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Effect of crack depth of Rotating stepped Shaft on Dynamic Behaviour

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Abstract - ***This study describes dynamic analysis of stepped shaft with single crack of mild steel material. The effects of crack depth, crack length & RPM on amplitude of acceleration are obtained through experimentation and finite element analysis. Obtained results from analysis are benchmarked from experimentation. It is observed that there is 33% increase in amplitude of acceleration of cracked shaft. Also maximum deviation of 11.4 % is observed in results of experimentation and finite element analysis.***

Key Words: *single cracked stepped shaft, crack depth ratio, amplitude of acceleration.*

1. 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.

2. EXPERIMENTATION

Design and development of a test rig for experimentation with artificial transverse crack on rotating shaft will be done. The frequency response curve will be obtained for cracked & intact shaft. By using FFT analyzer, the frequency response in the form of signal will be stored & processed. An experimental set up will be designed & developed for measuring frequency response of the rotor systems. Experimental setup consist of a shaft with two test frame support bearing & driven by a variable speed motor. The backside end of the continuous shaft will connect to an electric motor & driven at a speed of 500 rpm to 2500 rpm. The artificial crack will be developed on shaft by using any convenient method.

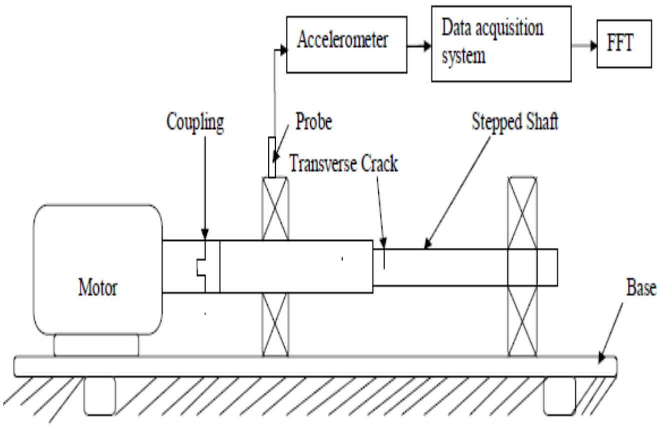


Fig.1 Schematic representation of proposed experimental setup.

A piezoelectric accelerometer will be placed on the test rotor system to measure the vibration. The Fast Fourier Transform (FFT) analyzer will be used to acquire the vibration data. The experiments would be performed on separate healthy shaft and on the shaft having transverse crack. The dynamic analysis will be carried out for different speeds. Figure.2 shows local view of experimental set up.

Fig.2 Local view experimental setup

3. 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. Dynamic analysis has been carried out for crack location 200mm, 350mm, 500 mm and 650 mm. Parametric modeling of stepped shaft by using ANSYS software is prepared. Material properties of MS 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 500-2500 rpm.

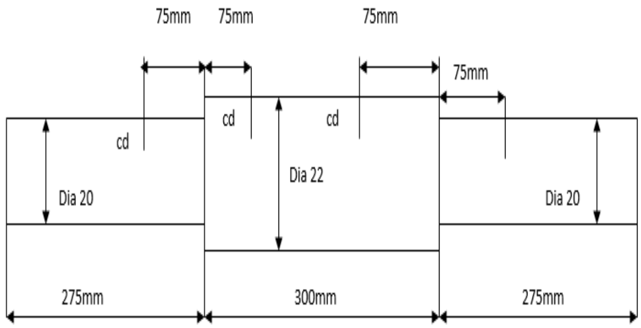
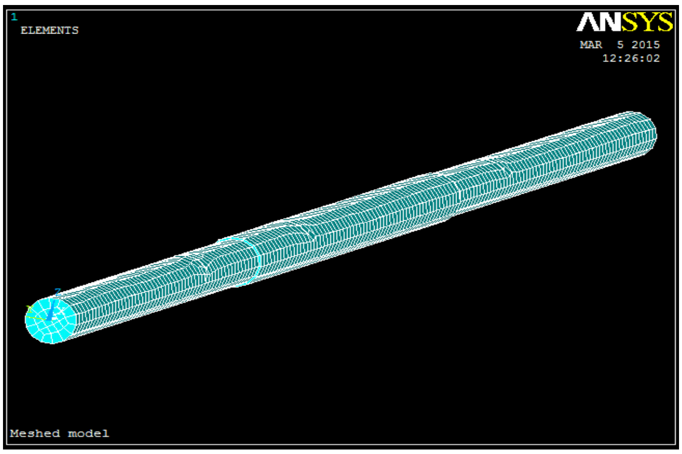


Fig.3 Schematic of stepped shaft with different crack location



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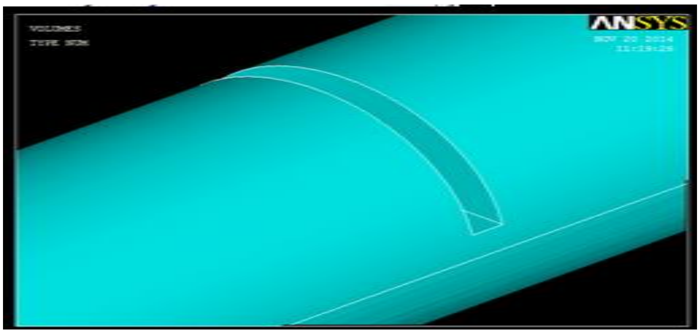
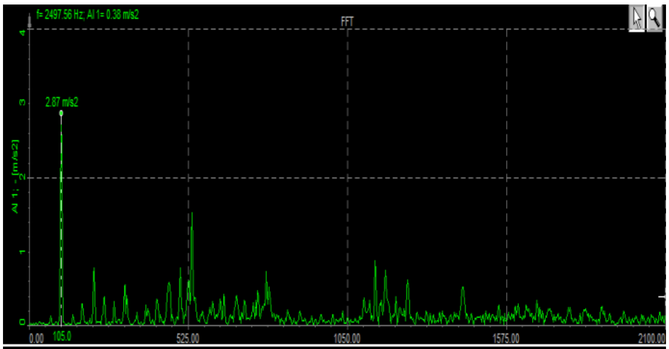


(b)

Fig 4: Meshed model (a) Stepped shaft with Crack location (b)

4. RESULT AND DISCUSSION

The dynamic analysis at variable rotational speeds is done for the shafts containing single transverse crack. For the analysis one shaft is intact (i.e. no crack exists in shaft) and other with different crack depth ratios are considered. Also, the dynamic analysis is done for the shafts with different crack depth ratios. The results were obtained in frequency domain using Fast Fourier Transform (FFT) and these results are discussed below. It gives the output in the form of graph between acceleration verses frequency. In the experiments, the shaft is supported on ball bearings. One case of experimentations discussed as follow. It consists of variation of crack depth and crack location from right end.



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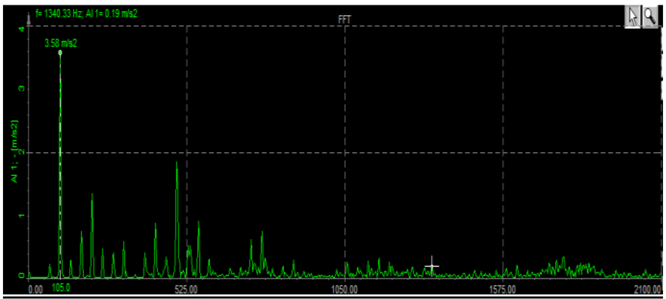

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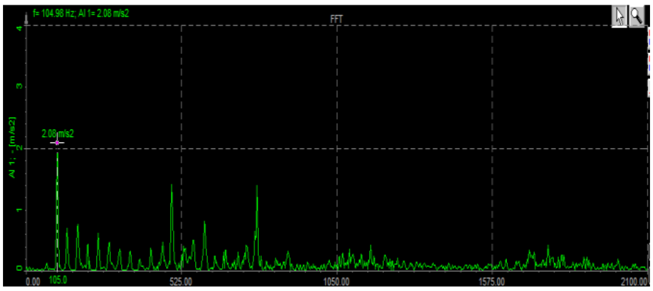

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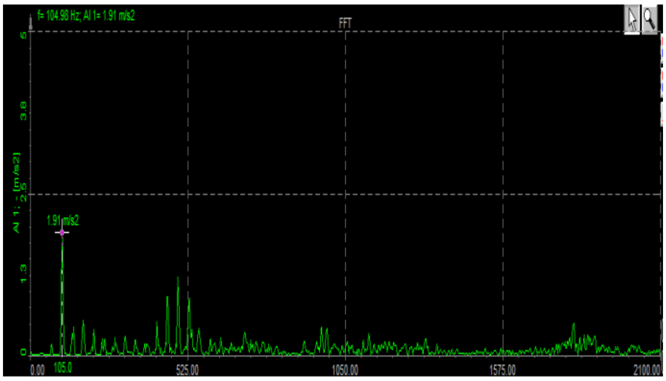

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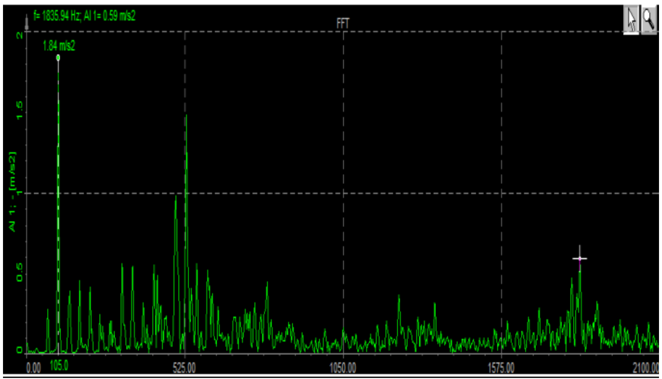
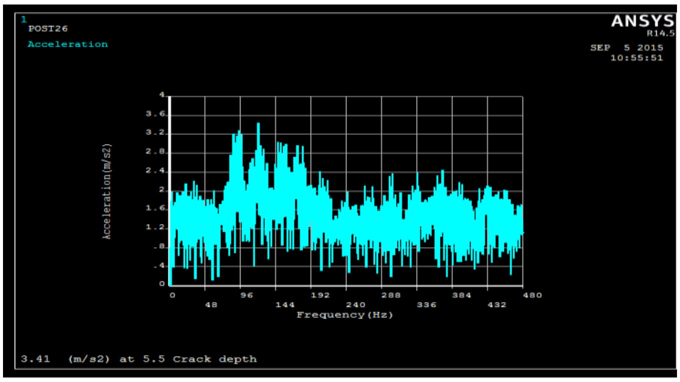


(j)

Fig. 5 results of FFT (amplitude vs. frequency)
(f)Crack depth 4.4mm & 2000RPM
(g)Crack depth 5.5mm &2000 RPM
(h)Crack depth 7.7mm &2000 RPM
(i)Crack depth 4.4mm &2000 RPM
(j)Crack depth 5.5mm &2000 RPM



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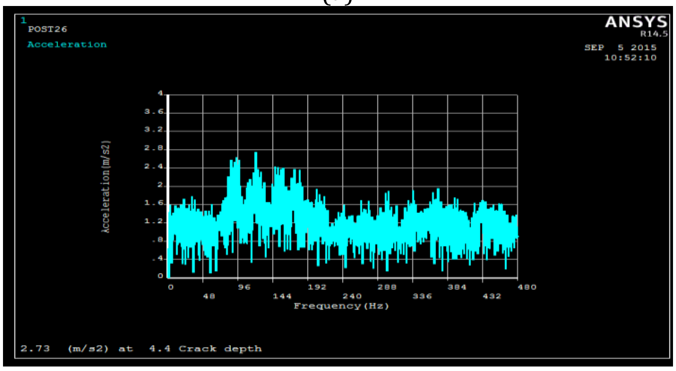

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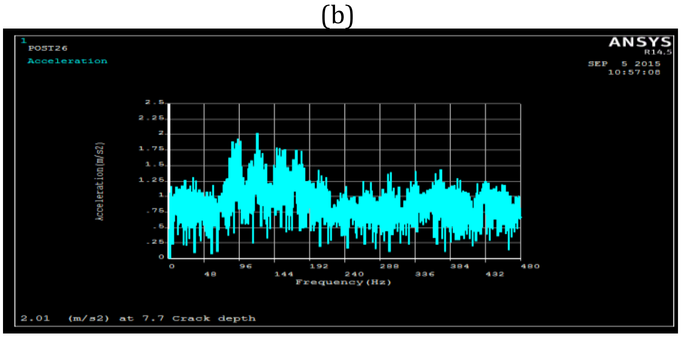

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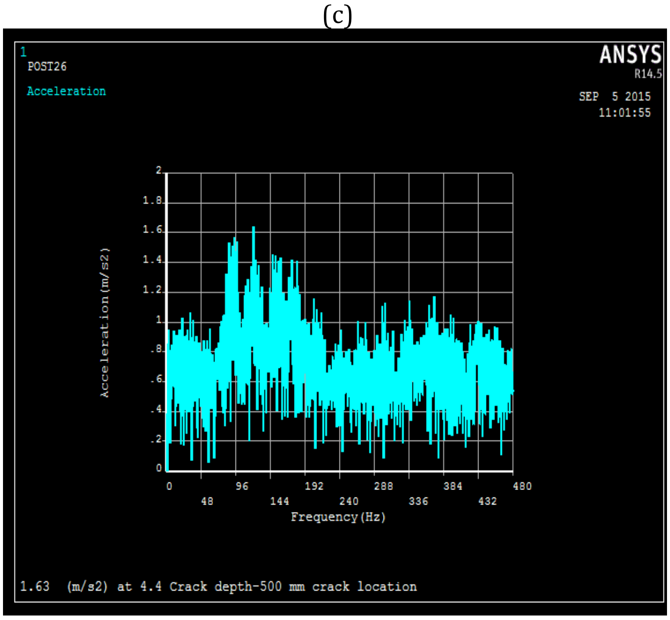

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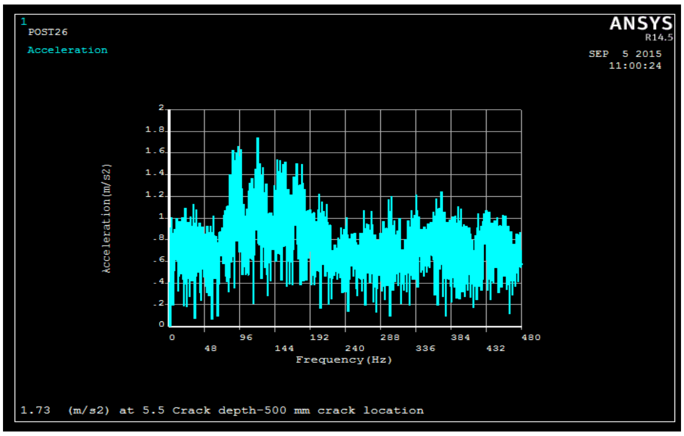

(e)

Fig. 6 Results of FEA(amplitude vs. frequency)
(a) Crack depth 4.4mm &crack location 350mm.
(b) Crack depth 5.5mm &crack location 350mm.
(c) Crack depth 7.7mm &crack location 350mm.
(d) Crack depth 4.4mm &crack location 500mm.
(e) Crack depth 5.5mm &crack location 500mm.

Results of experimentations are compared with finite element analysis .Fig 6 shows results of FEA.All cases are solved.i.e.2000rpm .Following table shows maximum percentage deviation of results.

Table -1: Comparison of results

Sr.No	Amplitude of acceleration (m/s2)		% Deviation
	Experimentation	FEA	
1	2.87	2.73	4.88
2	3.58	3.41	4.75
3	2.08	2.01	3.37
4	1.91	1.73	9.42
5	1.84	1.63	11.4

5. CONCLUSION

The conclusions obtained are summarized as Follows.

Dynamic analysis of stepped cracked shaft has been carried out successfully. Amplitudes of vibration for cracked stepped shaft at constant speed 2000 rpm are 2.87m/s2, 3.58 m/s2, 2.08 m/s2 and 1.91 m/s2 and 1.84 m/s2 respectively. Hence, as crack depth of stepped shaft increases, amplitude of vibration increases. When results of experimentation are compared with results of finite element analysis then maximum deviation of 11.4 % is observed for the stepped cracked shaft.

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