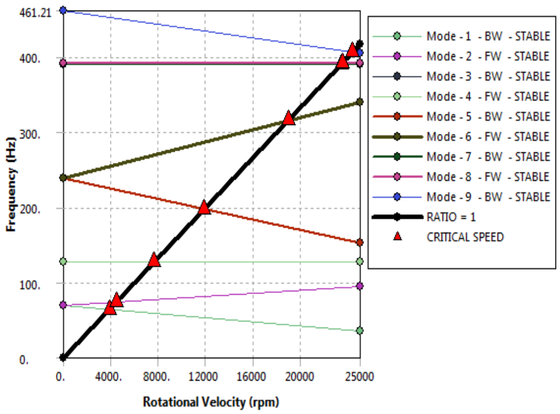


Figure No.:7.2 Result of Campbell diagram of frequency and rotational velocity distributions along the Gray Cast Iron Solid Shaft with Two Cracks

Table No.: 7.1 Critical Speed of Solid Shaft with two Cracks

Critical Speed		
Modes	Alloy 6061	Gray Cast Iron
1(BW)	4966.3	3859
2(FW)	5794.8	4447.8
3(BW)	9877.1	7628.7
4 (FW)	9902.8	7648.6
5(BW)	14958	11853

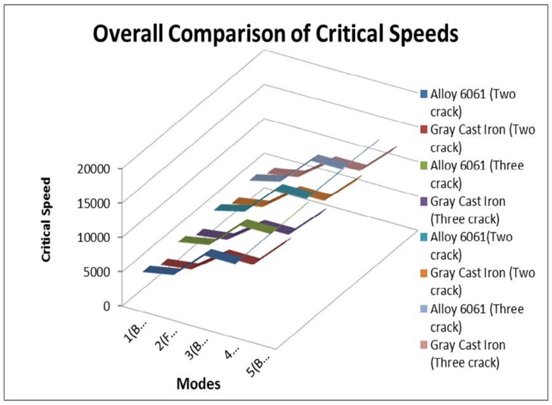
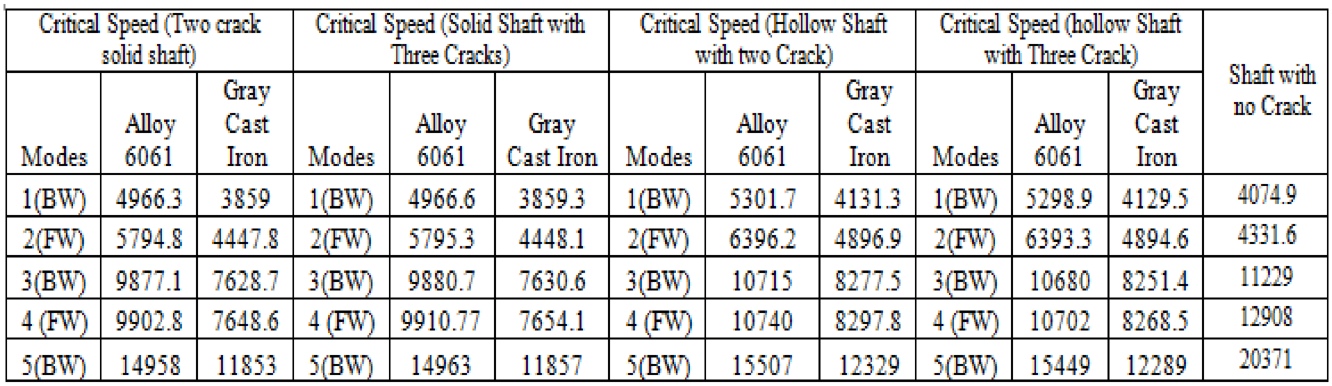


Figure No.: 7.3 Graph shows Overall Comparison of Critical Speeds

7.3 Contour Plots of Natural Frequency with their Different Modes and different materials of Solid Shaft with two Cracks

The deformations of shaft shown in contour plots are w.r.t. frequency at constant angular velocity of 25000rpm these deformation changes as per modes of frequency that at particular section the value of frequency is high and low, this frequency is damped natural frequency of shaft at synchronous speed which occurs due to mass imbalance also the modal damping ratio was considered, it is a ratio of damping constant to the damped natural frequency from below contour plots the values obtained are compared in graphs and was predicted that in every material damped natural frequency increases, Hence modal damping ratio decreases from this effect logarithmic decrement increases that means decrease in amplitudes.

Variable colored contours of shafts represents a deformation of a rotating element with respect to its natural frequency blue color on contours represents a minimum effect of frequency, Green color represents that a frequency is more than blue color, Red color represents that a frequency is maximum at a particular that section of a rotating element



Critical Speed (Two crack solid shaft)			Critical Speed (Solid Shaft with Three Cracks)			Critical Speed (Hollow Shaft with two Crack)			Critical Speed (hollow Shaft with Three Crack)			Shaft with no Crack
Modes	Alloy 6061	Gray Cast Iron	Modes	Alloy 6061	Gray Cast Iron	Modes	Alloy 6061	Gray Cast Iron	Modes	Alloy 6061	Gray Cast Iron	
1(BW)	4966.3	3859	1(BW)	4966.6	3859.3	1(BW)	5301.7	4131.3	1(BW)	5298.9	4129.5	4074.9
2(FW)	5794.8	4447.8	2(FW)	5795.3	4448.1	2(FW)	6396.2	4896.9	2(FW)	6393.3	4894.6	4331.6
3(BW)	9877.1	7628.7	3(BW)	9880.7	7630.6	3(BW)	10715	8277.5	3(BW)	10680	8251.4	11229
4 (FW)	9902.8	7648.6	4 (FW)	9910.77	7654.1	4 (FW)	10740	8297.8	4 (FW)	10702	8268.5	12908
5(BW)	14958	11853	5(BW)	14963	11857	5(BW)	15507	12329	5(BW)	15449	12289	20371

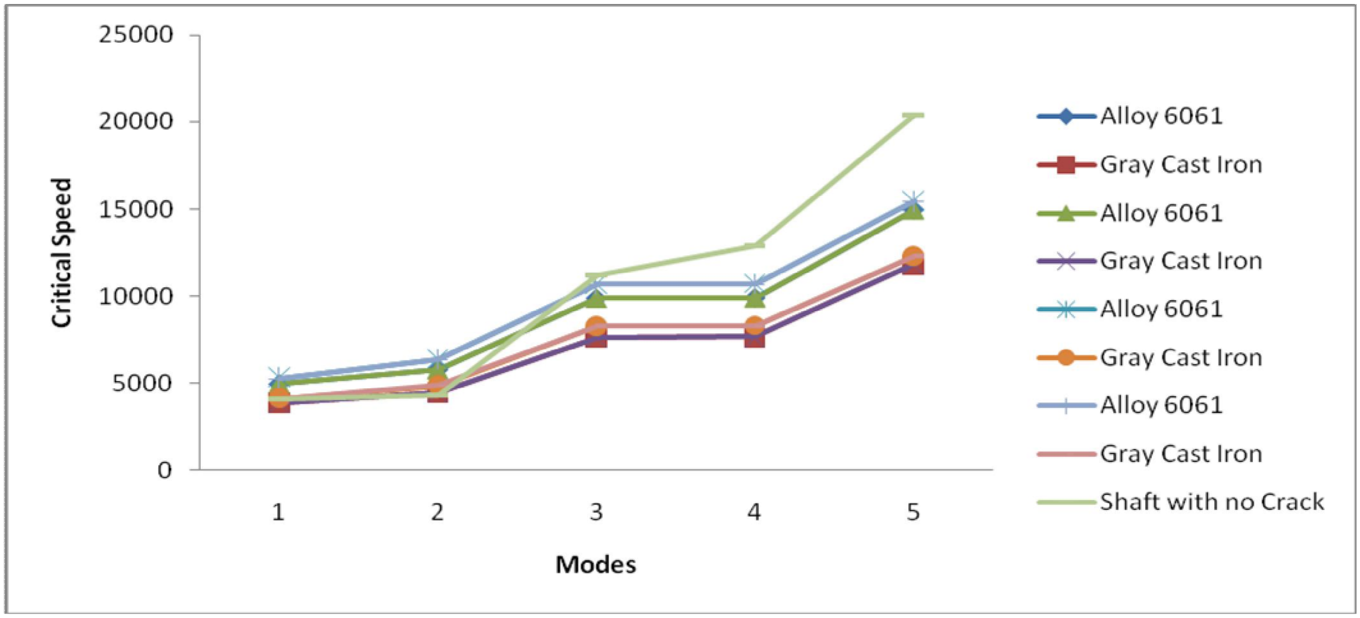


Fig – overall comparison of cracked shaft with non cracked plane shaft.

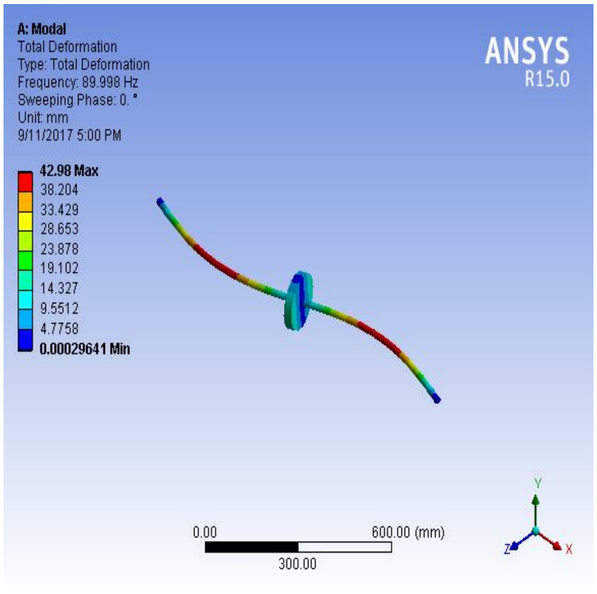


Figure:7.4 First modes frequency of alloy 6061 shaft

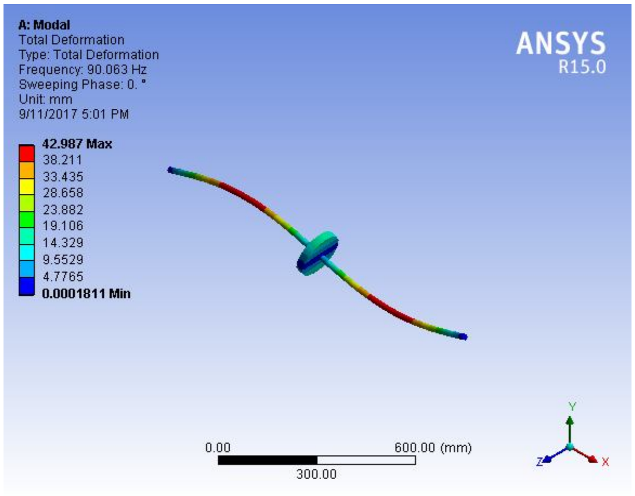


Figure: 7.5 Second mode frequency of alloy 6061 shaft

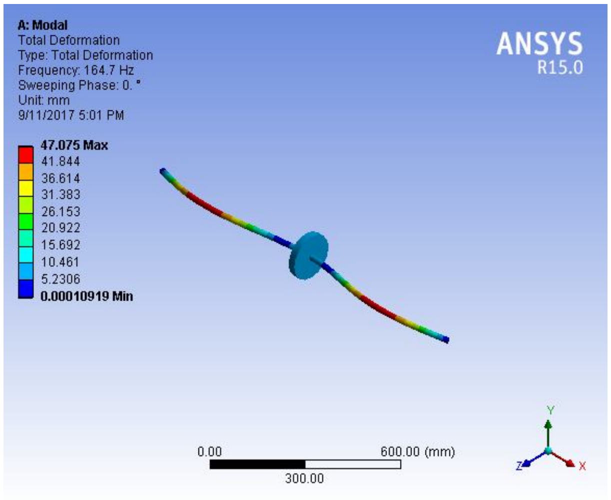


Figure: 7.6Third mode frequency of alloy 6061 shaft

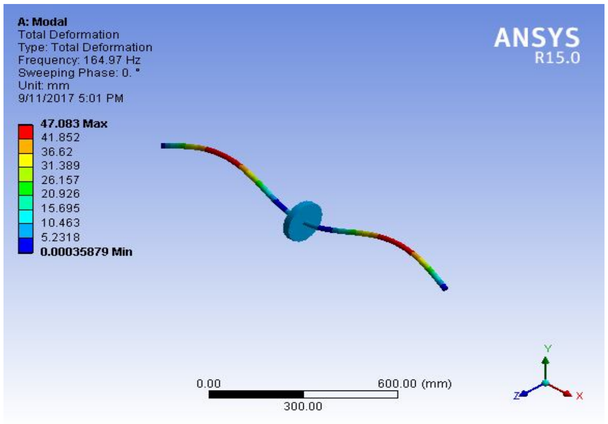


Figure: 7.7 Forth mode frequency of alloy 6061 shaft

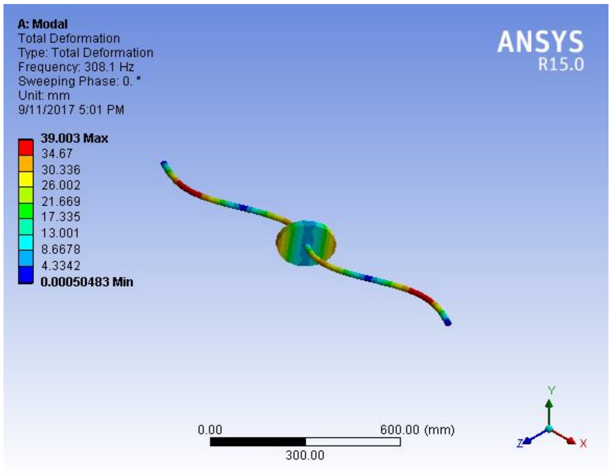
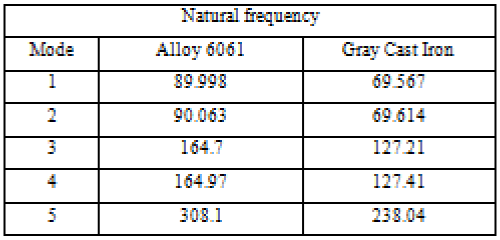


Figure: 7.8 Fifth mode frequency of alloy 6061 shaft

Table No.: 7.2Natural frequency of solid shaft with two Cracks.



Natural frequency		
Mode	Alloy 6061	Gray Cast Iron
1	89.998	69.567
2	90.063	69.614
3	164.7	127.21
4	164.97	127.41
5	308.1	238.04

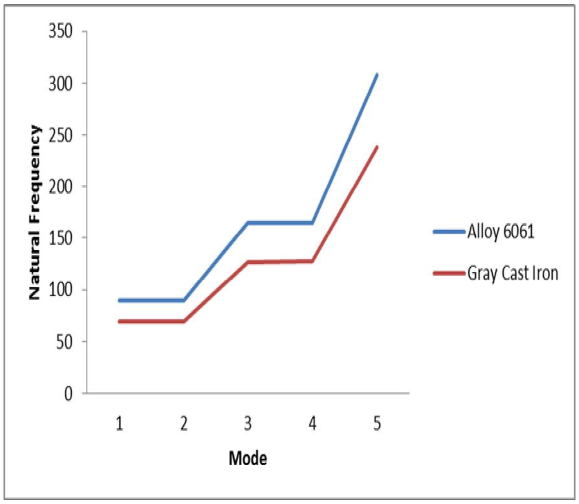


Figure No.: 7.9 Graph shows modes and frequency of a solid shaft with two Cracks

Table No.: 7.3 Natural frequency of solid shaft with three Cracks.

	Natural frequency	
Mode	Alloy 6061	Gray Cast Iron
1	90.012	69.577
2	90.058	69.611
3	164.75	127.24
4	165.11	127.51
5	308.2	238.1

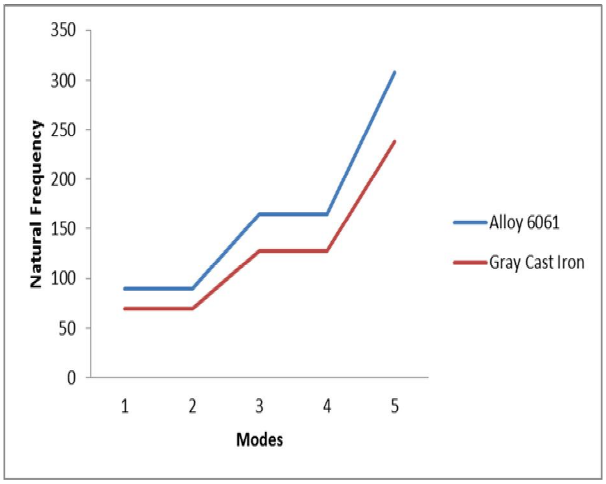


Figure No.: 7.10 Graph shows modes and frequency of a solid shaft with three Cracks

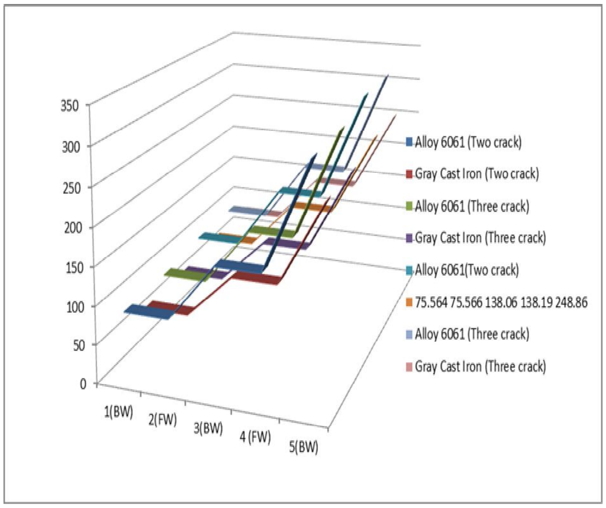


Figure No.: 7.11 Graph shows Overall Comparison of Natural Frequency

VIII. CONCLUSION

The current analysis has presented a study of natural frequency characteristics of a shaft of different profiles. Modal analysis was carried out on alloy 6061 and ray cast iron material. The effect of diameter with different profiles of the Shaft with two cracks and three cracks on the natural frequency and modes of different materials and critical speed effects were analyzed on different profile and materials of shaft and distribution along the shaft was studied. From the analysis of the results, following conclusions can be drawn.

8.1 Influence of different shaft profiles

- The natural frequency along the shaft profile is found to be maximum of the alloy 6061 material profile with hollow shaft with two cracks and varies along the length up to the shaft for all the two profiles. The critical speed distribution along the shaft is maximum for alloy 6061 and minimum for gray cast iron of a shaft with different profiles.
- The magnitude of frequency is minimum in the case of gray cast iron material profile with shaft with two cracks. The nature of the natural frequency is maximum near its end in 3rd and 4th, 5th mode.
- The nature of the critical speed is maximum near its masses and between the end of the shaft where masses are placed of shaft and changes with respect to shaft material with different profile towards the end and between masses of the shaft for the same 25000RPM and different modes of natural frequency.
- In a comparison with the gray cast iron and alloy 6061 material resulted in higher frequency characteristics close to the end of the shaft for a different shaft profile. The critical speeds are maximum for alloy 6061 at high

frequency and minimum for gray cast iron at less frequency on same RPM

8.2 Future Scope

- Different materials can be used for analyzing frequency and critical speed for different types of shaft.
- Different masses could be also analyzed for different RPM to predict critical speed for shaft for save design.
- Stiffness of bearing should be changed and also with damping coefficient for study of shaft system on Campbell diagram.

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