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Multiple Cracks Effects on Vibration Characteristics of Shaft Beam

Prof. D. R. Satpute[1], Prof. S. B. Belkar[2], Prof. M. S. Mhaske[3]

[1] Assistant Professor, Mechanical Engineering Department, Sandip Institute of Technology and research center, Nashik

[2] Head and Associate Professor, Mechanical Engineering Department, Pravara Rural Engineering College, Ahmednagar

[3] Assistant Professor, Mechanical Engineering Department, Pravara Rural Engineering College, Ahmednagar,

SavitribaiPhule Pune University, Pune, India

[1]satpute99@gmail.com

Abstract—Whenever a mechanical component is subjected to fluctuating stresses the crack is oriented in the component due to fatigue failure. The cracked component is failed due to most dangerous and frequent catastrophic failure without any prior indication. In this paper vibration analysis of cantilever shaft beam is done using Experimental Modal Analysis and Finite Element Analysis. First three Natural Frequencies of transverse vibration are determined and also the mode shapes of these modes of vibrations are extracted and plotted using ANSYS 14.5. The results obtained using Finite Element Analysis are compared with the Experimental Modal Analysis. The study shows good agreement between the results obtained using Finite Element Analysis and Experimental Analysis.

Keyword — Vibration Characteristics, Modal Analysis, Damage, Shaft Beam, Multiple Crack, Crack Detection, Condition Monitoring.

1. INTRODUCTION

Crack in the component if undetected results in to sudden failure without any prior indication. Different researchers has proposed different methods for mathematical modeling and crack detection .Ashish K. Darpe [1] present a novel way to detect transverse crack in a rotating shaft. He studied the behavior of simply supported shaft with transverse surface crack subjected to both bending and torsional vibration. K.M. Saridakis et al. [2] present the application of neural networks, fuzzy logic and genetic algorithm for the identification of cracks in shafts. In another research of Ashish K. Darpe [3] studied coupled vibrations of a rotor with slant crack. He model stiffness matrix for Timoshenko beam on concepts of fracture mechanics the behavior of the shaft slant crack was compared with transverse surface crack. Sachin S. Naik and Surjya K. Maiti [4] studied triply coupled bending and torsion vibration of Timoshenko and Euler–Bernoulli shaft beams with arbitrarily oriented open crack. The changes of compliance coefficients with angular position of the crack was presented. The study shows that the frequency of vibration decreases with increase in distance of the crack from free end. D. P. Patil and S. K. Maiti [5] studied detection of multiple cracks in the beam using frequency measurement. The results gives linear relationship between damage parameters and natural frequency of vibration of beam. A. K. Darpe et al. [6] studied dynamics of a bowed rotor with a transverse crack. They concluded that amplitude and directional nature of higher harmonic components of bowed rotor remains unchanged, however rotating frequency component changes in magnitude. Athanasios C. Chasalevris and Chris A. Papadopoulos [7] studied identification of multiple cracks in beams under bending load. They formulate compliance matrix of two DOF as a function of both crack depth and angle of rotation of the shaft. Their proposed method gives not only depth and size of the crack but also angular position of the crack. Ashish K. Darpe [8] studied dynamics of a Jeffcott rotor with slant crack. The Stiffness coefficients based on flexibility coefficients was used to model equation of motion. The study shows that the lateral and longitudinal stiffness is more for slant crack as compared to transverse crack. The trends of 3 x frequency component can be used to detect and to identify the type of crack. Tejas H. Patel, Ashish K. Darpe [9] present influence of crack breathing model on nonlinear dynamics of a cracked rotor. The study shows that for the rotor with deeper crack, the crack model displays chaotic, sub harmonic and quasi-periodic motion. A.S. Sekhar [10] presented a review on multiple cracks effects and their identification in which he summaries different methods of single as well as multiple crack detection. S.K. Georgantzinos, N.K. Anifantis [11] present the study of breathing mechanism of a crack in a rotating shaft beam. He studied the behavior of the transverse crack in cantilever shaft with two different cases of straight and curved front of the shaft beam. Flexibility coefficients were calculated on the basis of energy principle. He concludes that the breathing behavior depends on depth and shape of the crack. In the present work the Experimental Modal Analysis of the shaft beam with multiple cracks is done and the results are compared with results of Finite Element Analysis performed in ANSYS 14.5.

2. EXPERIMENTAL MODEL ANALYSIS

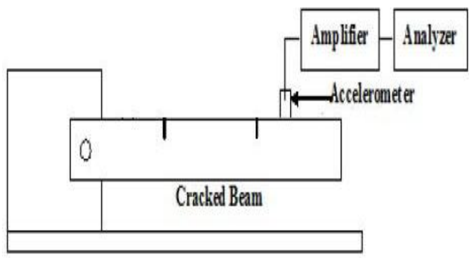

Fig. 1Test rig for Experimental Modal Analysis

The Natural frequencies and mode shapes for cantilever beam without crack and with two cracks of different crack depths and positions is determined. The results obtained experimentally are validated with the results obtained by FEA analysis. The method described has been applied to a cracked Euler Bernoulli's beam. The FFT analyzer used is 4 channelBruel and Kjaer make. The piezoelectric, miniature type unidirectional accelerometer is used to sense the frequency response function. The accelerometer is mounted on the beam by using special wax. The accelerometer is mounted just near the crack to capture the correct input signals. The impact hammer is used to excite the beam whose frequency response function is to be captured. The beam is tapped gently using an impact hammer. The range of excitation of impact hammer is 1-4000 Hz.

Specifications and properties of test specimen:

Diameter of the beam = 0.03 m

Length of the beam = 0.360 m

Width of the crack = 0.27mm

Elastic modulus of the beam = 2 x 1011 N/m2

Poisson's Ratio = 0.3

Density = 7850 Kg/m3

End conditions of the beam = One end fixed and other end free (Cantilever beam)

3. FINITE ELEMENT ANALYSIS OF BEAM

The Finite Element Analysis of the beam was done using ANSYS 14.5 software. A 3D model of the shaft beam was prepared and to model crack of width 0.27mm blocks of 0.27mm width was created and subtracted from the shaft model. The 3D model of the shaft is meshed with 20node186 element. The material used for the beam has following properties,

1) Modulus of Elasticity= $2x10^{11}$ N/m^2,

2) Poisons ratio= 0.3,

3) Mass Density= 7850 kg/m^2.

The degrees of freedom of all the elements at one end are made zero so as to get boundary conditions as cantilever beam. A Block Lanczos method is used for extraction of natural frequencies vibration. The first three modes of transverse vibration are extracted. The mode shapes of the first three modes of transverse vibration are plotted.

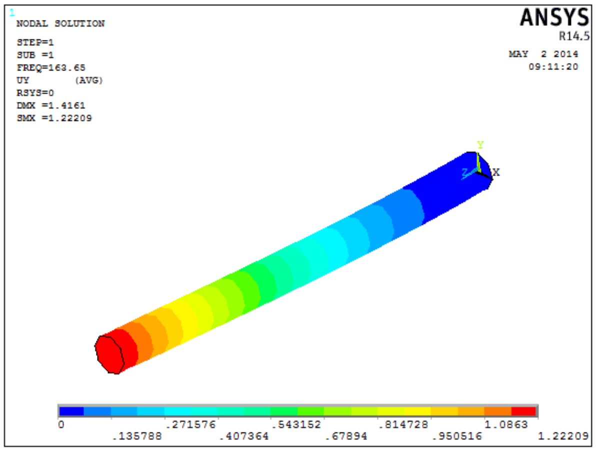

Fig.2 1st Mode of Vibration (Healthy beam)

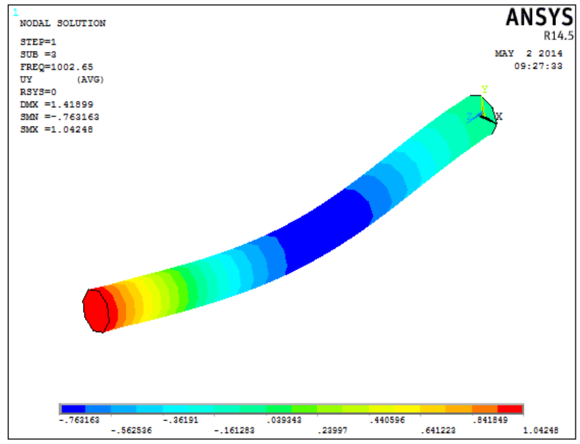

Fig.3 2nd Mode of Vibration (Healthy beam)

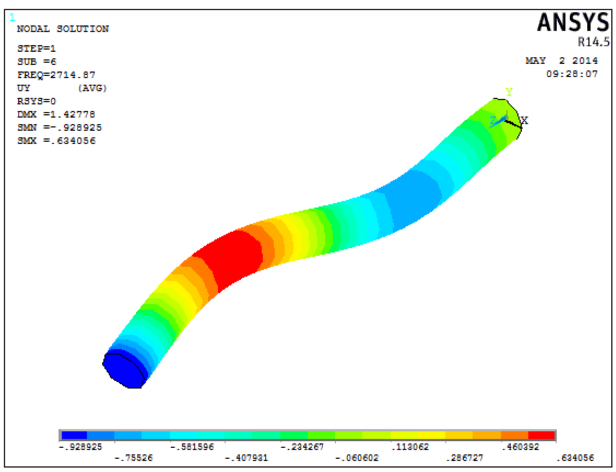

Fig.4 3rd Mode of Vibration (Healthy beam)

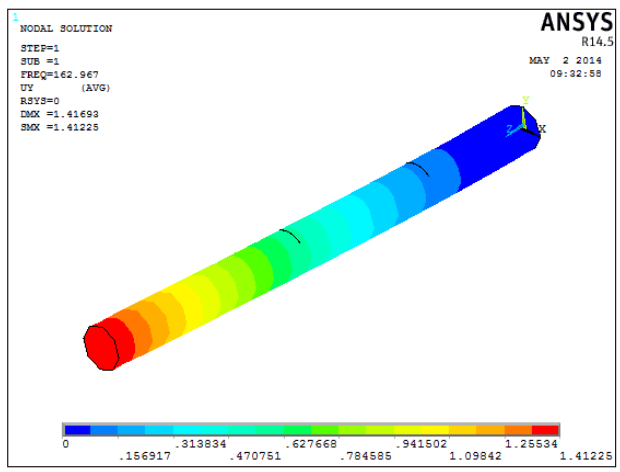

Fig.5 1st Mode (e_1=0.25, a_1/d=0.1, e_2=0.55, a_2/d=0.1)

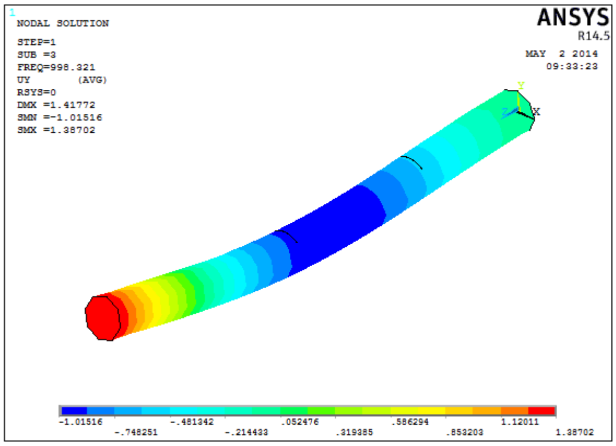

Fig.6 2nd Mode (e_1=0.25, a_1/d=0.1, e_2=0.55, a_2/d=0.1)

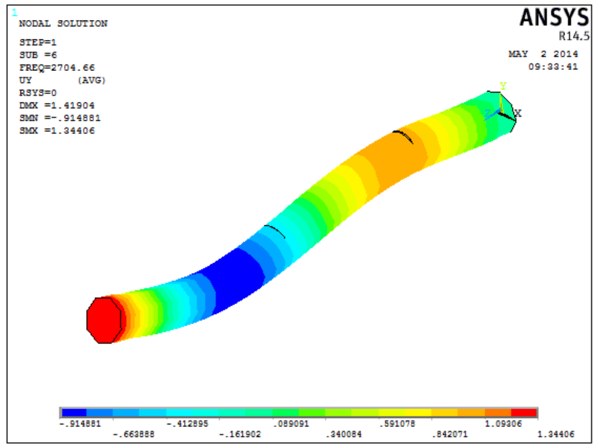

Fig.7 3rd Mode (e_1=0.25, a_1/d=0.1, e_2=0.55, a_2/d=0.1)

4. RESULTS

4.1 EXPERIMENTAL AND FEA RESULTS

The nomenclatures used are as follows,

L Length of the beam.
L_1 Distance of first crack from fixed end.
L_2 Distance of second crack from fixed end.
e_1 Ratio of L_1 and L.
e_2 Ratio of L_2 and L.
a_1 Depth of the first crack
a_2 Depth of the second cracks.
a_1/d Crack depth ratio of first crack.
a_2/d Crack depth ratio of second crack.

Table 1. Experimental and FEA results

Sr. no.	e1	a1/d	e2	a2/d	1st mode FEA, HZ	1st mode Experimental, HZ	2nd Mode FEA, HZ	2nd Experimental, HZ
1	Uncracked beam				1	1	1	1
2	0.25	0.1	0.55	0.1	0.995845	0.954458864	0.9957311	0.974742063
3	0.25	0.2	0.55	0.2	0.98069	0.966424574	0.98090963	0.95703373
4	0.25	0.3	0.55	0.3	0.949771	0.951660912	0.95078795	0.916974206
5	0.25	0.4	0.55	0.4	0.901192	0.864210025	0.90463794	0.891646825
6	0.25	0.5	0.55	0.5	0.827437	0.81343017	0.83648514	0.823263889

4.2 Comparison of Experimental and FEA Results

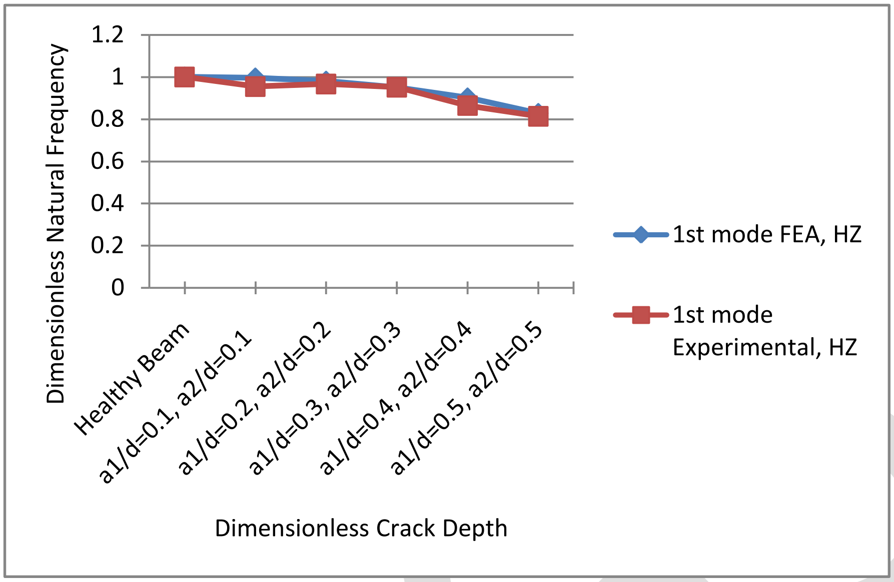

Fig.8 Comparison of FEA and Experimental Modal Analysis Results for 1st mode of vibration

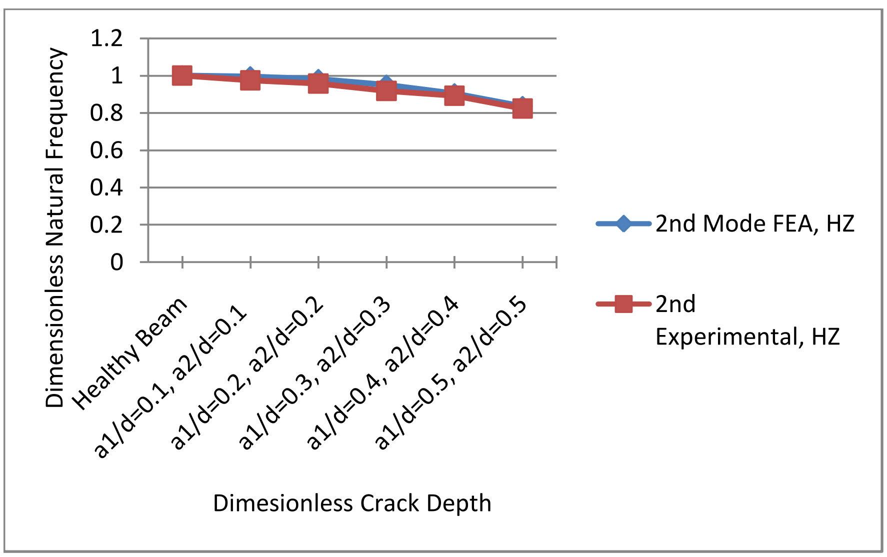

Fig.9 Comparison of FEA and Experimental Modal Analysis Results for 2nd mode of vibration

4.3 Variation of Natural frequency of vibration with increase in depth of crack

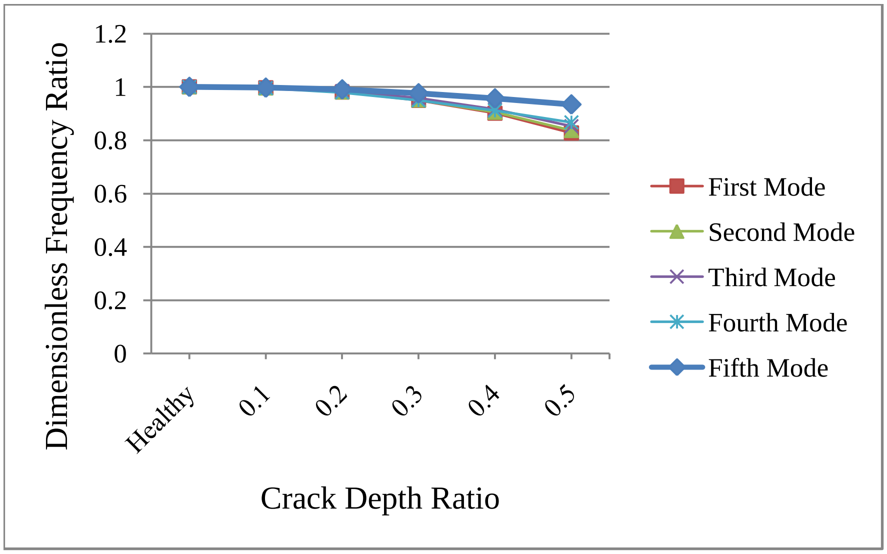

Fig.10 Natural Frequency ratio at different crack depths for e_1=0.25 and e_2=0.55

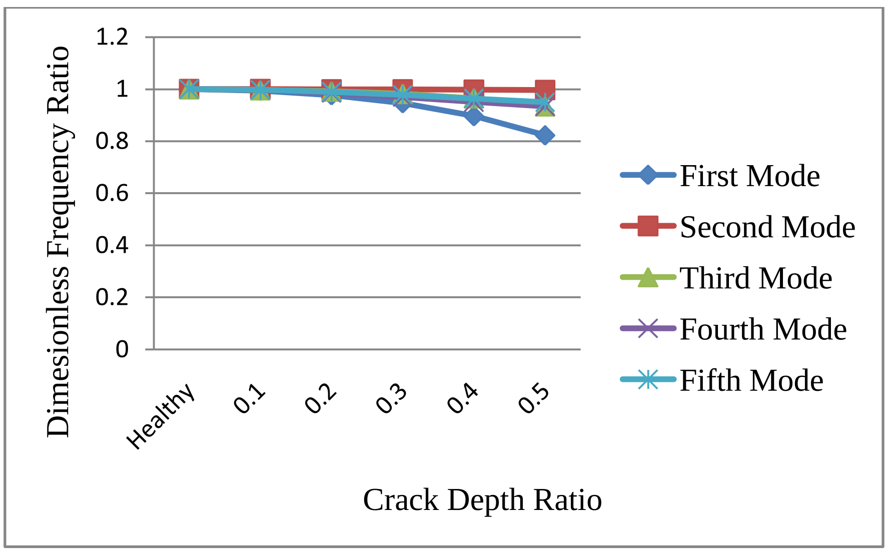

Fig.11 Natural Frequency ratio at different crack depths for e_1 =0.3 and e_2 =0.2

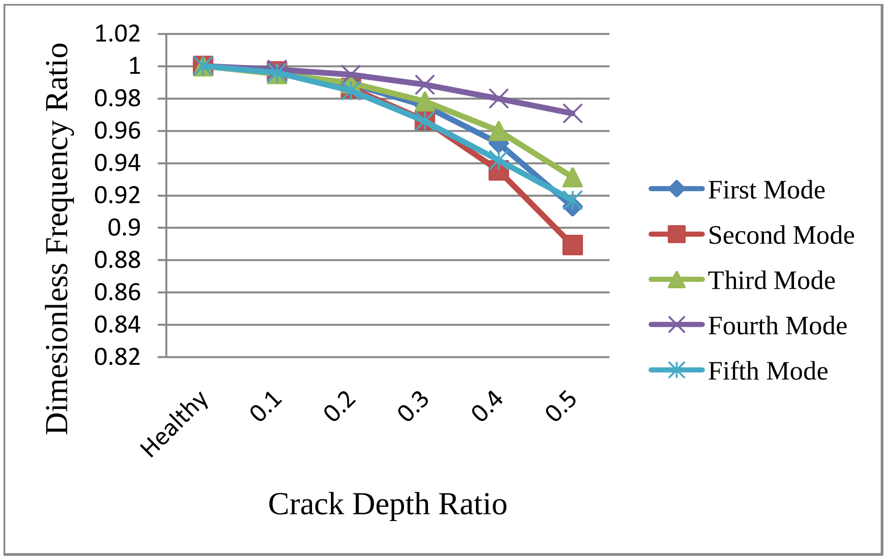

Fig.12 Natural Frequency ratio at different crack depths for e_1 =0.3 and e_2 =0.4

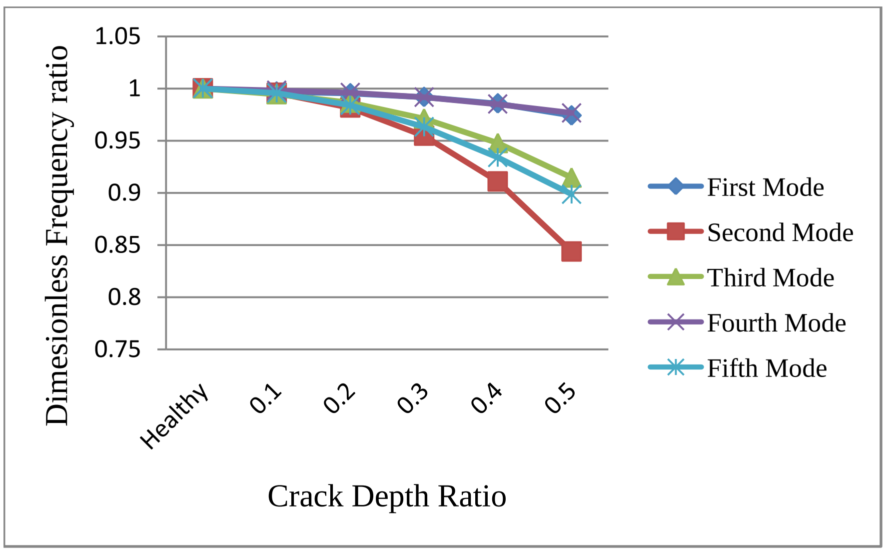

Fig.13 Natural Frequency ratio at different crack depths for e_1 =0.3 and e_2 =0.6

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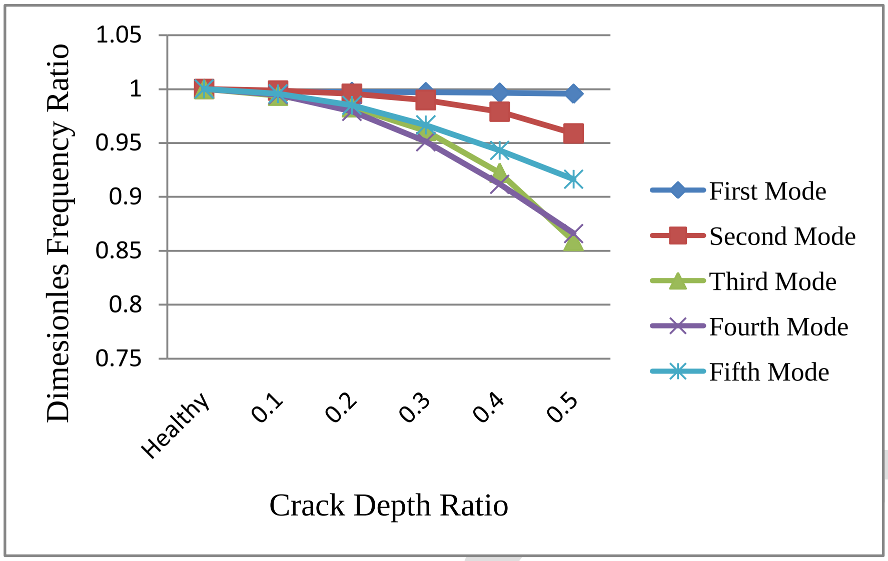

Fig.14 Natural Frequency ratio at different crack depths for e_1 =0.3 and e_2 =0.8

4.4 VARIATION OF DIFFERENT MODES OF VIBRATION WITH INCREASE IN CRACK DEPTH

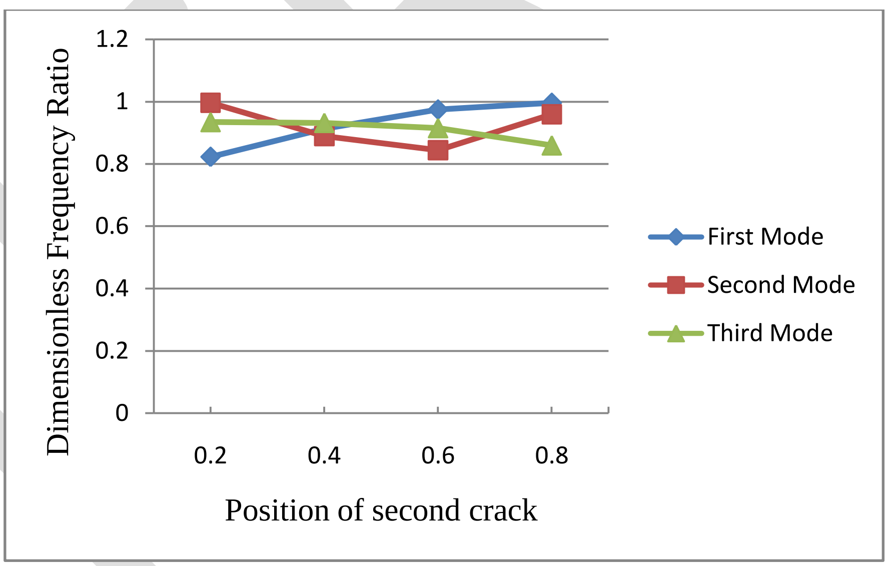

Fig.15 Natural frequency ratio at different crack positions for L_1=0.25, a_1=0.1 and a_2=0.1

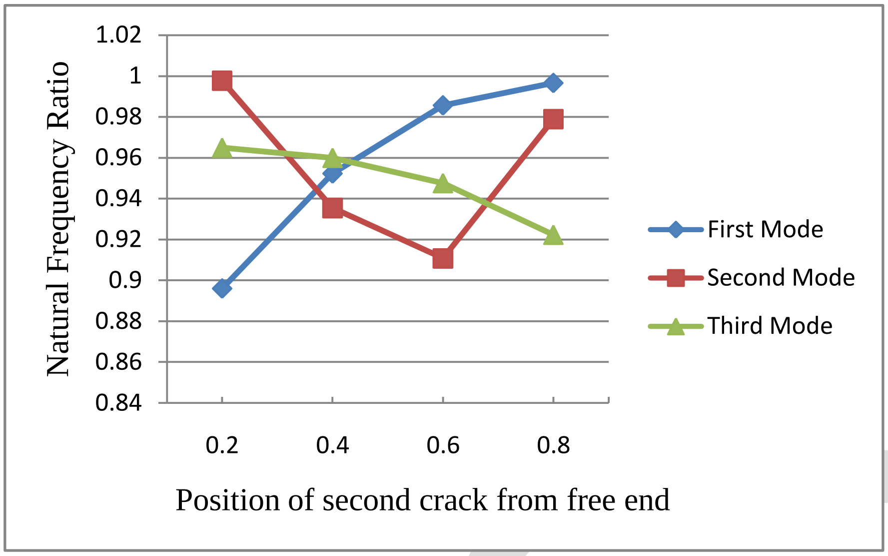

Fig.16 Natural frequency ratio at different crack positions for L_1=0.25, a_1=0.2 and a_2=0.2

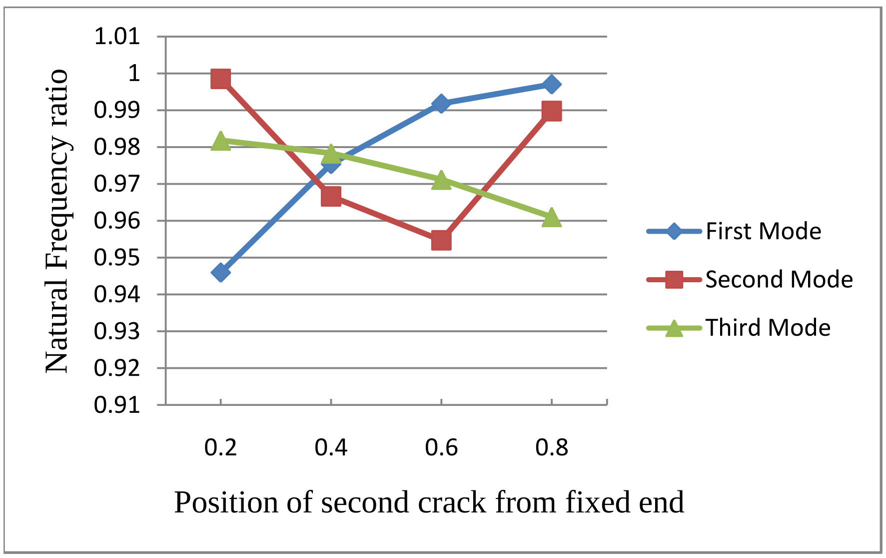

Fig.17 Natural frequency ratio at different crack positions for L_1=0.25, a_1=0.3 and a_2=0.3

4.5 VARIATION OF DIFFERENT MODES OF VIBRATION WITH INCREASE IN CRACK DEPTH

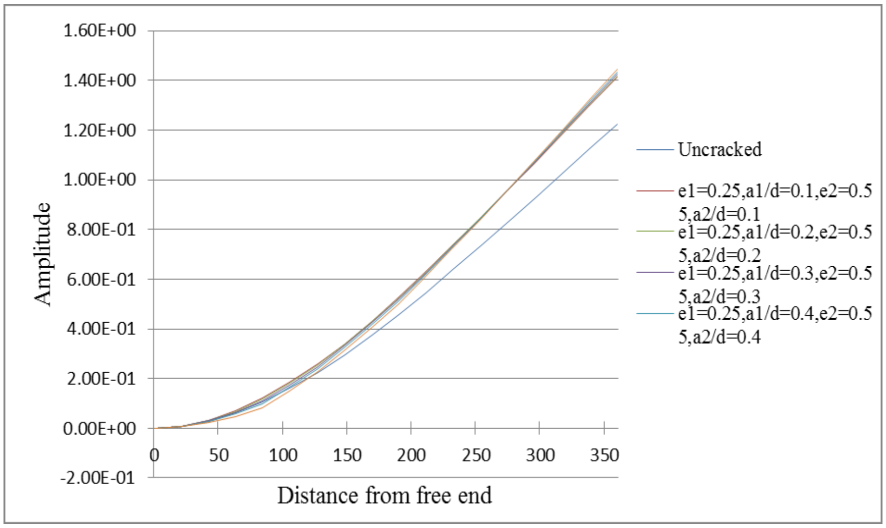

Fig.18 Mode shapes of 1st mode of vibration

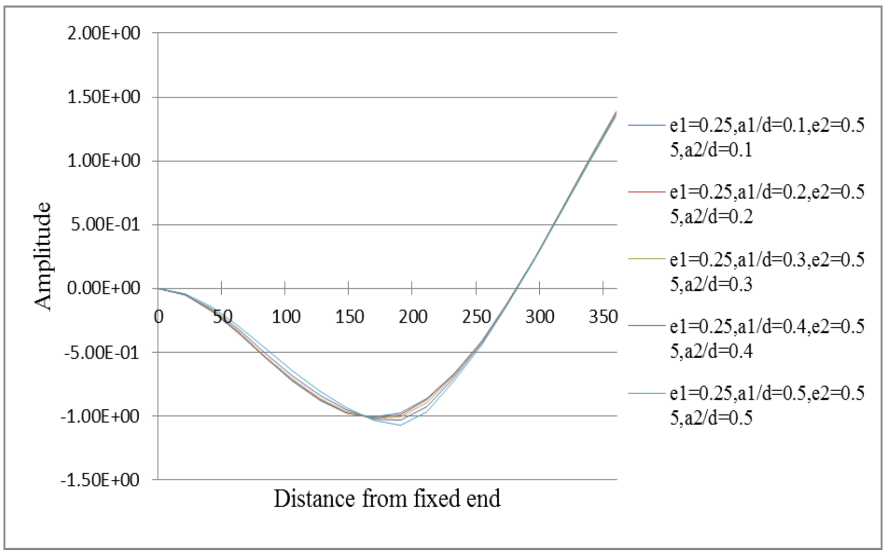

Fig.19 Mode shapes of 2nd mode of vibration

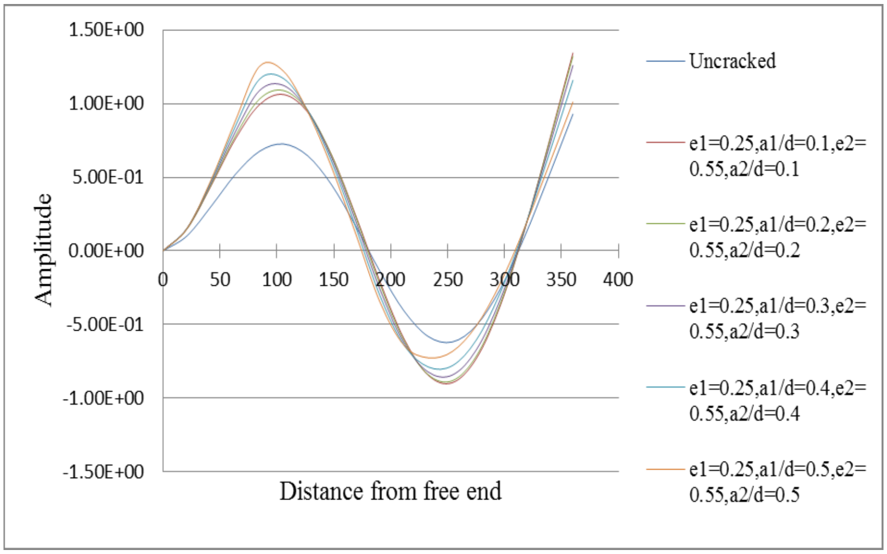

Fig.20 Mode shapes of 3rd mode of vibration

5. DISCUSSION

The Natural Frequencies of transverse vibration of the beam for first three modes are extracted from ANSYS 14.5. The results obtained using Finite Element Analysis for the first three transverse modes are compared with the results obtained using Experimental Modal Analysis of the shaft beam. The results obtained by FEA and Experimental Modal Analysis are in good agreement as shown in the figure 8 and figure 9. Also the variation of the Natural Frequencies of first three modes with increase in crack depth is studied. The oriented crack introduces local flexibility in the structure. The increase in flexibility results in increase in amplitude of vibration and decrease in natural frequency of vibration. As shown in the figure 10 to 14 the Natural Frequency of vibration decreases with increase in depth of the crack. This behavior is same for all positions of the cracks considered. Figure 15 to 17 shows the variation of the natural frequency ratio for various positions and depths of second crack. It can be seen that the frequency ratio of first mode increases with increase in distance of the crack from fixed end. Also, the frequency ratio of second and third mode decreases with increase in distance of the crack from fixed end. The mode shapes of the first, second and third modes of vibration are extracted using ANSYS and plotted as shown in figures 18 to 20. It has been observed that the mode shapes of the healthy beam and the cracked beam has different shapes as indicated in figures. This is because of increase in flexibility causes increase in amplitude of vibration.

CONCLUSION

In this work the Finite Element Analysis of a shaft beam with two transverse cracks was done in ANSYS 14.5 and its validation is done using Experimental Modal Analysis. The Mode shapes of first three modes of transverse vibration are plotted and comparison of mode shapes of healthy and cracked shaft beam was done. Also the comparison of the values of natural frequencies obtained by Finite Element Analysis is compared with the results of Experimental Modal Analysis.

1) The study shows good agreement between Experimental modal analysis and Finite Element Analysis results.
2) It is observed that the natural frequency of vibration of all three transverse modes of vibrations decreases with increase in depth of the crack as the presence of crack in structural member introduces local flexibilities.
3) As the position of the second crack changes from fixed end to free end the Natural Frequency of vibration increases for first mode but it decreases for second and third modes of vibration.
4) 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.
5) As the position of the second crack changes from fixed end to free end the mode shapes also shifts slightly with the crack.
6) The mathematical Modeling of the shaft is done using strain energy release rate approach.

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