

## Numerical Analysis of the Crack Inspections Using Hybrid Approach for the Application the Circular Cantilever Rods

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### ABSTRACT

The present study aims to investigate crack presence in a rigid steel beam so that it can be considered in structural design. A finite element method (FEM) had been used with the Ansys 16.1 software to simulate the whole steel body with three different forces and moments with a magnitude force subjected at the free end of the beam. The steel rod had been considered as simple cantilever to be modelled by the software. Von Mises stress had been considered in the simulation process where the maximum value of stress due to applied load and moment was 1.9 MPa. Total deformation of the whole body had also

been considered to instigate the maximum deformation (4.3mm) due to applied loads and moments. Furthermore, MATLAB and through fuzzy logic had been used to assist in the investigation of cracks. Both approaches had been governed by the Euler-Bernoulli theory for free vibration of motion equations. The other aim of this study is to evaluate results received from the Ansys with MATLAB for the same boundary conditions as the case.

**Keywords:** ANSYS; Euler- Bernoulli; fem; fuzzy logic; MATLAB

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## INTRODUCTION

Steel beams are widely used in the machinery and construction industries and need safety monitoring. Thus, damage analysis in beam structures is of critical importance. Many solutions have been extended in this respect, and there are several ongoing attempts to find a workable solution for crack detection in beam structures (Sapuan, 2005). A method was submitted to evaluate the difference between the two modal properties, i.e., mode beam shapes and their natural frequencies, leading to the identification of the crack on a damaged beam (Meade & Presley, 2002). This method simulated the crack with a similar spring at the crack spot. It is obvious that cracks in the turbocharging shaft and vibration parameters are related to each other. The purpose of this study is to show that the proposed model has a non-linear effect.

Zavadskas et al. (2014) and Kremer et al. (2012) have documented the introduction of local flexibility at the site of a vibrationally cracked structure and studied the response of its vibration. Due to the high cost of vibration-based maintenance of these machines, the dynamics of rotors have been very significant in the design of rotary machines in recent years. Due to its extensive usage in manufacturing and power plants, the rotor is the most important component of rotary machines. This provides the key purpose of the unit which focuses on the study of an uncracked and broken rotor (Sharaf et al., 2020a). There are several origins of excitation forces that can be found in the rotary machines. The most recognized cause of excitation in rotor-bearing structures is mass eccentricity, which creates unbalance power. Several structures with a single transverse surface crack are taken based on previous studies (Utili, 2013). When more than one crack occurs in a system, based on the relative locations and depths of such cracks, the hierarchical solution becomes more nuanced. In addition, different combinations of position and depth can contribute to the same changes in the natural frequencies. Several investigators recently examined the impact of two surface cracks on structural vibration reaction. Sander et al. (2013) analyzed the effect on the normal velocity of cantilever beams of the locations and depths of two-cracks.

Sheu and Lee (2011) had developed a method for investigating the crack position and depth of a vibrational beam structure without its release from a system, assuming that the local spring was at a crack position. Ertay et al. (2005) had developed an adequate method for damage detection in a transverse beam with a dynamic vibration status, which was supposed to be a cross-sectional open crack. Nepal et al. (2010) and Al-Harbi (2001) had shown a co-relation between the location of a crack, the crack depth and the difference in mode. The method used specific modes of vibration beam structure. The objective of the current study is to investigate the crack location numerically by using the results of the fuzzy logic approach along with a FEM.

### General Theorem

For MATLAB analyzes and the FEM used by the ANSYS, the Euler-Bernoulli approach is assumed. The crack is called an open crack in this particular case and no damping has been called. For the formulation, a single cross crack is considered (Srinivasan & Kraslawski, 2006).

Fuzzy logic theory of analysis fuzzy theory means a computational approach that considers several truths, without numerically identifying them as true or false, i.e. (1,0). For its linguistic variables, this approach uses specific functions (Al-Harbi, 2001). Fuzzy 's logic extends from control theory to artificial intelligence. Modern computation allows use of accurate data with confidence, but soft computing can use inaccurate data and calculate precisely to produce output. For describing such mapping laws, fuzzy logic uses terms instead of numbers (Chang et al., 2007).

### Governor Equations

By following the difference equation, a free bending vibration of an Euler-Bernoulli strap of a constant rectangular cross part is given as Equation 1:

$$EI \frac{d^4y}{dx^4} - m\omega^2 = 0 \quad (1)$$

Where 'm' is the mass of the beam per unit length (kg/m), 'ωi' is the natural force of the mode (rad/s), E is the modulus of elasticity (N/m<sup>2</sup>) and I is the moment of inertia (m<sup>4</sup>). By defining  $\lambda^4 = m\omega^2y/EI$  equation is rearranged as a fourth-order differential equation (Imihezri et al., 2005). Now applying moment of inertia for shape with and without crack as in Equation 2:

$$I = \frac{BW^3}{12} \quad (2)$$

In order to locate position (γ) of crack, following Equation 3 of moment of inertia should be used:

$$I = \frac{B(W - a)^3}{12} \quad (3)$$

The Equation 3 in characterization form is a function of position of the crack (γ), stiffness matrix (K), circular force (ω) and r crack depth (φ). The pictorial view of a free end rod geometry with dimensions (a1) as crack depth, (L1) as crack location and (BxW) as cross-sectional area which is under the influence of axial force (P1) that subject the beam to a single effect (Su & Lin, 2008).

## MATERIAL AND METHOD

### Boundary Condition Set Up

**MATLAB (Coding) Set Up.** MATLAB had been conducted to analysis input data by using fuzzy logic tool and input data as follow: First force = “FF”, Second force = “SF”, and Third force = “TF”. For the output of fuzzy logic controller process, following terms had been used: Crack depth = “CD” and Crack length= “CL” (Sharaf et al., 2021a). According to the fuzzy logic subset, the rules fuzzy are known with a general code as follows: “If (FF is FFi and SF is SFj and TF is TFk) then (CD is CDijk and CL is CLijk), where i= 1 to 9, j=1 to 9, and k=1 to 9” Because of “FF”, “SF”, and “TF” there are nine functions. Two kinds of rules can be written “If (FF is FFi and SF is SFj and TF is TFk) then CD is CDijk (Sharaf et al., 2021b) If (FF is FFi and SF is SFj and TF is TFk) then CL is CLijk”.

**ANSYS Software Set Up.** In ANSYS applications the FEM was used to calculate the position of the crack in steel bar depending on the natural force. As the governor equation for the formulation of the finite element, the Euler-Bernoulli Governor Equation was considered. The circular cross-sectional rod with a cross-sectional crack is set on the right-hand end, free of height, and continuously cut with a triangular cross. Drawing was done using the Model Modular in ANSYS, with segment 1000 mm and diameter 50 mm. The built model used Tri pave components in difficult areas and Quad paves in most of the areas. ANSYS offers full mesh flexibility with amorphous meshing solution and, once the grid is read in ANSYS, it can be polished or roughened in a solution (Kim et al., 2009).

### Material Properties

Based on previous research by Sharaf et al. (2020b), the mechanical properties of the steel bar are shown in Table 1. The main mechanical properties were conducted in the simulation process and the parameters are Young Modulus (E), density kg/m<sup>3</sup> and Poisson’s Ratio (ϑ).

Table 1

*Mechanical properties of steel rod*

Young Modulus (E),	density kg/m <sup>3</sup>	Poisson's Ratio (ϑ).
2.05× 10 <sup>11</sup>	7850	0.29

### Geometry and Meshing

The geometry of the current research has been modeled by using Design Modeler (DM) and it is a tool of the ANSYS 16.1 software. Figure 1 shows the meshed model uses Tri type pave components in difficult areas and paves of Quad type in the rest of the areas based on these types of mesh give the best solution. ANSYS allows the solution a full

mesh stability for amorphous meshes and the grid can be polished or roughened based on the solution if the grid was read into ANSYS.

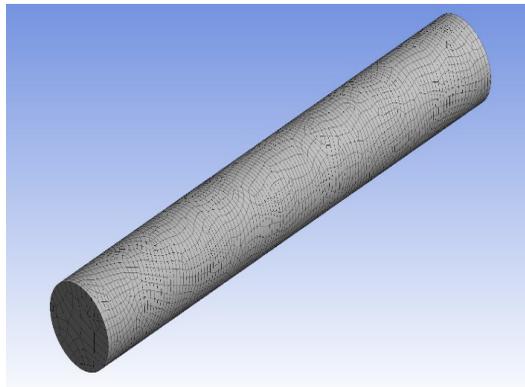


Figure 1. Meshed model of the steel rod

## RESULTS AND DISCUSSION

### Grid Independent Study

Based on the test, the incidence is shown to be commensurate with the number of components. Crack was set at 5 mm for four different frequencies; the first attempt was set at 10 KN when there were 261794 elements. Furthermore, no change in force occurred when the number of elements was considered to increase to 282893 at both 20 KN,30 KN.

### Investigation-based on Normal Force

Based on the outcomes, the simulation processes of the circular cantilever beam to predict the location of the possibility of the presence of the cracks of the supported beam is shown in Figure 2 (total deformation) and Figure 3 (equivalent stresses).

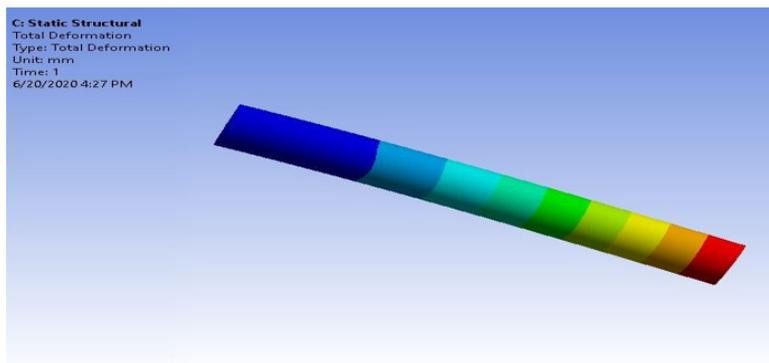


Figure 2. Total deformation due to the normal force

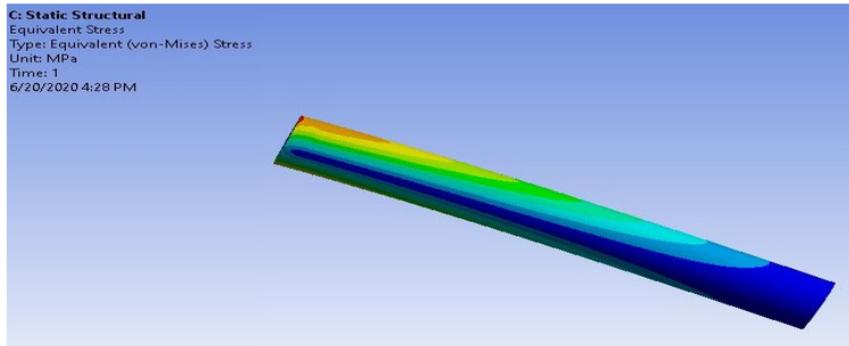


Figure 3. Equivalent stress due to the normal force

Figure 4 shows the maximum relationship between the forces to the total deformation of the beam body. It shows that the maximum deformation occurred at 10KN and deflection was at 4.3 mm.

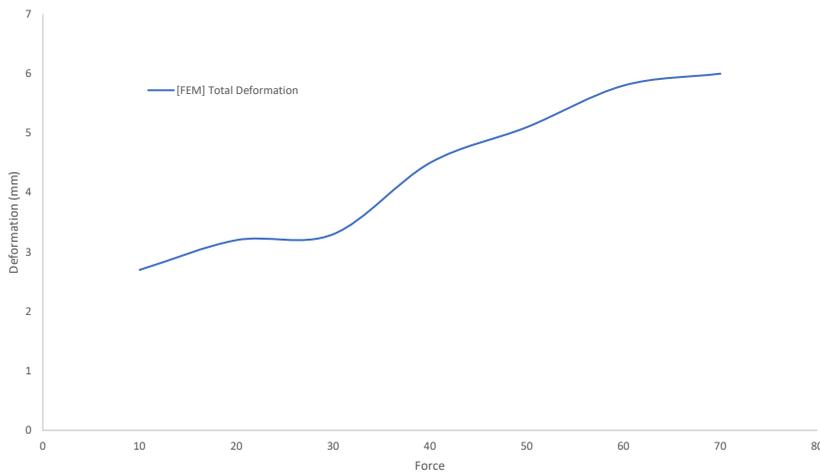


Figure 4. Deformation due to applied forces

### Investigation-based on Normal Moment

Normal moment has been considered for further validation of the prediction of possibility and presence of internal damage in the supported beams. Based on the outcomes, the simulation processes of the circular cantilever beam to predict the location of the possibility of the presence of the cracks of the supported beam is shown in Figure 5 (total deformation) and Figure 6 (equivalent stresses).

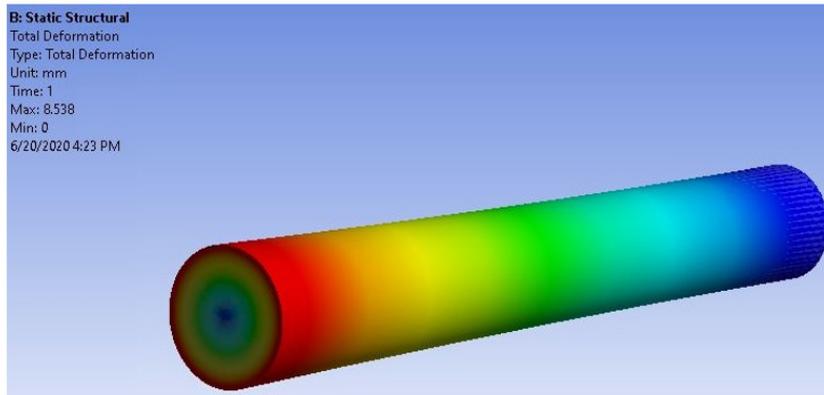


Figure 5. Total deformation due to the normal force

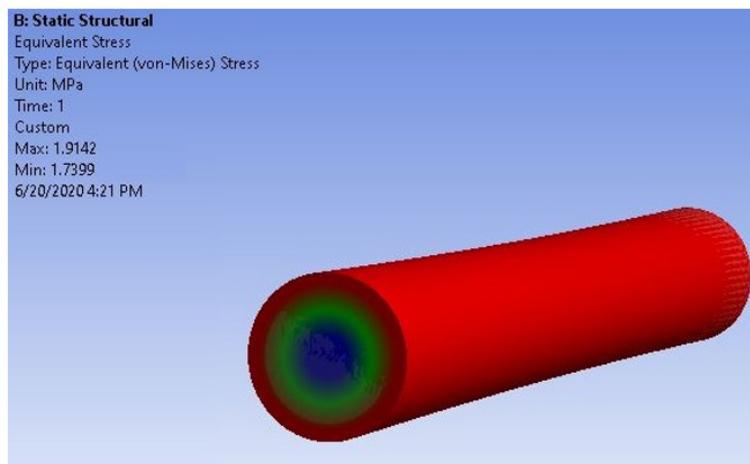


Figure 6. Equivalent stress due to the normal moment

Crack investigation of two main phases, force and moment has been considered to simulate in ANSYS structural. Assumption of crack depth is 5mm and located at distance of L1 from fixed end. Figure 6 shows the simulation result for those different forces. Structural analysis has been done in ANSYS for total deformation which was done by force.

## CONCLUSION

The principal objective of the current study was to confirm the outcome of the MATLAB analysis using ANSYS with the FEM simulation. The FEM had been used in ANSYS 16.1 to simulate the whole steel body with three different forces and moments with a magnitude force subjected at the free end of the beam. The steel rod had been considered

a simple cantilever to be modelled by the software. Von Mises stress had been considered in the simulation process where the maximum value of stress due to the applied load and moment was 1.9 MPa. Total deformation for the whole body had also been considered to instigate the maximum deformation due to the applied loads and moments. Furthermore, MATLAB had been conducted with fuzzy logic to assist in the investigation of cracks. Both approaches had been governed by the Euler- Bernoulli theory for free vibration of motion equations. The other main aim of this study was to evaluate results received from the Ansys with MATLAB for the same boundary conditions as the case.

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