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FINITE ELEMENT ANALYSIS OF DIFFERENT SHAFT MATERIALS WITH TRANSVERSE CRACK

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Abstract

Cracks in shafts have been identified as significant factors limiting the safety and reliability of machines. Cracked shafts still pose a significant and real threat to machines in spite of the great advances made in the areas of metallurgy, design and manufacturing. The ability to detect cracks at an early stage of progression is imperative to avert the aforementioned consequences which include failure of equipment resulting in costly process upsets and repairs among others. In this work, torsional and transverse vibration experiments are carried out to investigate transverse crack signatures for a shaft. The effect of the depth and position of an open transverse crack on the shaft's torsional rigidity, fundamental peak acceleration, and natural frequency was investigated. The influence of a transverse crack upon the dynamic behavior of a rotating shaft is studied. Two cases of fixing the shaft are suggested in this study to investigate and analyze the vibration characteristics of the shaft with and without cracks. The fundamental natural frequency showed strong dependence on the crack depth, this dependence is smaller as the order of the frequency increase. Finally, the results showed that the change in dynamic response is due to the crack.

1.Introduction: The presence of cracks in the shafts of the machines reduces torque transmitting capacity and in turn affects the performance of the machines. Identifying the crack at early stage is important so that sudden failure of machine components can be avoided. Many researchers have carried out their work in crack identification and suggested the measures to avoid the sudden failure of machine components. Nelson et al. [1] presented a theoretical analysis of the dynamics of a rotor-bearing system with a transversely cracked rotor. The rotating assembly is modeled using finite rotating shaft elements and the presence of a crack is taken into account by a rotating stiffness variation. This stiffness variation is a function of the rotor's bending curvature at the crack location and is represented by a Fourier series expansion.

The resulting parametrically excited system is nonlinear and is analyzed using a perturbation method coupled with an iteration procedure. The system equations are written in terms of complex variables and an associated computer code has been developed for simulation studies. Sinha et al., [2] developed a new simplified approach to modeling cracks in beams undergoing transverse vibration. The modeling approach uses Euler-Bernoulli beam elements with small modifications to the local flexibility in the vicinity of cracks. This crack model is then used to estimate the crack locations and sizes, by minimizing the difference between the measured and predicted natural frequencies via model updating.

Lee, C.W. [3] proposed various excitation methods for the effective use of complex modal testing for rotating machinery. The proposed excitation methods are developed, based on the input/output relationships for complex signals, for the direct or indirect assessment of frequency response and coherence functions between complex inputs and outputs. From the views of practicality, required testing efforts and estimation errors, the advantages and disadvantages of each method are investigated, when the measurement noises and the errors involved with realization of excitation forces are present. Numerical simulations are also performed to demonstrate the testing procedures and results using the proposed methods. Inoue et al. [4] developed a finite element model of the rotating shaft with an open crack. The analytical method for the calculation of the natural frequencies of such a rotor system with an open crack is investigated, and the modeling of the open crack element is discussed. The natural frequency of the experimental system is measured for various cases of positions and depths of the open crack. By comparing both the theoretical and experimental results of the natural frequencies, the accuracy of the developed finite element model of the rotating shaft with an open crack is verified.

Nagata et al., [5] investigated a rotor crack based on the nonlinear vibration diagnosis using harmonic excitation force. The open-close mechanism of crack is firstly modeled by a piecewise linear function. In addition, another approximation crack model using a power series function that is convenient for the theoretical analysis is used. When the power series function crack model is used, the equations of motion of a cracked rotor have linear and nonlinear parametric terms.

Davies et al., [6] studied the effects of a transverse crack on the dynamics of a multi-rotor, multi-bearing system experimentally using a spin rig. It is concluded that except for very large cracks, the vibrational behavior is similar to that of a slotted shaft with additional excitation due to the crack opening and closing. The dynamic stresses in the cracked shaft were also measured. The results show how the dynamic bending moment at the crack tip depends on the speed of rotation of the shaft and the crack depth. The results are compared with a theoretical treatment previously reported and good agreement obtained. Kulesza et al., [7] studied the serious problems that may lead to catastrophic accidents if not detected early and also studied the transverse cracks in rotors due to cyclic loading.

Seo et al., [8] proposed a method for identifying the location of an open transverse crack in flexible rotor systems by modeling the cracks as a localized element with rotating asymmetry. It exploits the strong correlations between the modal constants of the reverse directional frequency response functions and the degree and location of asymmetry. The proposed crack identification method is finally applied to a flexible rotor system with an open transverse crack in order to demonstrate the identification procedure for detection of the crack locations. WangS et al., [9] presented a general and efficient method for studying the effects of unbalance on the breathing mechanism of crack. Based on 3D finite element models combined with a nonlinear contact approach for crack modeling, the method is free from the assumption of weight-dominance and can be used to gain deep insights into the breathing mechanism of crack. Numerical results show that the unbalance can lead to significant changes in the breathing of crack, even when the unbalance force is about an order of magnitude smaller than the self-weight. Moreover, the level and orientation of the unbalance have also remarkable effects on the breathing behaviors of crack.

Bachschmid et al.,[10] introduced a method for the identification of the position and the depth of a transverse crack in a rotor system, by using vibration measurements. As it is reported in literature and from field experience, a transverse crack modifies the dynamic behaviour of the rotor, generating in a horizontal axis shaft periodical vibration with 1x ,2x and 3x rev. components. A model-based diagnostic approach and a least-squares identification method in the frequency domain are used for the crack localization along the rotor.

In the above literature surveyed the study of frequency of the stainless-steel shaft with and without crack is lacking, so the present work focuses on it and compares the amplitudes of Mild steel and Stainless shafts.

2. ANALYSIS OF MILDSTEEL AND STAINLESS-STEEL SHAFTS

The analysis of shaft is considered for normal and shear stresses of mild steel and stainless steel. The properties of these two materials are given in table 1. Table 1: Properties of materials

Material / Properties	Mild steel	Stainless steel
Young's Modulus (GPa)	197	193
Density (Kg/m^3)	7840	7750
Possion's ratio	0.3	0.3

Once the system is fully designed, the last task is to burden the system with constraints, such as physical loadings or boundary conditions. The assembly of components of shaft that which is drawn in Solid works is to be converted into igs or iges format for importing it into the Ansys for doing the harmonic analysis on those model. For doing harmonic analysis first the model is to be meshed, then frequency is applied on the model.

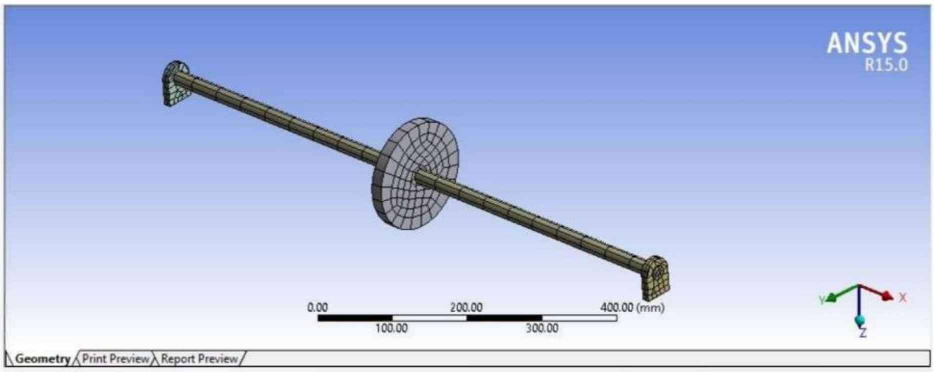
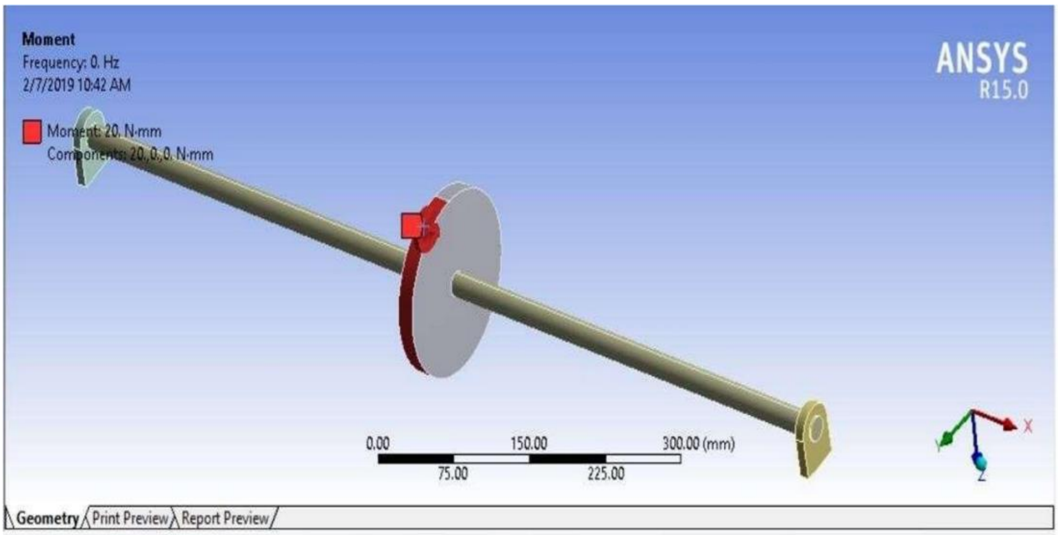
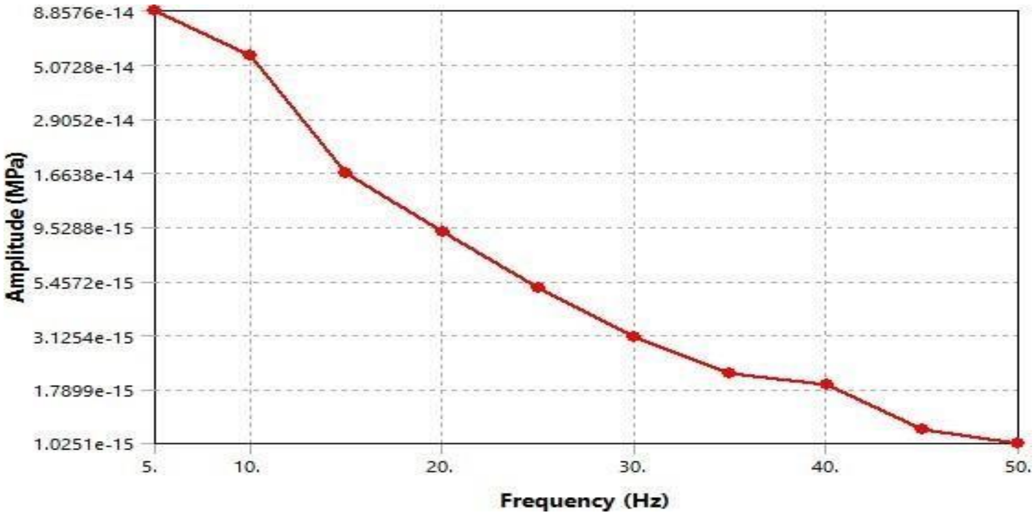


Fig.1 Meshing of shaft





Bending moment applied shaft

Fig.2 Bending moment applied shaft

Frequency response of mild steel shaft for normal stress

Fig.3 Frequency response of mild steel shaft of normal stress

Frequency response of mild steel shaft of shear stress

Fig .4 Frequency response of mild steel shaft of shear stress

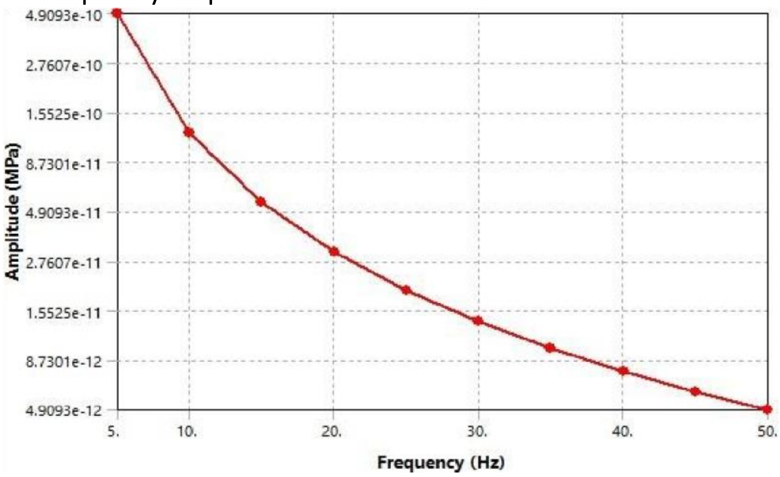
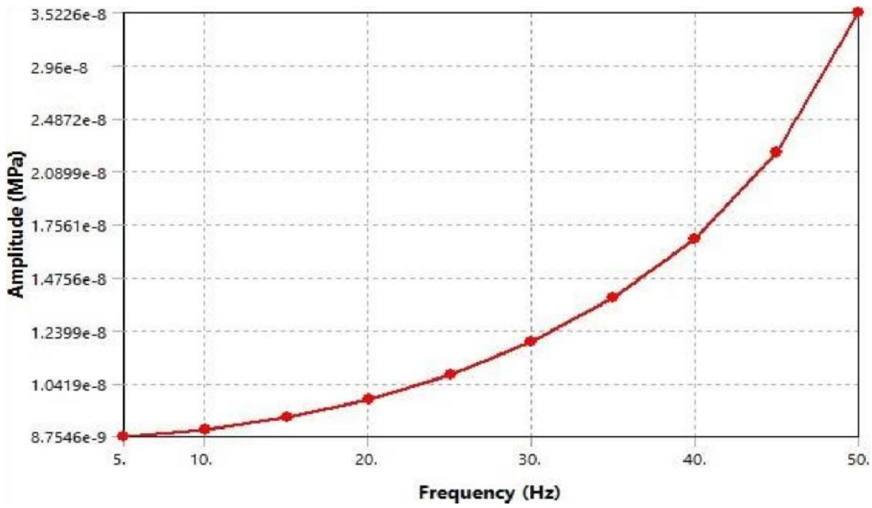
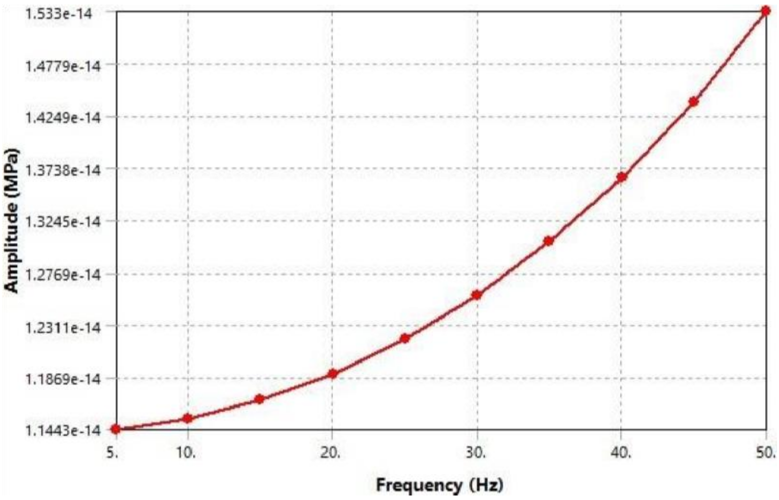


Fig.5 Frequency response of mild steel shaft with crack of normal stress

Fig.6 Frequency response of stainless-steel shaft of normal stress:





3. RESULTS AND DICUSSIONS

S.No	Shaft material	Intact Cracked shaft	Type of stress	Range of Frequency [Hz]	Range of Amplitude [Pa]
1	Mild Steel	Intact shaft	Normal Stress	5-50	8.8576e-008 to 1.0251e-009
2	Mild Steel	Cracked shaft	Normal Stress	5-50	4.9093e-004 to 4.9096e-006
3	Mild Steel	Intact shaft	Shear Stress	5-50	1.044e-007 to 1.2001e-009
4	Mild Steel	Cracked shaft	Shear Stress	5-50	1.0545e-003 to 1.0545e-009
5	Stainless Steel	Intact shaft	Normal Stress	5-50	1.443e-014 to 1.533e-014
6	Stainless Steel	Cracked shaft	Normal Stress	5-50	1.4771e-008 to 5.9434e-008
7	Stainless Steel	Intact shaft	Shear Stress	5-50	1.9917e-017 to 2.668e-017
8	Stainless Steel	Cracked shaft	Shear Stress	5-50	8.7546e-009 to 3.5226e-008

The natural frequency of a rotating shaft found to be considerably influenced by the presence of a transverse crack. The quantitative evaluation of this effect based on the derivation of an equation of motion to derive the formula of calculating the natural frequency of the rotating shaft. Also, it is depending on the strain energy function to get the integral relation between the local flexibility and the stress intensity factor. The crack on the rotating shaft will change in some property like the local flexibility. So, the local flexibility of a shaft in bending due to the crack is evaluated from the theoretical and experimental results relating to the derivation of the strain energy release function to the crack depth, contributed by some authors.

4. Conclusions: In the above analysis mild steel and stainless-steel shafts with and without crack are considered to compare the normal stress, shear stress and amplitude. The mild steel shaft has been recommended because of less amplitude. The same work can be carried out for other materials such as cast iron, carbon steel, aluminum.

References

Nelson., (1986) "The Dynamics of a Rotor System with a Cracked Shaft", Transaction of the American Society of Mechanical Engineer, Journal of Vibration, Acoustics, Stress, and Reliability in Design ,108(2), pp.189-197.

Sinha., (2002) "Simplified Models for the Location of Cracks in Beam Structures Using Measured Vibration Data", Journal of Sound and Vibration, 251(1) pp.13-38.

Lee, C.W., (1991) "A Complex Modal Testing Theory for Rotating Machinery", Mechanical Systems and Signal Processing ,5(2), pp.119-137.

Inoue., (2010) "FEM Modeling of a Rotor System with an Open Crack (Experimental Verification of Crack Model by Investigating the Double Frequency Vibration due to Crack)", Transactions of the Japa n Society of Mechanical Engineers, Series C,76(765), pp.1323-1330.

Nagata, N., and Inoue, T., (2013), "Finite Element Analysis of the Vibration of a Rotor System with an Open Crack under the Harmonic Excitation", Transactions of the Japan Society of Mechanical Engineers, Series C,79(799), pp.562-572.

Davies, W.G.R., and Mayes, I.W., (1984) “The Vibrational Behavior of a Multi- Shaft, Multi-Bearing System in the Presence of a Propagating Transverse Crack”, Transactions of the American Society of Mechanical Engineers, Journal of Vibration, Acoustics, Stress, and Reliability in Design ,106(1), pp.146-153.

Kulesza, Z., and Sawicki, J.T., (2012) “Rigid Finite Element Model of a Cracked Rotor”, Journal of Sound and Vibration ,331(18), pp.4145-4169.

Seo, Y.H, and Lee, C.W., (2009) “Crack Identification in a Rotating Shaft via the Reverse Directional Frequency Response Functions”, Journal of Vibration and Acoustic s ,131, pp.1-12.

Wang S, ZiYY, WangY, (2017) “A 3D nonlinear finite element method for the dynamic analysis of rotating rotor with a transverse crack”, 60, pp.219– 231.

Bachschmid, N., Pennacchi, P., Tanzi, E., and Vania, A., (2000) “Identification of Transverse Crack Position and Depth in Rotor Systems”, Mechanica ,35(6), pp.563- 582.