CRACK DETERMINATION IN PROPELLER SHAFT USING NATURAL FREQUENCY

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ABSTRACT

Present work gives an overview of cracks determination in material using natural frequency method and its application to current engineering problems. In this technique, comparison between actual natural frequency (without crack) and frequency due to crack propagation is made using Euler Beam theory. When cracks are present in structure, natural frequency of material deviates from its original frequency and result difference will measure in term of crack. Whole analysis procedure starting from modelling, meshing and result interpretation done on well-known numerical tool ANSYS. The main aim of proposed study is to detect critical areas especially crack initiative zone before doing actual fabrication of components and avoid the breakage of it. Effects of a breathing crack on the vibratory characteristics of a rotating propeller shaft are investigated. Results of numerical Finite Element Method (FEM) are validated using experimental apparatus called acoustic emission technique.

Keyword: *Natural frequency, ANSYS, Finite Element Method, acoustic emission technique.*

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1. INTRODUCTION

The initiation, development and propagation of a crack represents the most common and important beginning of failure in engineering structures. For rotating shafts, a propagating fatigue crack can lead to have detrimental effects on the reliability of a process where these vital parts are subjected to very arduous working conditions in harsh environment. It is one of the most serious causes of accidents and, an early warning is essential to extend the durability and increase the reliability of these machines. Today it is well known that a crack or a local defect in a structural member introduces a local flexibility which affects its vibration response. Thus, the dynamic characteristics have to be analysed in order to detect the existence and progression of cracks and develop monitoring methodology. In present paper, we discussed the different method of detecting crack in rotating propeller shaft and its analysis through finite element modelling. Major objective of this paper include finding the relationship between the natural frequency and vibrational characteristic of model, Effect of radial and transverse crack on natural frequency, finding nature of growth etc.

2. LITERATURE REVIEW

Tlaisi1 et al [1]: prospectors identify the presence of a crack in a cylindrical overhanging shaft with a propeller at the free end proved by experimental and numerical investigations. Shaft response parameters for lateral (using an Accelerometer) and torsional vibrations (using shear strain gages fixed at three different locations) are obtained using the modal analysis software. A numerical method was developed for determining the location of a crack in varying depths when the lowest three natural frequencies of the cracked beam are known. S. P. Leleand and S.K. Maitiuse had done frequency measurements for detection of location of crack in beams.

M. Messenia et al, [2]: worked on the natural frequency determination of a cracked reinforced concrete beam. They predicted the natural frequencies of a beam as a function of the maximal moment which was applied to the beam. This is experimentally validated with small-scale models and it is shown how that may be used to assess the damage of a beam. Mahdi Haidari et al, uses a continuous model for flexural vibration of beams with a vertical edge crack including the effects of shear deformation and rotary inertia is presented. The governing equation of motion for the beam has been obtained using Hamilton principle. The equation of motion is solved with a modified weighted residual method, and the natural frequencies and mode shapes are obtained. The results are compared to the results of similar model with Euler–Bernoulli assumptions and finite element model to confirm the advantages of the proposed modelling the case of short beams. Recently, many researchers have been dealing with the bifurcation and chaotic behaviour of a cracked rotating shaft.

Chen and Dai [3]: investigated the nonlinear dynamics of a cracked rotor system with viscoelastic supports. A linear spring was used to model the cracked transverse section, and truncated time-varying cosine series are utilized to account for the breathing mechanism of the crack. With various combinations of the rotor system parameters, the authors observed bifurcation, periodic of NT period, quasi-periodic and chaotic dynamical response. With the aim of developing an online crack detection method.

Zuo and Curnier [4]: have used bilinear model to characterize the vibrational response of a cracked rotating shaft. The authors, first, examined the 1 Degree of Freedom (DOF) system then studied the behaviour of a system with 2 DOF; By extending the Rosenberg normal mode notion for smooth and symmetric nonlinear systems to conwise linear systems, they defined the nonlinear modes of the bilinear system which were calculated numerically, and for simple cases, analytically. The application of this original method to systems with high number of DOF is complicated and would lead to high computation costs.

3. COMPUTATIONAL METHODOLOGY

Present analysis is carried out on robust, seamless, easy to use numerical tool “ANSYS”. Natural frequency calculated based on input from user as pre-processing data. Solvers solve simulation using the numerical technique and we can check the results in post-processing phase. We divide our methodology into following 3 phases:

1. Pre-processing
   i. Geometry and mesh generation
   ii. Material properties and sections details
   iii. Required Boundary conditions and loads etc.

2. Solver:
   i. Detail about the solver
   ii. Numerical techniques

3. Post-processing
   i. Contour plot
   ii. Report creations
   iii. History plot etc.

3.1 Problem definition and objectives:

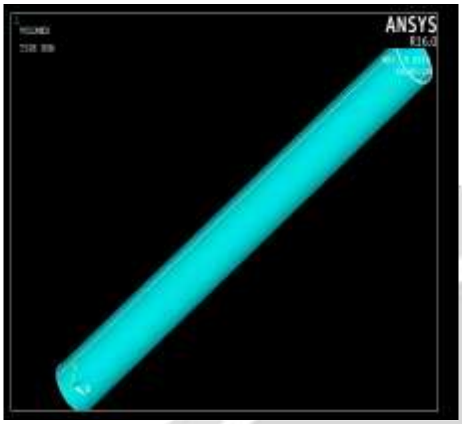
Whirling of shaft is very critical phenomenon seen in daily life with Passenger car, small truck as they need torque transmission capacity more than 3500 Nm and speed 6500 rpm. To avoid vibration problem, shaft length should be large enough to attain the desired specification but due to space limitation we can’t use bar of wider length. Because of such high load on engine, output shaft on engine vibrates vigorously at particular speed and attained high vibration amplitude called Critical speed of vibration. The main aim of proposed study is to study the vibrational characteristic of propeller shaft and detect the location of crack propagation using FEM Modal analysis. Natural frequency of healthy shaft and cracked model of 1 mm and 2 mm are analysed. Material properties of propeller shaft are standard and as shown in below table 1.

3. 2 Pre-processing:

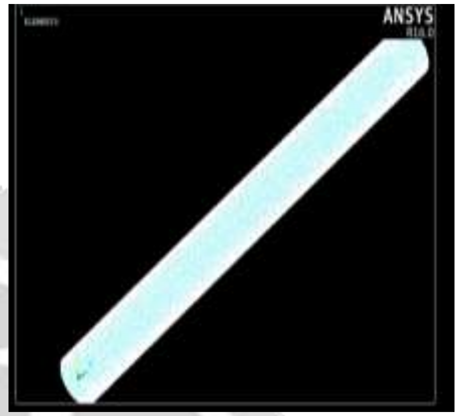
We prepare the geometric model of desired dimension on ANSYS workbench itself and has done meshing using SOLID 186 sweep mesher as it is very convenient to evaluate structural result because required less computational time and very flexible to attain the exact shape of model. Number of elements are measures nearly as 0.2 million. Geometry for shaft without crack called as “Healthy shaft”and shaft with crack modelled as shown below with mesh generated shown in figure 1.

We selected 2 model conditions for crack of 2 mm and crack of 3mm with loading condition as below:

1. Cantilever load – Compare the natural frequency with Healthy shaft, axial crack (2 and 3mm), Radial crack (2 and 3 mm)
2. Simply supported load: Compare the natural frequency with Healthy shaft, axial crack (2 and 3mm), Radial crack (2 and 3 mm)



(a) Geometric model – Healthy shaft



b) Mesh generation

(c) Axial crack geometry (2 mm)

d) Radial crack (2mm)

Fig-1: Geometry and mesh generation

Desired solid section is applied with necessary standard material properties as shown in following table 1.

Table -1: Material Properties of Propeller shaft

Sr. No.	Properties	Structural steel
1	Young's Modulus,(E)	2.0* 10^5 MPa
2	Poisson's Ratio	0.30
3	Tensile Ultimate strength	460MPa
4	Tensile Yield strength	250 MPa
5	Compressive yield strength	250MPa
6	Density	7850kg/m3
7	Behavior	isotropic

3.3 Solver

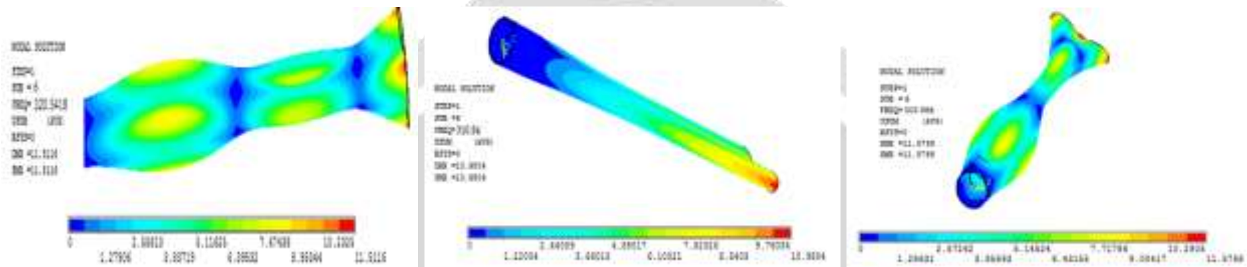
The solution phase deals with the solution of the problem according to the problem definitions. All the tedious work of formulating and assembling of matrices are done by the computational method and finally displacements and stresses are given as output. Model analysis has been used to determine the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component while designing. We set 6 numbers of desired mode shapes and used Campbell diagram and other minor parameters to find natural frequency.

3.4 Post-processing

This is very interesting part of simulation because you will get the output of your efforts and it will show you whether you did good job or not. Here all results are accumulated in single paper so very few screenshot of mode shape of each condition are displayed. Finally result table would show you the exact comparison between all conditions with variable diameter.

Condition 1: Cantilever loaded condition

Below plot show you the difference in natural frequency of Healthy shaft, shaft with axial crack (2mm) and shaft with radial crack (2mm)

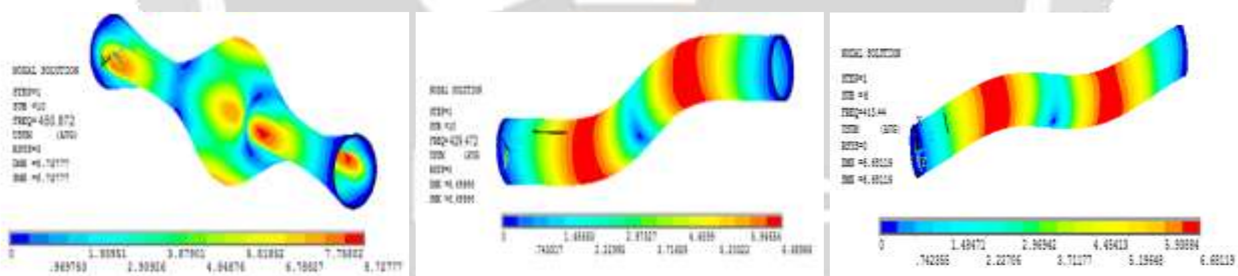


(a) Healthy shaft with 2 mm diameter (b) Axial crack with 2 mm diameter (c) Radial crack with 2 mm diameter

Fig-2: Cantilever loaded condition

Condition 2: Simple supported condition

Below plot show you the difference in natural frequency of Healthy shaft, shaft with axial crack (2mm) and shaft with radial crack (2mm)



(a) Healthy shaft with 2 mm dia. (b) Axial crack with 2 mm dia. (c) Radial crack with 2 mm dia.

Fig-3: Simple supported condition

Table -2: Summary of all results cases

Healthy Shaft		2mm Axial crack		3mm Axial crack		2mm Radial crack		3mm Radial crack	
Cantilever	SSB	Cantilever	SSB	Cantilever	SSB	Cantilever	SSB	Cantilever	SSB
29.499	169.81	26.830	158.31	23.556	149.99	23.560	170.10	29.474	169.91
172.05	308.12	166.37	283.80	161.93	271.72	152.06	281.12	171.91	281.35
259.83	345.39	243.31	322.46	235.79	308.93	236.44	320.22	260.33	320.50
274.81	417.23	266.54	412.66	255.88	397.73	255.79	411.11	276.86	411.23
280.89	429.66	270.57	418.38	263.83	402.97	263.31	418.42	284.79	418.30
320.54	450.87	310.84	429.47	294.91	418.46	303.57	418.44	325.11	418.46

4. CONCLUSION

It is simple to know that vibration characteristic of any rotating model are well studied using natural frequency of models. Natural frequency of model is changed according to crack propagation. FE analysis has done on basis of axial and radial crack propagation for cantilever beam and simply supported beam. Results have been summarized which results into variable natural frequency. It is observed that for axial crack the natural frequency decreases with increase the depth of the crack for both cantilever beam and simply supported beam. While for radial crack it is observed that natural frequency for both the cases increases with increase in crack depth.

REFERENCES

[1]. A. Tlaisi et al., "Crack Detection in Shaft Using Lateral and Torsional Vibration Measurements and Analyses," Mechanical Engineering Research; Vol. 2, No. 2; 2012, ISSN 1927-0607 E-ISSN 1927-0615.

[2]. M. Massenzio, et al., "Natural frequency evaluation of a cracked RC beam with or without composite strengthening for a damage assessment,'' Material and Structures, 865-873, 11 January 2005.

[3]. Chen c et al., "Nonlinear response and dynamic stability of a cracked rotor with an active magnetic bearing." Journal of sound and vibration, 265, p. 469-487.

[4]. L. Zuo et al., "Nonlinear real and complex modes of cone wise linear systems," J. Sound and Viberation," 174(3):289–313, 1994.

[5]. Aly El-Kafrawy, "Crack detection by modal analysis in 3D beams based on FEM," Int J Mech Mater Des 2011, 265–282.

[6]. Yang Yong et al., "Shafting Coupled Vibration Research Based on Wave Approach," J. Shanghai Jiaotong University (Sci.), 2014, 19(3): 325-336.

[7]. Nan Wu et al., "Study of forced vibration response of a beam with a breathing crack using iteration method," Journal of Mechanical Science and Technology 29 (7) (2015) 2827-2835.

[8]. H. G. Park et al., "Analytical method of beat tuning in a slightly asymmetric ring," JMST, 21 (2007) 1226-1234.

[9]. Jinhee Lee et al., "Boundary element method based sensitivity analysis of the crack detection in beams, Journal of Mechanical Science and Technology 29 (9) (2015) 3627-3634.

[10]. S. Y. Baek et al., "fatigue design for plug/ring type gas welded joints of sts301l including welding residual stresses," International Journal of Automotive Technology, Vol. 9, No. 6, pp.729−734 (2008).

[11]. Saber El Arem et al., "Nonlinear dynamics of a rotating shaft with a breathing crack," Ann. Solid Struct. Mechanical, (2012) 3:1-14.