Investigation on Crack Modulation of Simply Supported Shaft for Determination of Critical Speed by using Finite Element Method

Vikas Yadav[1] Amitesh Paul[2] Vishal Kumar Jaiswal[3] Akanksha Yadav[4]
[1,3]P.G. Student (M.Tech) [4]P.G. Student (M.B.A)
[1,2,3,4]Department of Mechanical Engineering
[1,3,4]Sri Satya Sai College of Engineering, RKDF University, Bhopal [2]RKDF University, Bhopal

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 with two and Three Cracks. A natural frequency was analysed and critical speed was predicted by using Campbell diagram and analysis was also performed for validation. 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 shaft with two and three cracks of shaft profile an alloy 6061 gives better frequencies in different modes. Alloy 6061 material shaft are made by powder metrology and gray cast iron material shaft are made by casting and gray cast iron is made by remelting pig iron. It is highly resistant to deformation and provides a rigid frame. So gray cast iron material shaft is better compare to alloy 6061 material shaft.
Key words: 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.

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.

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.

A. 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

V. 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.

VI. 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

VII. Modeling & Analysis

A. 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

B. Preprocessing

Preprocessing include CAD model, meshing and defining boundary conditions.

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

Table 5.1: Dimension of Shaft.

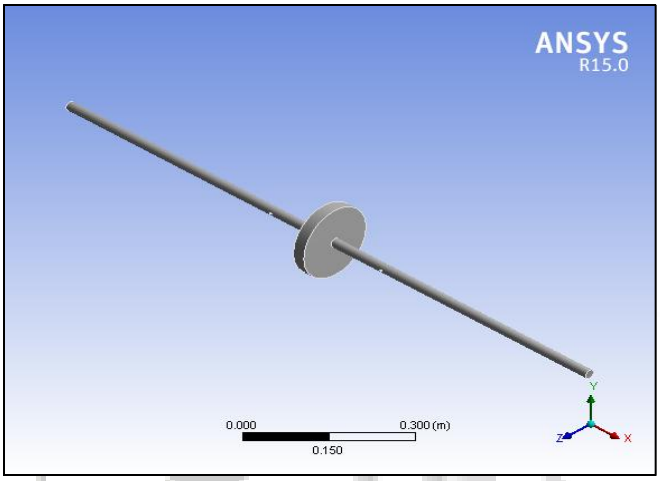

Fig. 5.1: Model of Solid shaft with Two Crack

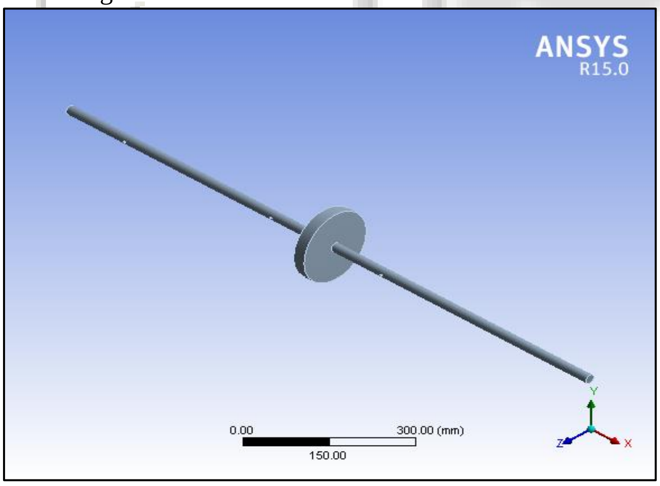

Fig. 5.2: Mode of Solid Shaft with Three Crack

VIII. Result & Discussion

A. Analysis of Solid Shaft with two Crack and Different Materials

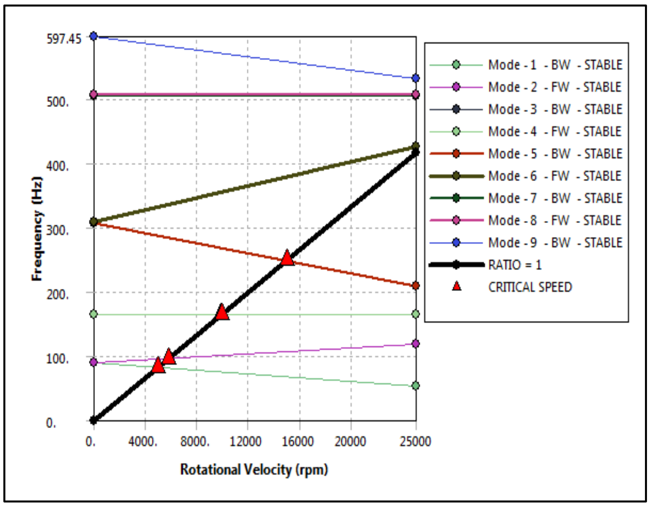

Figure No.:6.1 Result of Campbell diagram of frequency and rotational velocity distributions along the Alloy6061solid shaft with two Cracks

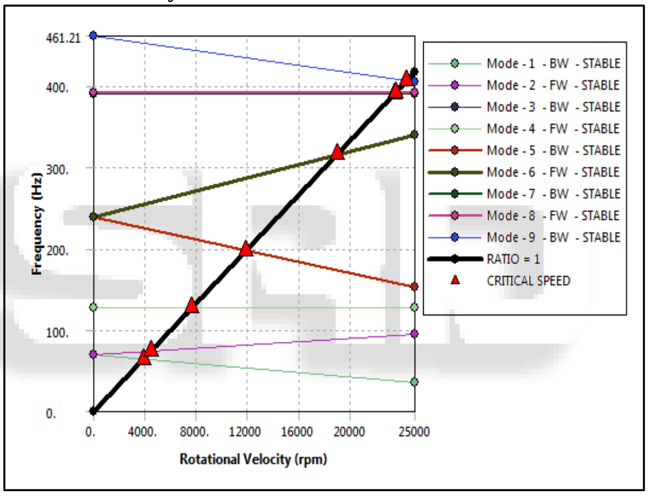

Fig. 6.2: Result of Campbell diagram of frequency and rotational velocity distributions along the Gray Cast Iron Solid Shaft with Two Cracks

Table No.: 6.1 Critical Speed of Solid Shaft with two Cracks

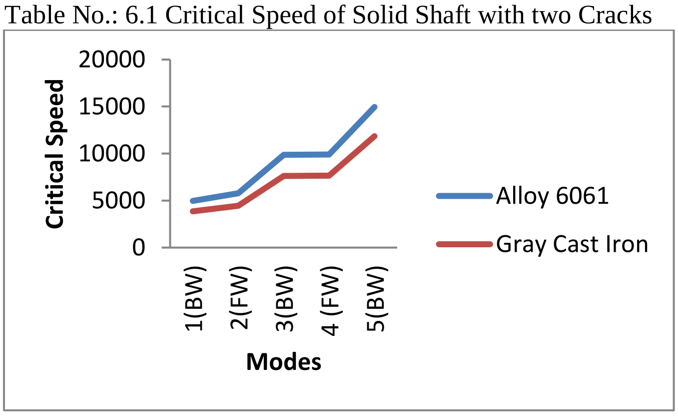

Fig. 5.3: Graph shows comparison of critical speed of solid shaft with two cracks and two different materials

B. Analysis of Solid Shaft with Three Cracks and Different Materials

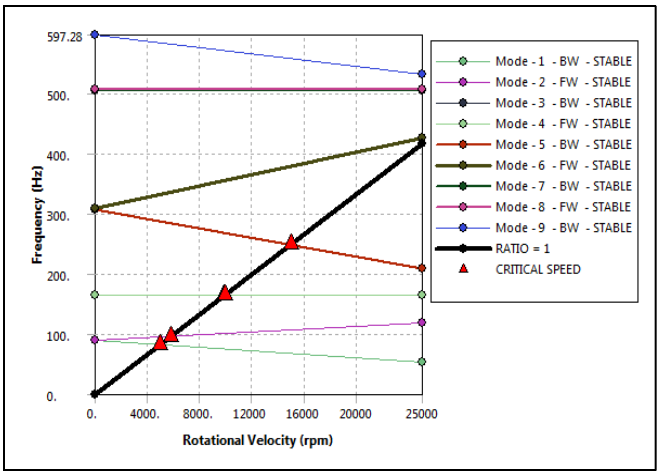

Fig. 6.4: Result of Campbell diagram of frequency and rotational velocity distributions along the Alloy 6061solid shaft with Three Cracks

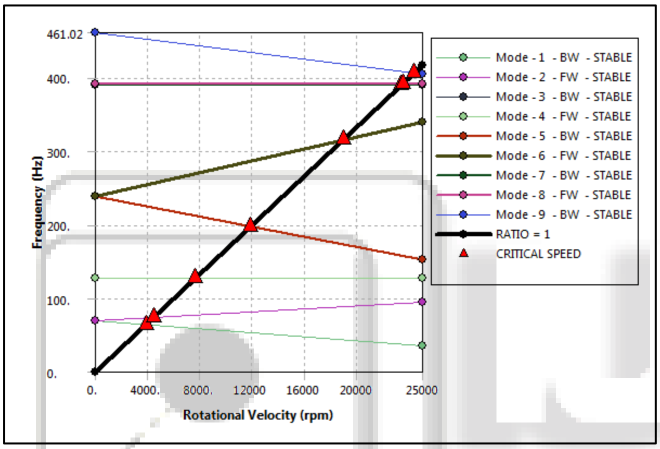

Fig. 6.5: Result of Campbell diagram of frequency and rotational velocity distributions along the Gray Cast Iron Solid Shaft with three Cracks

Table No.: 5.2 Critical Speed of Solid Shaft with Three Cracks.

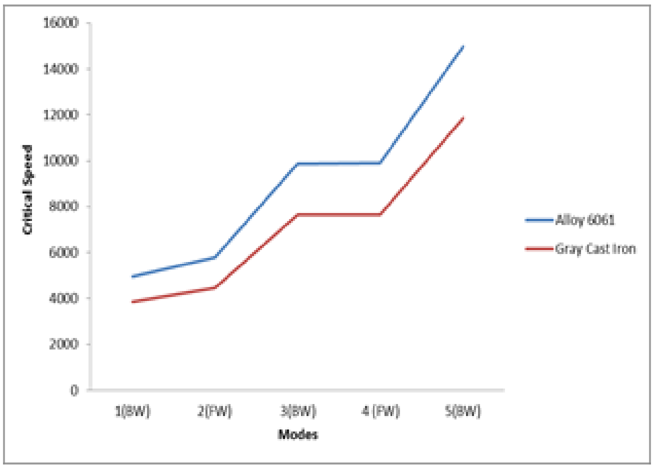

Figure No.: 5.6 Graph shows comparison of critical speed of two different materials

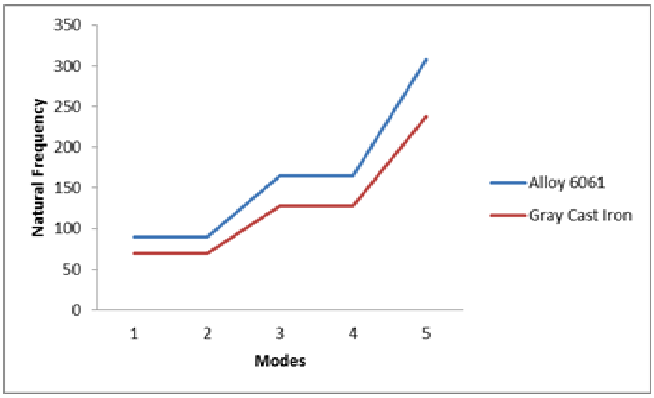

Fig. 6.10: Graph shows modes and frequency of a solid shaft with three Cracks

IX. 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.

A. Influence of different shaft profiles

- The natural frequency along the shaft profile is found to be maximum of the alloy 6061 material profile with solid 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
- Alloy 6061 material shaft are made by powder metrology and gray cast iron material shaft are made by casting and gray cast iron is made by remelting pig iron. It is highly resistant to deformation and provides a rigid frame. So gray cast iron material shaft is better compare to alloy 6061material shaft.

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] 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] 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] A. D. Dimarogonas, "Vibration of cracked structure: a state of the art review," Engineering Fracture Mechanics, vol. 55, no. 5, pp. 831–857, 1996.
[4] G. Sabnavis, R. G. Kirk, M. Kasarda, and D. Quinn, "Cracked shaft detection and diagnostics: a literature review," Shock and Vibration Digest, vol. 36, no. 4, pp. 287–296, 2004.
[5] D. Guo and Z. K. Peng, "Vibration analysis of a cracked rotor using Hilbert-Huang transform," Mechanical Systems and Signal Processing, vol. 21, no. 8, pp. 3030–3041, 2007.
[6] T. Ramesh Babu, S. Srikanth, and A. S. Sekhar, "Hilbert-Huang transform for detection and monitoring of crack in a transient rotor," Mechanical Systems and Signal Processing, vol. 22, no. 4, pp. 905–914, 2008.
[7] N. Bachschmid, P. Pennacchi, and E. Tanzi, "Some remarks on breathing mechanism, on non-linear effects and on slant and helicoidal cracks," Mechanical Systems and Signal Processing, vol. 22, no. 4, pp. 879–904, 2008.
[8] T. H. Patel and A. K. Darpe, "Influence of crack breathing model on nonlinear dynamics of a cracked rotor," Journal of Sound and Vibration, vol. 311, no. 3–5, pp. 953–972, 2008.
[9] O. S. Jun, H. J. Eun, Y. Y. Earmme, and C.-W. Lee, "Modelling and vibration analysis of a simple rotor with a breathing crack," Journal of Sound and Vibration, vol. 155, no. 2, pp. 273– 290, 1992.
[10] L. Zheng, H. Gao, and T. Guo, "Application of wavelet transform to bifurcation and chaos study," Applied Mathematics and Mechanics, vol. 19, no. 6, pp. 593–599, 1998.
[11] B. Yang, C. S. Suh, and A. K. Chan, "Characterization and detection of crack-induced rotary instability," Journal of Vibration and Acoustics, vol. 124, no. 1, pp. 40–48, 2002.
[12] A. K. Darpe, "A novel way to detect transverse surface crack in a rotating shaft," Journal of Sound and Vibration, vol. 305, no.1-2, pp. 151–171, 2007.
[13] 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.
[14] J. X. Ma, J. J. Xue, S. J. Yang, and Z. J. He, "A study of the construction and application of a Daubechies wavelet-based beam element," Finite Elements in Analysis and Design, vol. 39, no. 10, pp. 965–975, 2003.
[15] X. F.Chen, S. J. Yang, J.X.Ma, and Z. J.He, "The construction of wavelet finite element and its applications," Finite Elementsin Analysis and Design, vol. 40, no. 5-6, pp. 541–554, 2004.
[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] 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] 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] 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] 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] 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] 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.
[23] M. A. Mohiuddin and Y. A. Khulief, "Modal characteristics of cracked rotors using a conical shaft finite element," Computer Methods in Applied Mechanics and Engineering, vol. 162, no. 1–4, pp. 223–247, 1998.
[24] A. S. Sekhar and P. Balaji Prasad, "Dynamic analysis of a rotor system considering a slant crack in the shaft," Journal of Sound and Vibration, vol. 208, no. 3, pp. 457–473, 1997.
[25] A. S. Sekhar, "Vibration characteristics of a cracked rotor with two open cracks," Journal of Sound and Vibration, vol. 223, no. 4, pp. 497–512, 1999.
[26] A. Nandi, "Reduction of finite element equations for a rotor model on non-isotropic spring support in a rotating frame," Finite Elements in Analysis and Design, vol. 40, no. 9-10, pp. 935–952, 2004.
[27] A. K. Darpe, "Dynamics of a Jeffcott rotor with slant crack," Journal of Sound and Vibration, vol. 303, no. 1-2, pp. 1–28, 2007.
[28] N. Bachschmid and E. Tanzi, "Deflections and strains in cracked shafts due to rotating loads: a numerical and experimental analysis," International Journal of Rotating Machinery, vol. 10, pp. 283–291, 2004.
[29] Huichun Peng, Qing He, Pengcheng Zhai, Yaxin Zhen, "Stability analysis of an open cracked rotor with the

anisotropic rotational damping in rotating operation", Elsevier 2017.
[30] R. Tamrakar and N. D. Mittal, "Campbell diagram analysis of open cracked rotor", Engineering Solid Mechanics Growing Science 2016.
[31] Zhiwei Huang et al, "Dynamic analysis on rotor-bearing system with coupling faults of crack and rub-impact", MOVIC 2016 & RASD 2016.
[32] Anuj Kumar Jain, Vikas Rastogi, Atul Kumar Agrawal, "Experimental Investigation of Vibration Analysis of Multi-Crack Rotor Shaft", Science Direct 2016.
[33] M. Serier, A. Lousdad, K. Refassi, A. Megueni, "Analysis of Parameters Effects on Crack Breathing and Propagation in Shaft of Rotor Dynamic Systems", Material Research 2013.
[34] Sri Raghava M., G. Diwakar, P. Madhu Kumar, "Vibration Analysis of Cracked Rotor Using Numerical Approach", IOSR-JMCE 2013.
[35] Guangming Dong, Jin Chen, "Vibration analysis and crack identification of a rotor with open cracks", Japan Journal of Industrial Applied Mathematics 2011.