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Vibration Analysis of Multiple Cracked Shaft

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Abstract: *Crack in component if undetected may lead to catastrophic failure of the component. The cracked rotor problem received the first attention in 1970 and after that the interest among the researchers started. The vibration behavior of cracked structures, in particular cracked rotors, is important to study as the introduction of the crack alters the vibration characteristics of the structure. The problem of damage and crack detection in structural components has acquired important role in past few years. However, cracked rotor studies are mainly deals with single crack. For multiple cracked structures the problem of crack sizing and location becomes more complex. Only few authors have pointed out the multiple crack assessment in the rotor. The proposed work is on vibration analysis of multiple cracked shaft beam. An Euler Bernoulli beam fixed at one end with two transverse cracks is considered. The vibration characteristics of the shaft are studied using Experimental Modal Analysis and Finite Element Analysis. The mode shapes and natural frequencies of the beams are studied and their variation with change in position and depth of the crack is also studied. The study shows good agreement of the results obtained using Finite Element Analysis and Experimental Modal Analysis.*

Keywords: *vibration analysis, crack detection, modal analysis, damage, condition monitoring.*

I. INTRODUCTION

There are number of methods of crack detection in the beam has been presented by many authors. The problem of crack detection is simple whenever dealt with single crack but as number of cracks to handle are more than one then the problem becomes relatively complex. D. P. Patil and S. K. Maiti [1] propose method to detect multiple cracks in the beam using frequency measurement. Their results give linear relationship between damage parameters and natural frequency of vibration of beam. A. K. Darpe et al. [2] studied dynamics of a bowed rotor with a transverse surface crack. They concluded that amplitude and directional nature of higher harmonic components of bowed rotor remains unaltered, however rotating frequency component changes in magnitude. In another research Athanasios C. Chasalevris and Chris A. Papadopoulos [3] studied identification of multiple cracks in beams under bending. They formulate compliance matrix of two DOF as a function of both crack depth and angle of rotation of the shaft. Their stated method gives not only depth and size of the crack but also angular position of the crack. Ashish K. Darpe [4] proposes a novel way to detect transverse surface crack in a rotating shaft. He studied the behavior of the simply supported shaft with transverse crack subjected to both bending and torsional vibration. K.M. Saridakis et al. [5] propose the application of neural networks, genetic algorithm and fuzzy logic for the identification of cracks in shafts. In another research of Ashish K. Darpe [6] he present coupled vibrations of a rotor with slant crack. He established stiffness matrix for Timoshenko beam on concepts of fracture mechanics the behavior of the shaft slant crack was compared with transverse crack. Sachin S. Naik and Surjya K. Maiti [7] studied triply coupled bending–torsion vibration of Timoshenko and Euler–Bernoulli shaft beams with arbitrarily oriented open crack. The variation of compliance coefficients with angular position of the crack was illustrated. The study shows that the frequency of vibration decreases as the distance of the crack from free end increases. Ashish K. Darpe [8] studied dynamics of a Jeffcott rotor with slant crack. Stiffness coefficients based on flexibility coefficients was used to form equation of motion. His study shows that the lateral and longitudinal stiffness is more for slant crack as compared to transverse crack. The trend of 3 x frequency component can be used to detect as well as to identify the type of crack. Tejas H. Patel, Ashish K. Darpe [9] studied influence of crack breathing model on nonlinear dynamics of a cracked rotor. Their study shows that for the rotor with deeper crack, the switching crack model displays chaotic, quasi-periodic and sub harmonic motion. A.S. Sekhar [10] presented a review on multiple cracks effects and identification. He summaries different methods of single and double crack detection. S.K. Georgantzinos, N.K. Anifantis [11] presented the study of breathing mechanism of a crack in a rotating shaft. He studied the behavior of the transverse crack in cantilever shaft beam with two different cases of straight and curved front of the shaft. Flexibility coefficients were calculated based on energy principle. He concludes that the breathing behavior depends on depth and shape of the crack front. In the present work the Experimental modal analysis of the shaft beam was done and the results are compared with results of Finite Element Analysis performed in ANSYS 14.5.

II. FEA ANALYSIS OF SHAFT BEAM

The 3-D modeling of the shaft with diameter 0.03m and length 0.360m is done in ANSYS 14.5. The 3-D model of the shaft is meshed with element 20node186. The material used for the shaft has following properties,

1) Modulus of Elasticity= $2x10^{11}N/m^2$,
2) Poisons ratio= 0.3 and
3) Mass Density 7850 kg/m^2.

Boundary Conditions as cantilever beam is applied by making all degrees of freedom zero at one end of the shaft. A Block Lanczos method was used for extraction of natural frequency of free vibration. The first three modes of transverse vibration are extracted. Also the mode shapes of the first three modes of transverse vibration are plotted.

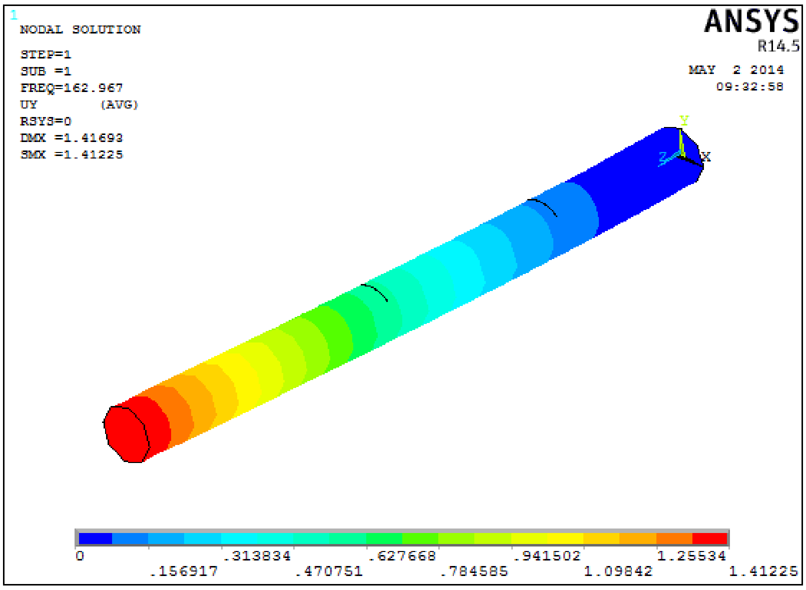

Fig.1. 1^{st} Mode of Vibration (e_1=0.25, a_1/d=0.1, e_2=0.55, a_2/d=0.1)

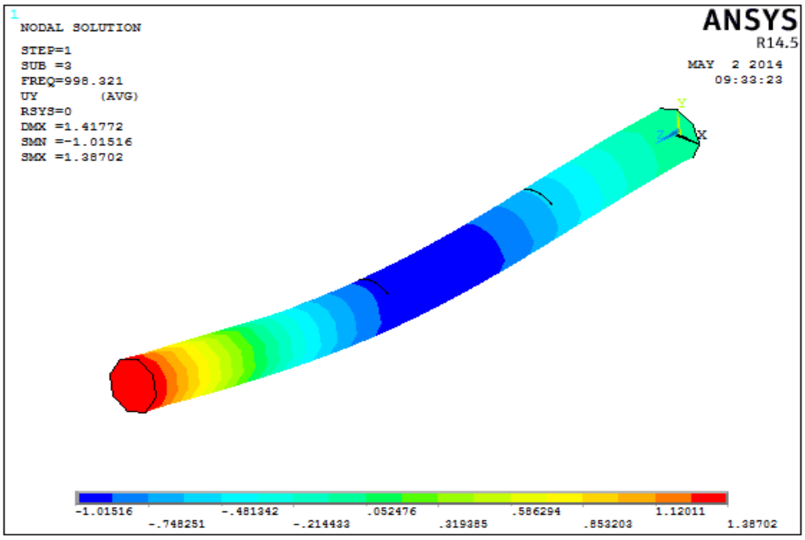

Fig.2 2^{nd} Mode of Vibration (e_1=0.25, a_1/d=0.1, e_2=0.55, a_2/d=0.1)

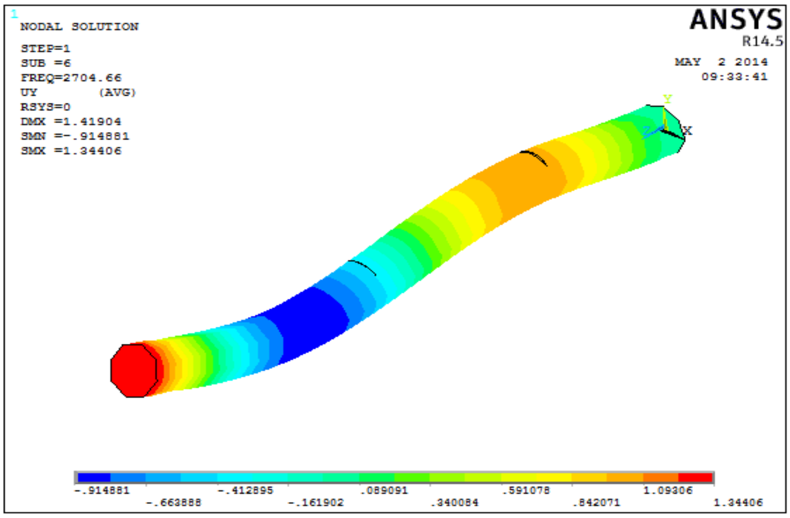

Fig.3 3rd Mode of Vibration (e_1=0.25, a_1/d=0.1, e_2=0.55, a_2/d=0.1)

III. EXPERIMENTAL MODAL ANALYSIS

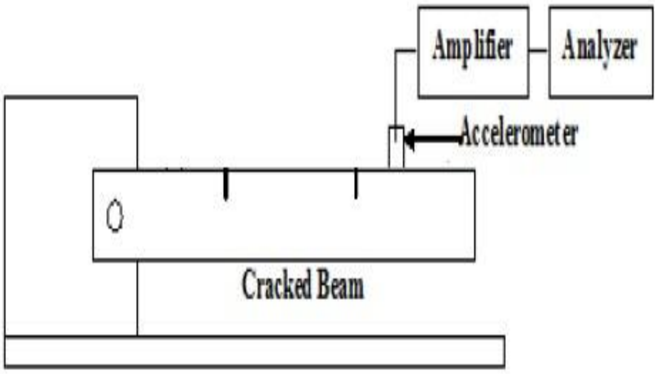

Fig.4 Test rig for Experimental Modal Analysis

The fig. 4 shows the test rig used for experimental modal analysis of the shaft beam. The instruments used for experimental modal analysis are Fast Fourier Transform analyzer, accelerometer, impact hammer and related accessories. The FFT analyzer used is 4 channel Bruel and Kjaer make with measuring range 10-200 dB, amplitude stability + 0.1 dB. RT-PRO™ software, compatible with the FFT analyzer is used. The piezoelectric, miniature type unidirectional accelerometer is used to sense the frequency response functions. The accelerometer is mounted on the beam using wax. The accelerometer is mounted just near the crack to capture the correct signals. The impact hammer is used to excite the beam whose frequency response function is to be captured. The beam is tapped gently using impact hammer. Impact hammer has the range of excitation 1-4000 Hz.

IV. RESULTS

4.1 Experimental and FEA Results

Table 1. Experimental and FEA results

Sr. no.	e_1	a_1/d	e_2	a_2/d	ω_1 FEA, HZ	ω_1 Exp., HZ	ω_2 FEA, HZ	ω_2 Exp., HZ
1	Healthy beam				163.65	167.98	1002.6	1008
2	0.25	0.1	0.55	0.1	162.97	160.33	998.32	982.54
3	0.25	0.2	0.55	0.2	160.49	162.34	983.46	964.69
4	0.25	0.3	0.55	0.3	155.43	159.86	953.26	942.31
5	0.25	0.4	0.55	0.4	147.48	145.17	906.99	898.78
6	0.25	0.5	0.55	0.5	135.41	136.64	838.66	829.85

Where, L is the length of the beam. L_1 is the distance of first crack from fixed end. L_2 is the distance of second crack from fixed end. e_1 is the ratio of L_1 and L. Similarly e_2 is the ratio of L_2 and L. a_1 and a_2 are the depth of the first and second cracks. a_1/d and a_2/d are crack depth ratios.

4.2 Comparison of Experimental and FEA Results

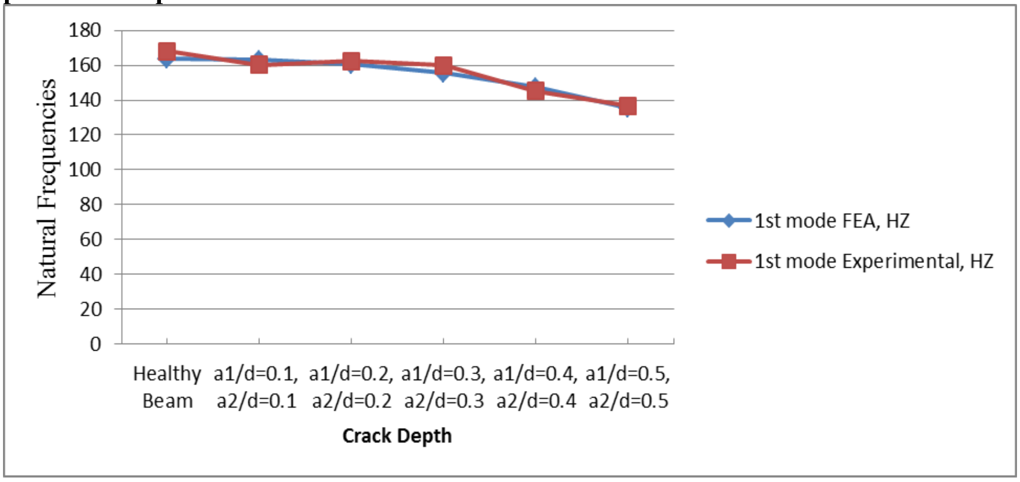

Fig.5 Comparison of FEA and Experimental results for different crack depth and e1=0.25, e2=0.55 for 1st mode of vibration.

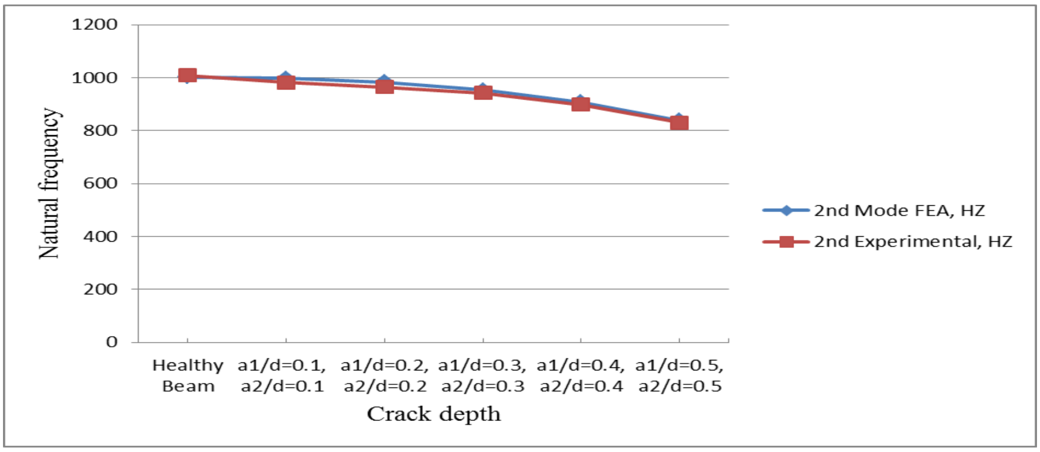

Fig.6 Comparison of FEA and Experimental results for different crack depth and e1=0.25, e2=0.55 for 2nd mode of vibration.

4.3 Variation of Natural Frequency of Vibration with Increase in Depth of Crack.

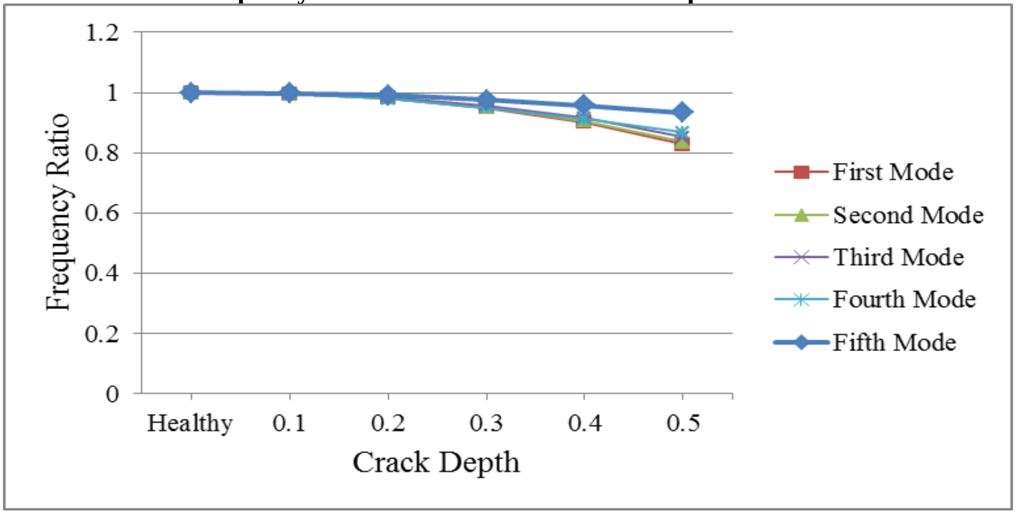

Fig.7 Natural Frequency ratio at different crack depths for e1=0.25 and e2=0.55

4.4 Variation of Mode Shapes of the Beam

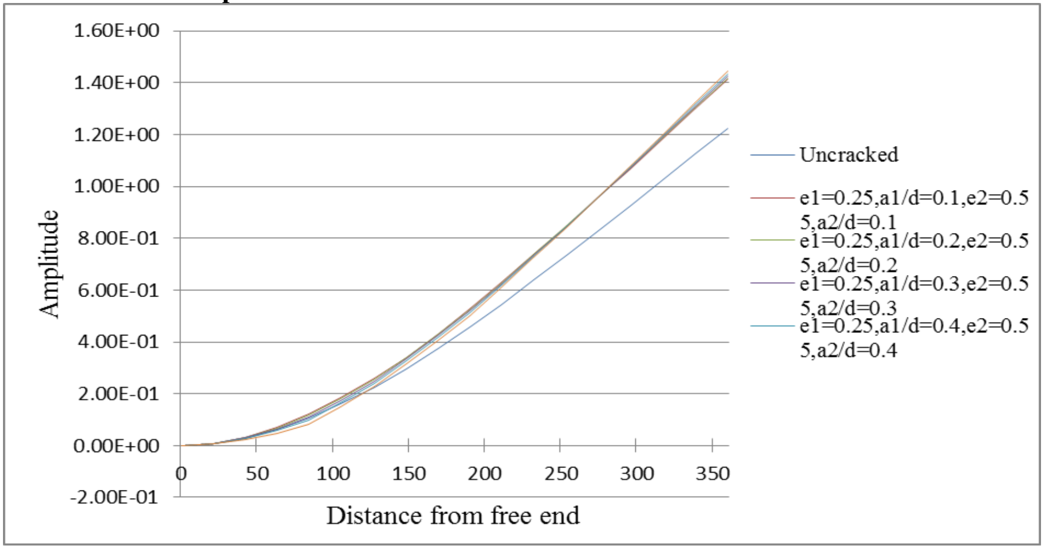

Fig.8 Mode shapes of 1st mode

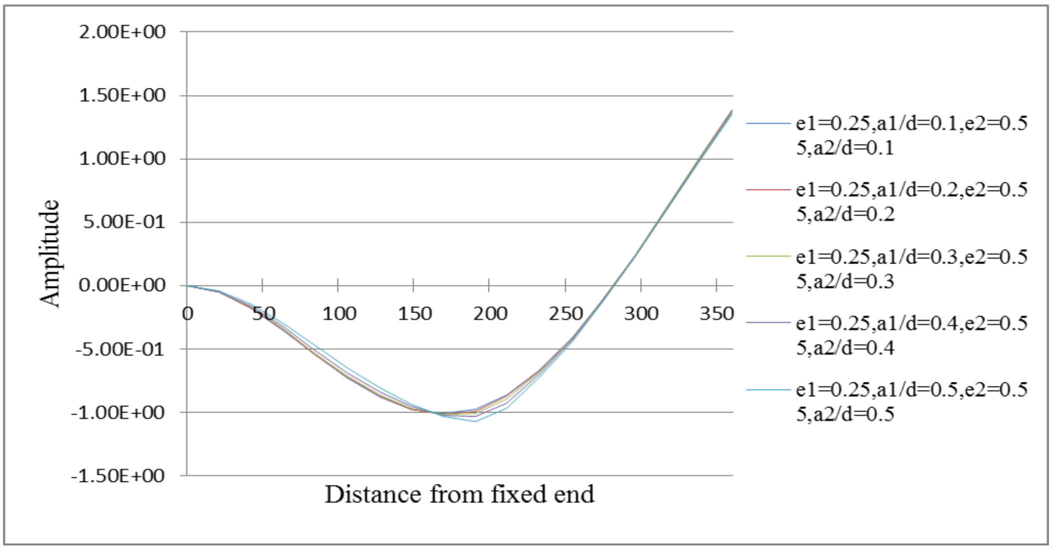

Fig.9 Mode shapes of 2nd mode

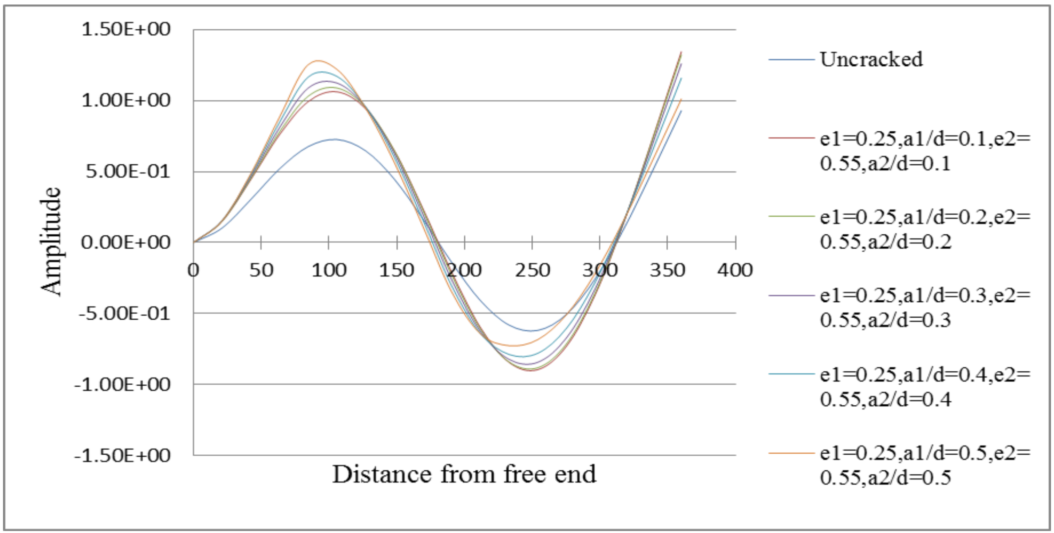

Fig.10 Mode shapes of 3rd mode

V. DISCUSSION

The Natural Frequency of the beam for first three modes of transverse vibration is extracted from ANSYS. The results obtained using Finite Element Analysis for the first three modes are compared with the results obtained using Experimental Modal Analysis of the beam. The results obtained by FEA and Experimental Modal Analysis show good agreement as shown in the figure 5 and figure 6. Also the variation of the Natural Frequencies of first three transverse modes with increase in crack depth is studied. The orientation of the crack in the structure caused the local flexibility. As shown in the figure 7 the Natural Frequency of vibration decreases with increase in depth of the crack. The mode shapes of the first, second and third modes of transverse vibration are extracted and plotted as shown in figures 8 to 10. It has been observed that the mode shapes of the healthy beam and the cracked beam has different shapes. This is because of increase in flexibility causes increase in amplitude of vibration.

VI. CONCLUSION

In this study the Finite Element Analysis of a shaft beam with two transverse cracks was done in ANSYS and its validation is done using Experimental Modal Analysis. Mode shapes of first three modes of transverse vibration are plotted and comparison of mode shapes of healthy and cracked shaft was done. Also the comparison of the values of natural frequency obtained by Finite Element Analysis is compared with the results of Experimental Modal Analysis. The study shows good agreement between Experimental modal analysis and Finite Element Analysis results. It is observed that the natural frequency of vibration of all three transverse vibrations decreases with increase in depth of the crack as the presence of crack in structural member introduces local flexibilities. The mode shapes of the first three modes of vibration are plotted on the graph and it can be seen that the introduction of the crack changes the shape of mode shapes.

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REFERENCES

[1] D.P. Patil, S.K. Maiti [2002], “Detection of multiple cracks using frequency measurements”, Engineering Fracture Mechanics 70, pp1553–1572.

[2] A.K. Darpe, K. Gupta, A. Chawla [2006], “Dynamics of a bowed rotor with a transverse surface crack”, Journal of Sound and Vibration 296, pp888–907.

[3] Athanasios C. Chasalevris, Chris A. Papadopoulos [2006], “Identification of multiple cracks in beams under bending”, Mechanical Systems and Signal Processing 20, pp1631–1673.

[4] Ashish K. Darpe [2007], “A novel way to detect transverse surface crack in a rotating shaft”, Journal of Sound and Vibration 305, pp151–171.

[5] K.M. Saridakis, A.C. Chasalevris, C.A. Papadopoulos , A.J. Dentsoras [2007], “Applying neural networks, genetic algorithms and fuzzy logicfor the identification of cracks in shafts by using coupled response measurements”, Computers and Structures 86 pp1318–1338

[6] Ashish K. Darpe [2007], “Coupled vibrations of a rotor with slant crack”, Journal of Sound and Vibration 305, pp172–193

[7] Sachin S. Naik, Surjya K. Maiti [2009], “Triply coupled bending–torsion vibration of Timoshenko and Euler–Bernoulli shaft beams with arbitrarily oriented open crack”, Journal of Sound and Vibration 324, pp1067–1085.

[8] Ashish K. Darpe [2007], “Dynamics of a Jeffcott rotor with slant crack”, Journal of Sound and Vibration 303, pp1–28

[9] Tejas H. Patel, Ashish K. Darpe [2007], “Influence of crack breathing model on nonlinear dynamics of a cracked rotor”, Journal of Sound and Vibration 311, pp953–972.

[10] A.S. Sekhar [2007], “Multiple cracks effects and identification”, Mechanical Systems and Signal Processing 22, pp845–878

[11] S.K. Georgantzinos, N.K. Anifantis [2008], “An insight into the breathing mechanism of a crack in a rotating shaft”, Journal of Sound and Vibration 318, pp279–295.