RESEARCH ARTICLE OPEN ACCESS

Dynamic Analysis of Rotating stepped Shaft with Transverse Crack

Mr. S.P. Bhide, Prof. S. D. Katekar
Mechanical Dept SKN Sinhgad College of Engineering Korti, Pandharpur
Mechanical Dept SKN Sinhgad College of Engineering Korti, Pandharpur

Abstract
This study describes dynamic analysis of stepped shaft with single crack of EN8 material. The objective is to compare results of healthy stepped shaft and single cracked stepped shaft for different crack depth ratios at variable rpm .The dynamic analysis is carried out by using finite element method. Obtained results from analysis are benchmarked from literature. It is observed that there is 84.80% increase in amplitude of acceleration of cracked shaft. Also modal analysis of shaft has been carried out to know effect on natural frequencies of healthy shaft and cracked shaft. The effects of crack depth, crack length & RPM on amplitude of acceleration are obtained.
Keywords-single cracked stepped shaft, crack depth ratio, amplitude of acceleration.

I. INTRODUCTION

One of the most common incipient losses of structural integrity in mechanical structures is the development and propagation of cracks. A crack may propagate from some small imperfections on the surface of the body or inside of the material and it is most likely to appear in correspondence of high stress concentration. The research work in two decades has been published on the detection and diagnosis of crack developed by using vibration and acoustic methods. Cracks are assumed to be both near the step and far from the step. The multi-crack identification algorithm has been applied for a stepped shaft. [1].The free vibration characteristics of uniform and non-uniform stepped thick beams are compared. Also the effect of transverse shear deformation and rotary inertia on the lateral vibrations of stepped thickness beams and shafts are analyzed and the results are compared [2].A modeling procedure to obtain an exact dynamic matrix for a Timoshenko shaft element is presented by using a spatial state equation and the Laplace transformation [3]. The frequencies are obtained for both cracked and healthy simple and overhang shafts. Also the support reactions of the overhang shaft are obtained by the TMM [4].A systematic method for analyzing the vibration of a rotating geometrically discontinuous shaft with general boundary conditions is presented. Both Rayleigh and Timoshenko beam models are considered in the analysis. Exact closed form solutions for the free and forced responses are obtained by the distributed transfer function method and generalized displacement formulation. Numerical results of the natural frequencies mode shapes and steady state response of a rotating stepped two span shaft are presented [5].One of the failures might be due to the crack initiation and propagation in any of the moving part. Being susceptible to minute changes, the natural frequency is monitored to access crack location and crack size in beam [6]. The study is based on observation of changes in natural frequency. In theoretical analysis, the crack is simulated by a spring connecting the two segments of the beam. The model of beam is generated using Finite Element Method of analysis [7].A mathematical model of spinning stepped-shaft work piece is obtained. A two-node, 16-degree-of-freedom Timoshenko beam finite element is used [8].Experimental verification of an algorithm for detection and localization of multiple cracks in simple shaft system had carried out .The algorithm is based upon detecting the slope discontinuity due to cracks. A scheme is proposed to improve the working of the algorithm in low signal to noise ratio [9].The position of the crack by comparing the fundamental mode shapes of the shaft with and without a crack is predicted. Furthermore the depth of the crack is obtained by change of natural frequency of the shaft with and without a crack [10].It is found that many researchers have worked on vibration analysis of continues shaft with transverse crack but very less light is thrown on vibration analysis of stepped shaft with single transverse crack.

II. FINITE ELEMENT MODELLING

Incremental transient type of dynamic analysis is carried out in ANSYS L.S.Dyna. Healthy and cracked shaft are analyzed. Comparison of amplitude of acceleration of both shafts has been done. Schematic of cracked shaft with different location of crack is as shown in figure 1.CD indicates crack depth. All dimensions are in mm. Figure 1 shows stepped shaft with different crack location.

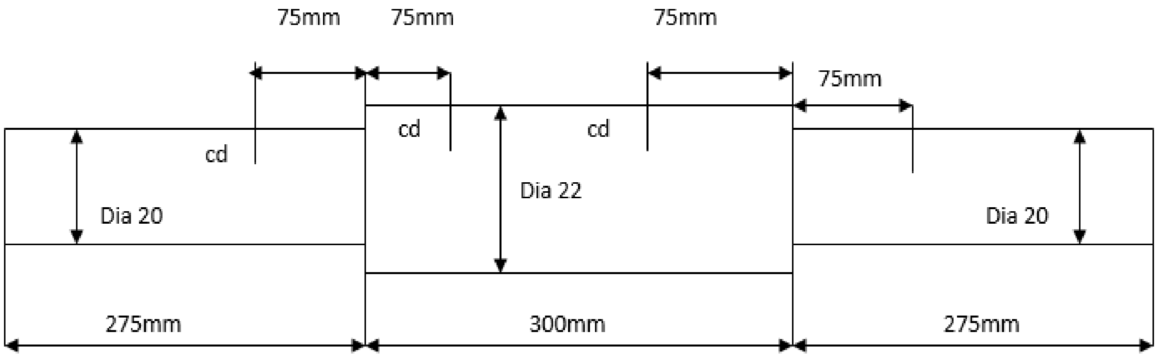


Fig.1 Schematic of stepped shaft with different crack location

Dynamic analysis has been carried out for crack location 200mm, 300mm, 500 mm and 650 mm. Parametric modeling of stepped shaft by using ANSYS software is prepared. Material properties of EN8 material are input to ANSYS software. Free meshing of model with 3mm element edge length is obtained. 4510 elements & 2371 nodes are generated. While elements in crack region are refined in minimal 0.1 degree Meshed model is shown in figure 2. In boundary conditioning, elastic support at 15mm from both sides is provided in Y direction in order to compensate for bearing function. Response is observed within 0.001 second. Rotation /speed have varied from 500-2000 rpm.

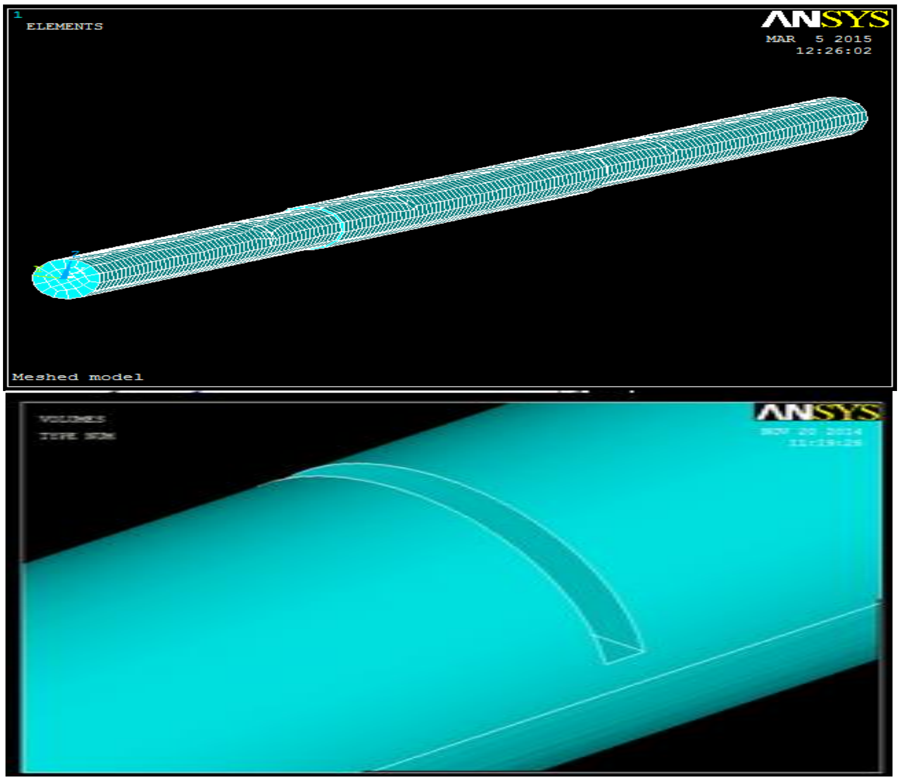


Fig.2 Stepped shaft with different crack location

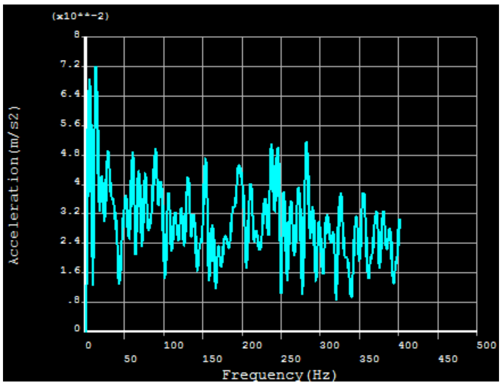
Amplitude of acceleration has obtained at point of elastic support. Also variation in amplitude of acceleration is observed with respect to variation in rotational speed.

III. Result and Discussion

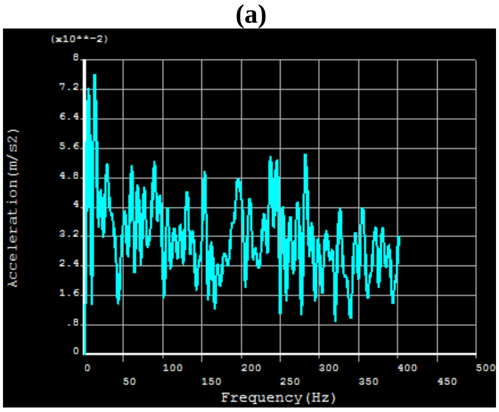
Table 1 shows values of acceleration and crack depth. Crack depth is varied from 4 mm to 7 mm so as to vary the crack depth ration. Corresponding values of accelerations have been obtained.Fig.3 shows response of stepped shaft amplitude versus frequency. It is obtained at different values of crack depth at constant speed 500rpm.

CD(mm)	**Acceleration (m/s^2)**		**Deviation (%)**
	literature	**Simulation**	
0	0.08 m/s2	0.0720 m/s2	10.89%
4	0.0845 m/s2	0.076 m/s2	10.05%
5	0.0854 m/s2	0.08 m/s2	6.32%
6	0.0865 m/s2	0.0813 m/s2	6.01%
7	0.0892 m/s2	0.0827 m/s2	7.29%

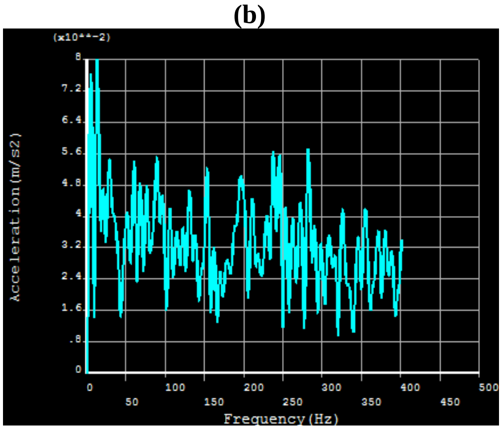
Table 1 shaft with different CD at 500rpm



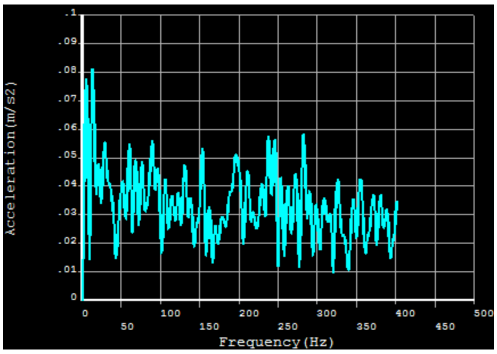
(a)



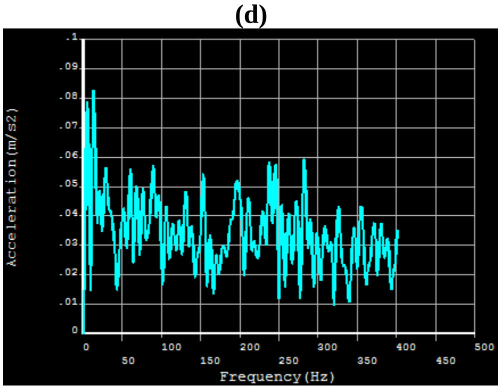
(b)



(c)



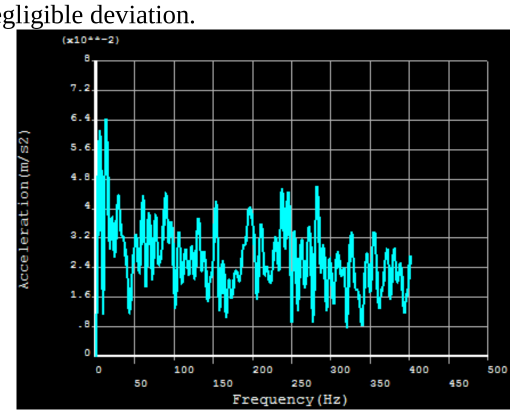
(d)



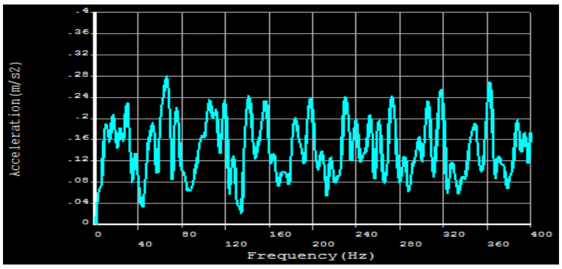
(e)

Fig.3 Responses of EN8 shaft at 500rpm with different crack depth (a) healthy stepped shaft (b) 4mm (c) 5mm (d) 6mm and (e) 7mm

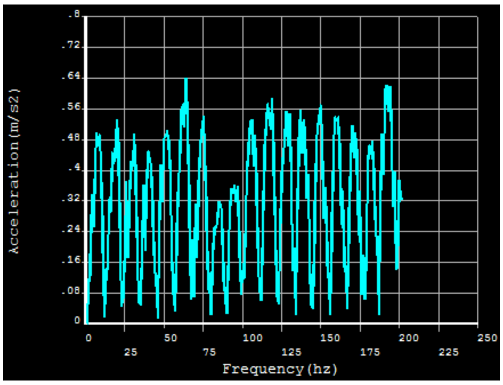
It can be concluded that if crack depth increases from 4mm to 7 mm then 86% increase in amplitude of acceleration is observed .At crack depth there is more uncertainty in amplitude of acceleration .In turn it reduces natural frequency of shaft .Results validation is done for shaft of EN8 material with different crack depths at 500rpm. It is observed that there is a maximum deviation of 10.89% in results of literature and results of simulation for this shaft. From above FEA analysis it is clear that FEA readings are in good agreements with literature with negligible deviation.



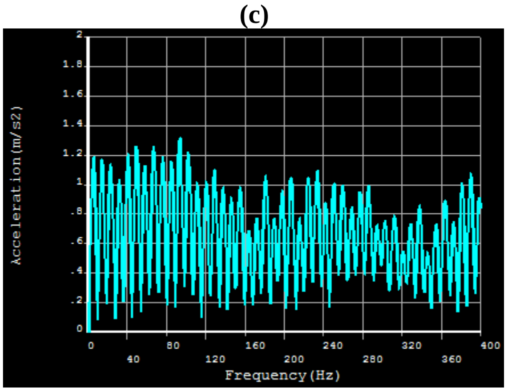
(a)



(b)



(c)



(d)

Fig.4 Responses of EN8 shaft with different speed (a) 500 rpm (b) 1000 rpm (c) 1500 rpm and (d) 2000 rpm.

After validation of results, the same simulation loop has been continued by varying speed and amplitudes of accelerations are obtained. Figure shows variation of speed from 500rpm to 2000rpm .Different values of acceleration are obtained at variable rotational speed. The amplitude of vibration for intact EN8 shaft at 500rpm is 0.0642 m/s2. Similarly, amplitudes of acceleration at variable speed are tabulated as follows.

Sr.No	Speed (RPM)	Acceleration (m/s^2)
1	500	0.0642 m/s2
2	1000	0.28 m/s2
3	1500	0.64 m/s2
4	2000	1.31 m/s2

Table 2 Speed verses Amplitude of acceleration

Hence, it is observed that the presence of crack in the shaft results in increase in amplitude of vibration. Similar effect is observed for other rotational speeds. Also, as speed of shaft increases, the amplitude of vibration increases. The peak is observed nearly at variable compliance frequency for the respective speed of shaft.

Modal analysis had carried out for the intact shaft and the shafts with different crack depth (i.e. 4 mm, 5 mm, 6 mm and 7 mm) at location 200mm right end. Block Lanczos method had been used for extracting modes. There are 14 number of modes are extracted for the analysis. Only material properties are given as an input to the program i.e. density 7800 Kg/m3 which defines the mass of system. Elastic modulus is 200GPa. 4428nodes and 18220 elements are generated for two systems. Natural frequencies are tabulated as follows.

Natural Frequencies (Number of modes =14)				
Intact shaft	Crack Depths			
	4 mm	5 mm	6 mm	7 mm
0.13004	3.96E-05	1.49E-05	5.58E-06	8.73E-05
0.730032	3.17E-05	1.19E-05	4.46E-06	8.03E-05
0.730021	2.06E-05	7.75E-06	2.90E-06	6.26E-05
0.730072	7.25E-05	2.73E-05	1.02E-05	5.48E-05
0.73003	2.97E-05	1.12E-05	4.19E-06	3.39E-05
0.730038	3.76E-05	1.42E-05	5.31E-06	2.34E-05
5.34186	4.61E+00	1.74E+00	6.50E-01	1.23E-05
5.360496	4.63E+00	1.74E+00	6.53E-01	2.10E-05
14.34284	1.36E+01	5.12E+00	1.92E+00	3.84E-05
14.43909	1.37E+01	5.16E+00	1.93E+00	3.98E-05
28.40124	2.77E+01	1.04E+01	3.90E+00	4.93E-05
28.57319	2.78E+01	1.05E+01	3.92E+00	5.23E-05
36.62364	3.59E+01	1.35E+01	5.06E+00	5.58E-05
0.730038	3.76E-05	1.42E-05	5.30E-06	1.23E-05

Table 3 Natural frequencies and crack depth

From table 3, it is observed that natural frequencies of cracked shafts are less as compared to the intact (i.e. no crack exists in shaft) shafts. The natural frequencies go on decreasing as crack depth increases from 4 mm to 7 mm.

IV. CONCLUSION

The conclusions obtained are summarized as follows

1 Amplitudes of vibration for healthy shaft) EN8 shaft at 500rpm, 1000rpm, 1500rpm and 2000 rpm are $0.0642 m/s^2$, $0.28\ m/s^2$, $0.0.64\ m/s^2$ and $1.31\ m/s^2$ respectively. Hence, as speed of stepped shaft increases, amplitude of vibration increases.

2 The analysis of EN8 shaft is done at 500rpm for the different crack depth. Amplitude of vibration for intact (i.e. no crack exists in shaft) EN8 shaft is 0.0720 m/s2 and for crack depth ratios 0.2, 0.23, 0.25 and 0.27 amplitudes are 0.076m/s2, 0.08m/s2, 0.0813m/s2, 0.0827m/s2 respectively. Hence as crack depth increases amplitude of vibration increases. When results from literature are compared with these results then maximum deviation of 10.89 % is observed for the intact shaft.

3 For studying modal characteristics of intact shaft and cracked shafts, modal analysis is carried out. It is observed that natural frequency decreases as the crack depth ratio increases.

V. REFERENCES

[1] M.farahmandian, "Theoretical and experimental study on vibration of cracked shaft using order analysis," Advanced Design And Manufacturing Technology 2014; vol 7;pp 77-87.

[2] Sachin .K.Singh, Rajiv Tiwari, "Detection and localization of multiple cracks in shaft system: an experimental investigation," Measurement 2014; vol53; pp182-193.

[3] S.K.Singh and R.Tiwari," Detection and localization of multiple cracks in a stepped shaft," FFEMS Engineering and structures Wiley Publishing Ltd 2012; vol36;pp 85-91.

[4] P. R. Baviskar& V.B. Tungikar," Analysis of crack in shaft of blower using finite element analysis and experimental technique," IJRRAS2011 ;vol 8;pp1-05.

[5] Bingen Yang, "Exact transient vibration of stepped bars, shaft & string carrying lumped masses," Journal of Sound and Vibration 2010; vol 329; pp 1191-1207.

[6] Anooshirvan Farshidianfar, et. al, "Damage detection of an overhang cracked shaft by frequency analysis," The Sixteenth International Congress On Journal of Sound and Vibration 2009; pp 1-9.

[7] Z.C.Wang and W.L.Cleghorn, "Stability analysis of spinning stepped shaft work piece in a turning process," Journal of Sound and Vibration 2002; vol250; pp 356-367.

[8] J. Pan, R.S.Ming, T.Lin, "Three dimensional response & intensity of tortional vibration in a stepped shaft, "Journal of Sound and Vibration 2000; vol 236; pp 115-128.

[9] S.-W. Hong, "Dynamic analysis of multi-stepped, distributed parameter rotor-bearing system," Journal of Sound and Vibration; 1999; vol.227; pp 769–785.

[10] T.C.Tsai and Y.Z.Wang, "Vibration analysis and diagnosis of cracked shaft, "Journal of Sound and Vibration 1996; vol192; pp 607-620.

[11] C.A Tan and W. Kuang, "Vibration of a rotating discontinues shaft by the distributed transfer function method," Journal of Sound and Vibration; 1995; vol.183;pp 451–474.

[12] A.S .Aydin and G.Aksu, "A finite difference method for the free vibration analysis of stepped of beams and shafts," Mechanism and Machine theory 1986; vol.2; pp1–12.