TO STUDY AND ANALYSIS, THE EFFECT OF NOTCH GEOMETRY ON THE CRITICAL SPEED OF STRUCTURAL STEEL SHAFT

Ravi Kumar[1], **Aditya Litoria**[2]
[1, 2] Department of Mechanical Engineering,
[1, 2] Oriental Institute of Science and Technology, Bhopal

Abstract —The research was carried out using the finite element method. We create the model and analysis it for ANSYS 19.2 as well. The analysis shows that when the RPM increases, the critical speed is simultaneously lowered by a solid shaft and materials such as structural steel of the shaft. To compare the natural frequency of the shaft, three different notch angles 45°, 60°, 80° are used. According to projections, 60° notch angle shaft will provide higher frequencies in different modes for solid shaft profiles. 60° notch angle shows higher convergence in the stability of a rotor dynamics system as a result. As We have considered three different notch angle 45°, 60°, 80°, the gyroscopic effect is effect at 45° and 80° of notch angle this is due to the approach of these notch angles affects the frequency as indeterminant effect occurs at axial distance of shaft but this effect is minimized at 60° of notch angle. We found the best results with the structural steel material as it has a lower critical speed and higher natural frequency than alloy 6061 at all different notch angles.

Keywords— Critical speed, Campbell diagram, notch angle effect, Gyroscopic effect, Single mass, Natural frequency.

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 uneven distribution of hundreds in the rotor creates whirl phenomenon which receives terrific at the essential speeds and creates immoderate threat to the bearings. The gyroscopic effects arise from the presence of rotating masses hooked up at the rotor and their orientation with admire to the bearing centre line. This, together with the bearing support situations continuously reasons forward and backward whirl phenomenon inside the rotor and induces fatigue loading in the bearings. Throughout rotation, the components go through continuous precession due to coriolis force and subsequently set off gyroscopic impact. The effect produces moments on the rotor which leads to backward whirling and ahead whirling of the rotor. The results in turn on the bearings are fatigue loadings.

A. 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.

B. 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.

C. Analytical model of a continuous shaft with two breathing cracks

The governing equation of lateral motion of a continuous rotating shaft with a disc located at the mid-span

$$EI\frac{\partial^4 u}{\partial x^4} - \left(\frac{EI\rho}{kG} + \rho A r_0^2\right)\frac{\partial^4 u}{\partial x^2 \partial t^2} + 2i\rho A r_0^2 \Omega \frac{\partial^2 u}{\partial^2 x \partial t} + \frac{\rho^2 A r_0^2}{kG}\frac{\partial^4 u}{\partial t^4} - 2i\frac{\rho^2 A r_0^2 \Omega}{kG}\frac{\partial^3 u}{\partial t^3} + \rho A\frac{\partial^2 u}{\partial t^2} = 0$$

D. Crack modeling

$$C = \begin{bmatrix} c_{yy} & c_{yz} \\ c_{zy} & c_{zz} \end{bmatrix}$$

$$f(t) = \frac{1 - cos(\Omega t + \chi_r)}{2}$$
$$\chi_r = |\Phi_r - \Phi_1|, \ \ r = 1, 2$$

$$f(t) = \frac{1}{2} - \frac{1}{4}(e^{i(\Omega t + \chi_r)} + e^{-i(\Omega t + \chi_r)})$$

II. MODELING OF PRESENT CONTINUA

A. The procedure for solving the problem

- 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

Table 1: Dimension of Shaft.

Length of shaft.	1000 mm
Diameter of shaft	19.05 mm
Diameter of Disc	134.4 mm
Thickness of Disc	25.4 mm

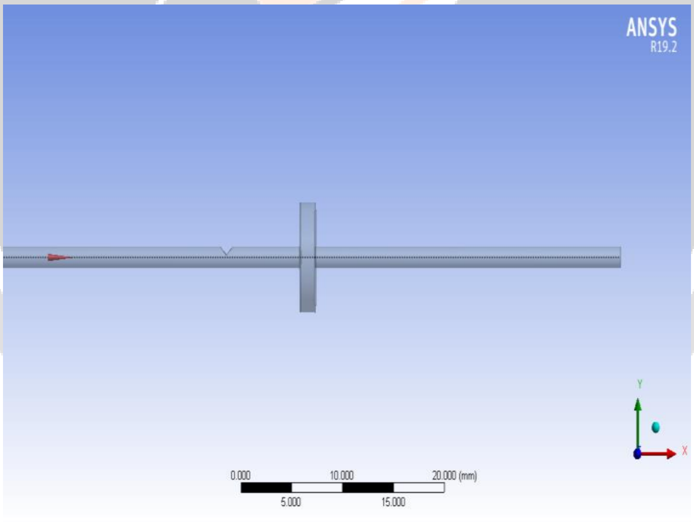

Figure 1: *Model of Solid shaft with 45^0*

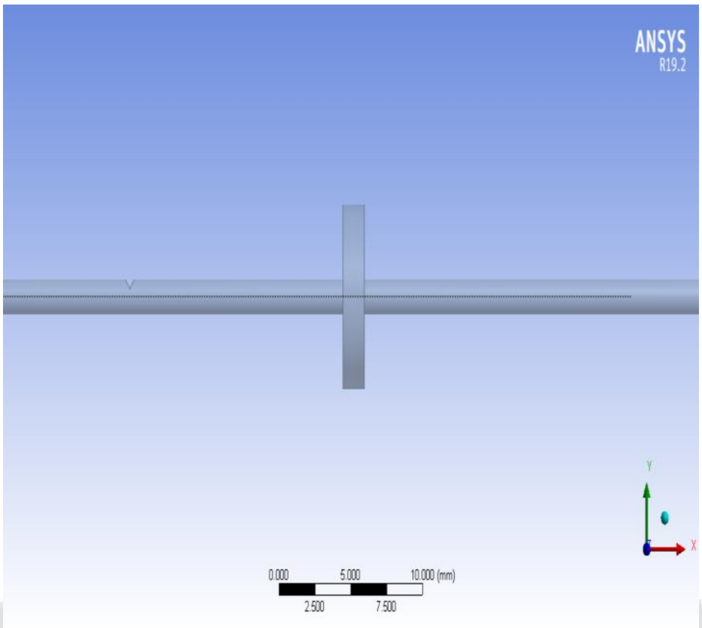

Figure 2: *Model of Solid shaft with 60^{0}*

III. RESULT AND DISCUSSION

Analysis of Solid Shaft with two Crack and Different Materials

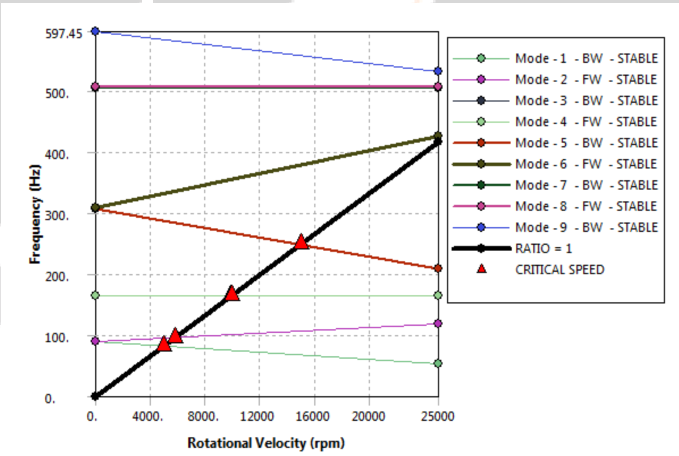

Figure No.3: *Result of Campbell diagram of frequency and rotational velocity distributions along the Structural Steel shaft with 45^{0}*

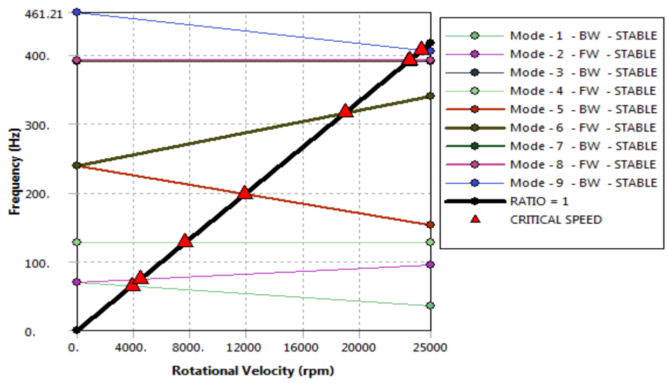

Figure No.4: *Result of Campbell diagram of frequency and rotational velocity distributions along the Structural Steel shaft with 60^0*

Table No.2: *Critical Speed of Solid Shaft with different Notch Angles*

Critical Speed of Solid Shaft with different Notch Angles			
Modes	**45^0**	**60^0**	**80^0**
1(BW)	4371.3	3859	4957.7
2(FW)	5527	4447.8	5784.3
3(BW)	8977.1	7628.7	9855.6
4 (FW)	9502.8	7648.6	9880.6
5(BW)	12958	11853	14927

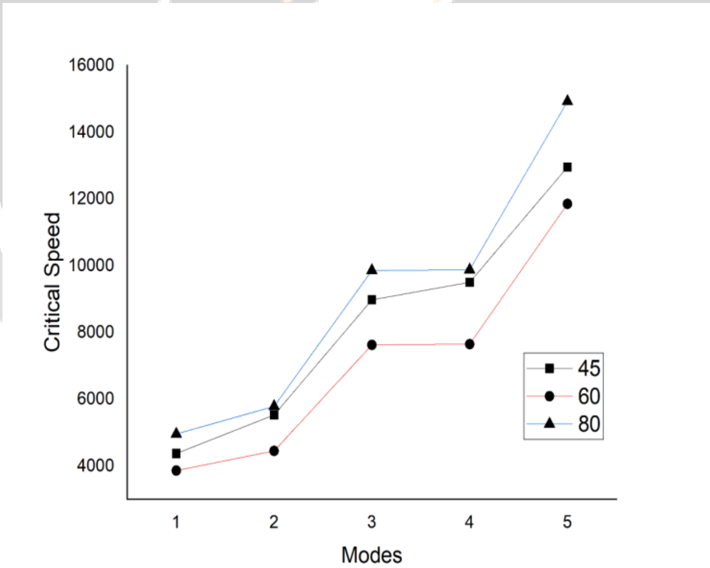

Figure No.5: *Graph shows comparison of critical speed of solid shaft with different Notch Angle*

Natural frequency of solid shaft with Different Notch Angle

Natural frequency of shaft with different Notch Angle			
Mode	**45^0**	**60^0**	**80^0**
1	83.333	89.998	69.567
2	78.997	90.063	69.614
3	153.88	164.7	127.21

4	154.34	164.97	127.41
5	280.3	308.1	238.04

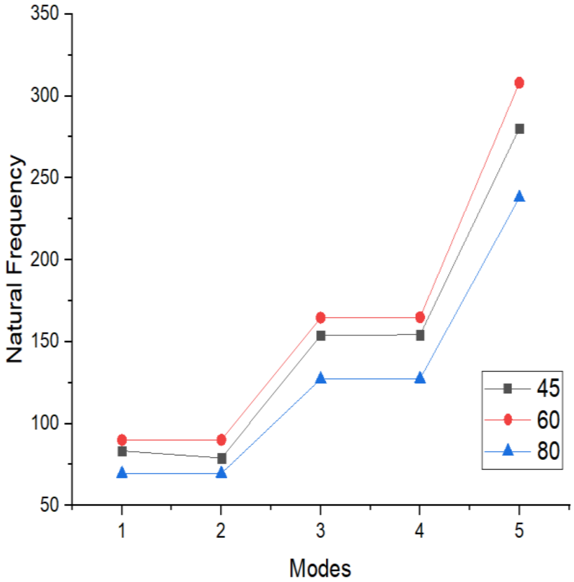

Figure No.6: *Graph shows modes and frequency of a solid shaft with different Notch Angle*

Critical Speed of Solid Shaft with different Notch Angles

Critical Speed of Solid Shaft with different Notch Angles			
Modes	**45^0**	**60^0**	**80^0**
1(BW)	4421	4067	5147
2(FW)	5607	4729	5837
3(BW)	9054	7791	10134
4 (FW)	10421	8346	11764
5(BW)	13769	12745	13912

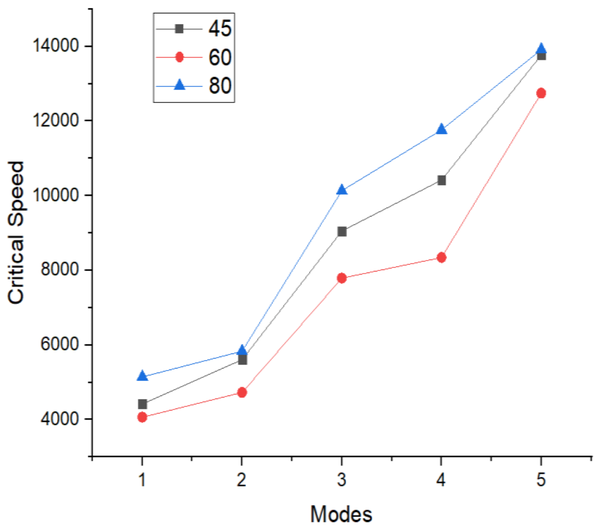

Figure No.7: *Graph shows comparison of critical speed of solid shaft with different Notch Angle*

Natural frequency of alloy 6061 shaft with Different Notch Angle.

Natural frequency of Alloy 6061 shaft with different Notch Angle			
Mode	**45^0**	**60^0**	**80^0**
1	63.24	82.66	78.11
2	74.54	94.51	86.42
3	94.78	124.65	106.34
4	148.36	180.25	164.82
5	190.28	220.31	207.49

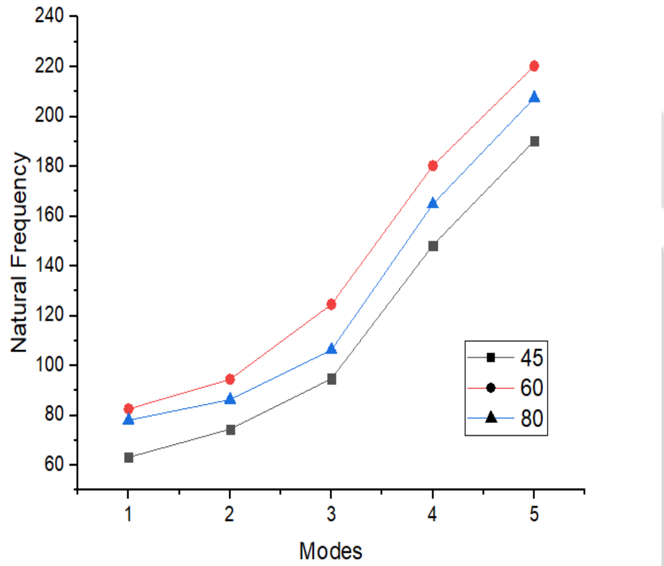

Figure No.8: Graph shows comparison of critical speed of two different materials.

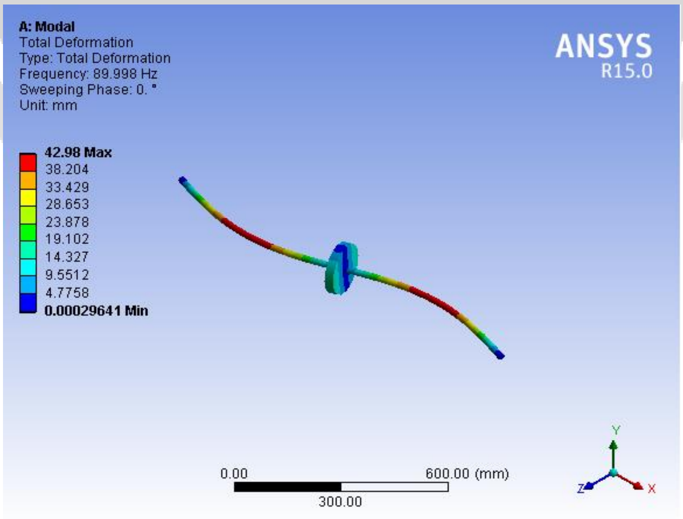

Figure 9: First modes frequency of alloy 6061 shaft

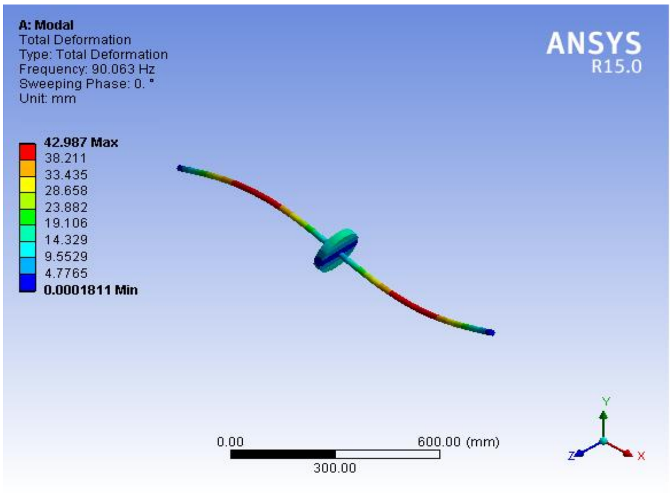

Figure 10: Second mode frequency of alloy 6061 shaft

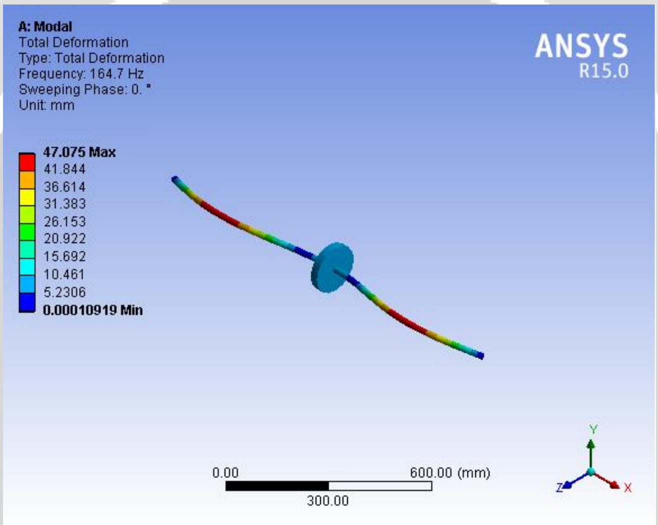

Figure 11: Third mode frequency of alloy 6061 shaft

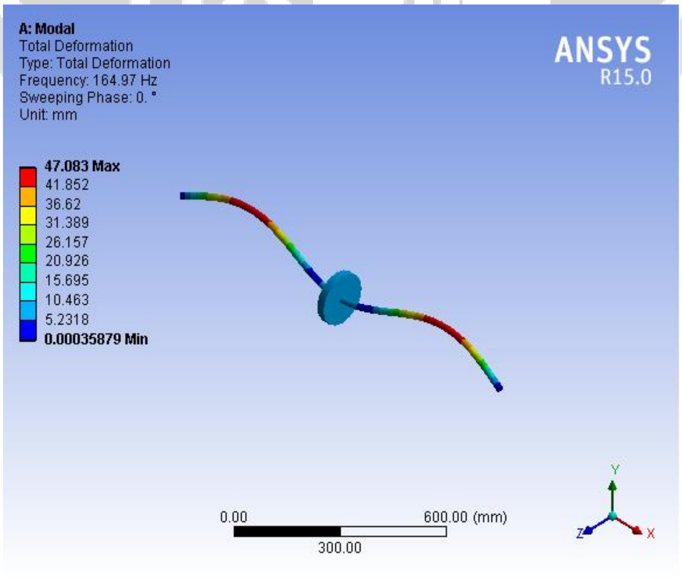

Figure 12: Forth mode frequency of alloy 6061 shaft

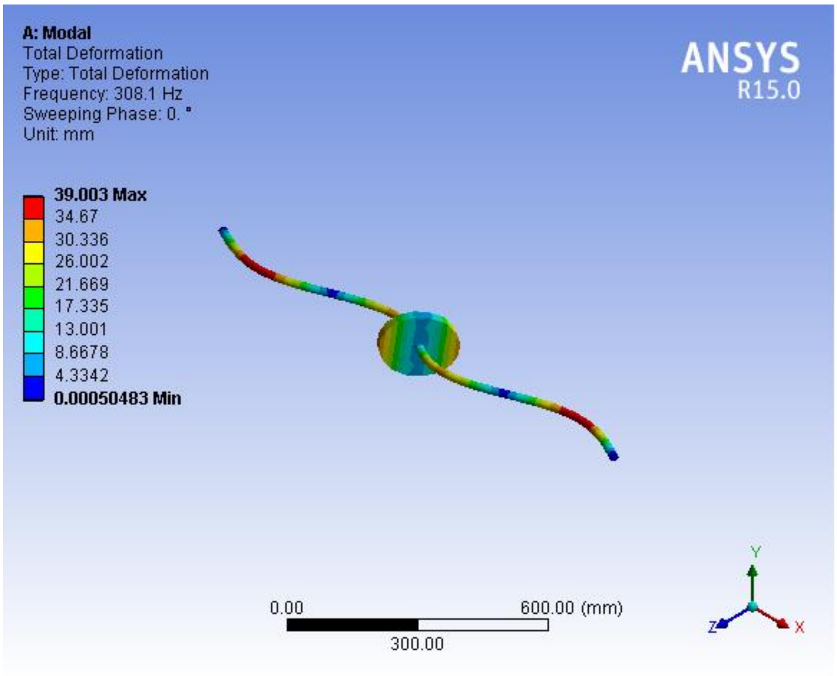

Figure 13: Fifth mode frequency of alloy 6061 shaft

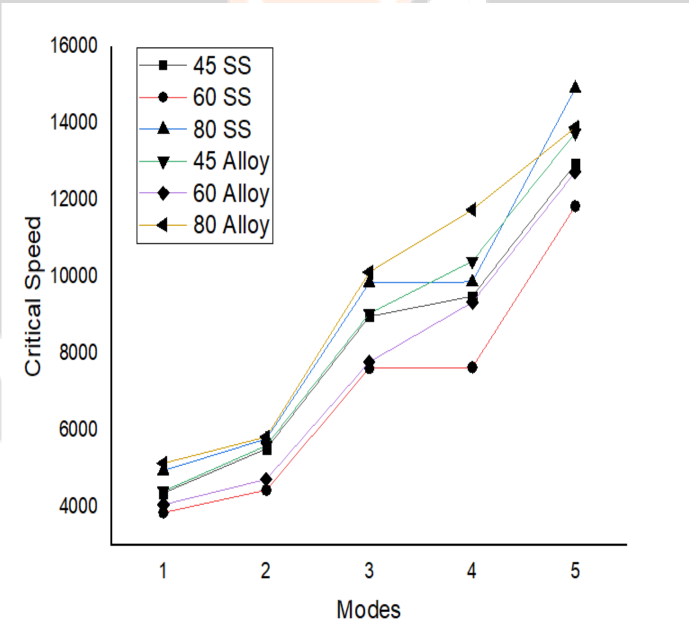

Figure No.14: *Graph shows Comparison of Critical Speed of Solid Shaft for Different Notch Angles with Both Material*

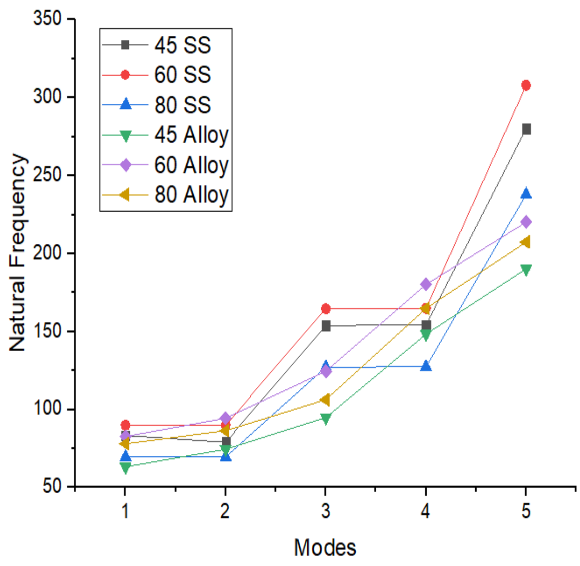

Figure No.15: *Graph shows Comparison of Natural Frequency of Solid Shaft for Different Notch Angles with Both Material*

IV. CONCLUSION

A. Influence of different shaft profiles.

- Modal analysis is what we are doing now. The materials used for it were structural steel. Utilizing the Finite Element Method, critical speed and natural frequency have been examined. The investigations have made use of both a non-simplified finite element model of the process and an idealized and simplified finite element model by applying symmetry assumption. The impact of diameter on the natural frequency and modes of various materials, as well as the critical speed effects, was examined in relation to various shaft profiles and materials, and the distribution along the shaft was examined. The shaft featured different notch angle.

- As per our study we determine the critical speed of shaft they result emphasizes the critical speed effect of shaft assigned with structural steel material, as RPM is increased and when it achieves the natural frequency of respected material due to this effect the axis of spin of shaft starts whirling motion due to critical speed which acts as an axis of spin this effect relets to gyroscopic behaviours of shaft.

- 600 notch angle shaft produced greater frequency characteristics towards the shaft's end for a different notch angle shaft with both materials.

- The shaft with 600 notch angle exhibits lower critical speed with increase natural frequency, this effect is observed because the orientation of 600 notch has less approach to the axial distance of shaft, thus it doesn't affect the frequency of shaft.

- We discovered that the 800 Notch angle shaft critical speed is lower than that of the other notch angle shaft.

- As We have considered three different notch angle 45o, 60o, 80o, the gyroscopic effect is effect at 45o and 80o of notch angle this is due to the approach of these notch angles affects the frequency as indeterminant effect occurs at axial distance of shaft but this effect is minimized at 60o of notch angle.

- We found the best results with the structural steel material as it has a lower critical speed and higher natural frequency than alloy 6061 at all different notch angles.

B. 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.

References

[1]. 1.Hamid Khorrami, Subhash Rakheja, Ramin Sedaghati, “Vibration behavior of a two-crack shaft in a rotor disc-bearing system” Mechanism and Machine Theory 113 (2017) 67–84.

[2]. 2.Nicoara Dumitru, Eugenia Secara, Mircea Mihalcica. “Study of Rotor-Bearing Systems Using Campbell Diagram” “1st International Conference on Manufacturing Engineering, Strength and Production Systems (Volume II)”.

[3]. 3.Xujun Lyu, Long Di, Se Young Yoon, Zongli Lin, Yefa Hu. “A platform for analysis and control design: Emulation of energy storage flywheels on a rotor-AMB test rig” “Mechatronics 000 (2016) 1–15”.

[4]. 4.Jing-min and Yong-sheng. “Vibration and Stability of Variable Cross Section Thin-Walled Composite Shafts with Transverse Shear” “Hindawi Publishing Corporation Shock and Vibration Volume 2015”.

[5]. 5.Mohammad Hadi Jalali, Mostafa Ghayour, Saeed Ziaei-Rad, Behrooz Shahriari. “Dynamic analysis of a high speed rotor-bearing system” “Measurement 53 (2014) 1–9”.

[6]. 6.S. A. A. Hosseini, S. E. Khadem. “Combination resonances in a rotating shaft” “Mechanisms”.

[7]. 7.O. N. Kirillov. “Campbell diagrams of weakly anisotropic” “proceeding of a royal society (2009) 465, 2703–2723”.

[8]. 8.R. Whalley, A. Abdul-Ameer. “Contoured shaft and rotor dynamics” “Mechanism and Machine Theory 44 (2009) 772–783”.

[9]. 9.F. C. Nelson. “Rotor Dynamics without Equations” “International Journal of COMADEM, 10(3) July 2007”.

[10]. 10.Keyu Qi, Zhengjia He, Zhen Li, Yanyang Zi, Xuefeng Chen. “Vibration based operational modal analysis of rotor systems” “Measurement 41 (2008) 810–816”.

[11]. 11.Erik Swanson, Chris D. Powell, Sorin Weissman. “A Practical Review of Rotating Machinery Critical Speeds and Modes” “Sound and Vibration/May 2005”.

[12]. 12.S. P. Harsha, K. Sandeep, R. Prakash. “The effect of speed of balanced rotor on nonlinear vibrations associated with ball bearings” “International Journal of Mechanical Sciences 45 (2003) 725–740”.

[13]. 13.Chun-Ping Zou, Hong-Xing Hua, Duan-Shi Chen. “Modal synthesis method of lateral vibration analysis for rotor-bearing system” “Computers and Structures 80 (2002) 2537–2549”.

[14]. 14.J. Victor. “The analysis and synthesis of steeped shafts use an interactive approach” “dissertation”.

[15]. 15.Nelson and McVaugh. “The dynamics of rotor bearing systems using finite elements” “jounral of engineering for industry(1976)”..

[16]. 16)X. F. Chen, Z. J. He, J. W. Xiang, and B. Li, “A dynamic multi scale lifting computation method using Daubechies wavelet,” Journal of Computational and Applied Mathematics, vol. 188, no. 2, pp. 228–245, 2006.

[17]. 17)B. Li, X. F. Chen, J. X. Ma, and Z. J. He, “Detection of crack location and size in structures using wavelet finite element methods,” Journal of Sound and Vibration, vol. 285, no. 4-5, pp. 767–782, 2005.

[18]. 18) J. W. Xiang, X. F. Chen, B. Li, Y. M. He, and Z. J. He, “Identification of a crack in a beam based on the finite element method of a B-spline wavelet on the interval,” Journal of Sound and Vibration, vol. 296, no. 4-5, pp. 1046–1052, 2006.

[19]. 19)J.W. Xiang, X. F. Chen, Q. Mo, and Z. J. He, “Identification of crack in a rotor system based on wavelet finite element method,” Finite Elements in Analysis and Design, vol. 43, no. 14, pp. 1068–1081, 2007.

[20]. 20)C. A. Papadopoulos and A. D. Dimarogonas, “Coupling of bending and torsional vibration of a cracked Timoshenko shaft,” Ingenieur-Archiv, vol. 57, no. 4, pp. 257–266, 1987.

[21]. 21)A. S. Sekhar and B. S. Prabhu, “Vibration and stress fluctuation in cracked shafts,” Journal of Sound and Vibration, vol. 169, no. 5, pp. 655–667, 1994.

[22]. 22)B. O. Dirr, K. Popp, and W. Rothkegel, “Detection and simulation of small transverse cracks in rotating shafts,” Archive of Applied Mechanics, vol. 64, no. 3, pp. 206–222, 1994. al Applied Mathematics 2011.