RESEARCH ARTICLE | OCTOBER 11 2021

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AIP Conference Proceedings 2404, 080016 (2021)
https://doi.org/10.1063/5.0069538

Prediction of the Affections of Critical Cracks in the Rotating Part of the Gas Turbine by Employing FEM Along with a Fuzzy Logic Tool for the Application in Aircrafts

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Abstract. The present study is aiming to investigate and predict the possibility of cracks occurring in the rigid hollow shaft. Numerical analysis has been carried out using structural analysis tool for the angular frequencies . These results have been refining by employing MATLAB software . Fuzzy Logic tool has been employed to perform the pro-cess that conducted by MATLAB software. FEM has been conducted in ANSYS software to simulate whole body with three different angular velocity with a magnitude moment that subjected at the free end of the shaft. Three different angular velocities 1500 rpm ,2000 rpm and 2500 rpm were considered as input of both software (ANSYS and MATLAB). These values of angular velocities and moment are considered based on records that taken from the previous studies on gas turbines of aircraft. FEM approach has been governed by Paris equations crack detection, shear stresses equations and geometry equations. Results have been evaluated for both approaches (FEM and FUZZY logic). As well as this study is revealed that the results that gotten by MATLAB software is confidant with results that is gotten by ANSYS software for the same boundaries

INTRODUCTION

In last century the services of gas turbine in serials equipment such as power plants , aircrafts and aero-space applications was significantly increase. The reason of high demand on gas turbine is that it has low , comb ability and good mechanical performance. Based on these demand , there are another reason for choosing gas turbine , can use multi kinds of fuels [1]. Nowadays gas turbines are being considered a high efficiency engines due to the high performance. Thus, they can be considered an Internal combustion engine. In order to understand the functionality of the system , Gaseous energy was usually used of the air for conversion chemical energy of the fuel into machine energy chemical energy of fuel to mechanical energy. Several researchers have reported that , Hollow shafts have been employing to use in gas turbines due its High efficiency, especially for the applications in aerospace such as rockets and aircrafts. The aero derivative gas turbine is a lighter weight variation of a gas turbine. Although being classified as a gas turbine, the fuel source for the aero derivative turbine is not really gas. Actually, , it is designed so that fuel and air are mixed and then ignited to achieve the desired output [2][21].

[3] have presented a procedure to evaluate the difference between two corresponding modal characteristics i.e. mode shapes of the shafts and its angular velocities that lead to the identification of crack in a damaged beam. They have simulated the crack by considering an equivalent spring at the crack position. So that , they have established a clear relationship between cracks in the shaft of a turborotor assembly and vibration parameters. The purpose of their study is to show a non-linear effect of the proposed model. The papers [4-5] have introduced a local flexibility at the location of a dynamically vibrating cracked structure and have studied its vibration responses. [6] have developed a methodology for investigating crack position and crack depth of a vibrating beam structure with an open transverse crack of a stationary shaft without its disengagement from its system assuming a local spring at the crack po-sition.

In terms of research methods , [7] have established a suitable methodology for damaged detection in a beam having a transverse cracks which is under a state of dynamic vibration assuming the crack as a transverse open crack. Also ,they have presented a co-relation between crack location, crack depth and their corresponding mode difference [8]. The methodology uses Eigen modes of beam structure under vibration mode. In the current paper the main targets

2nd International Conference on Engineering & Science
AIP Conf. Proc. 2404, 080016-1–080016-8; https://doi.org/10.1063/5.0069538
Published by AIP Publishing. 978-0-7354-4136-1/$30.00

are to confirm and verify results that conducted by Fuzzy logic approach and the results the is done by finite element method which is done by ANSYS 16.1.Forever to make comparison with these approach [9].

This study seeks the challenges that face the gas turbines in power plants and other uses such as aerospace in term of design and other fundamentals components. There for this study aiming to reduce the fatigue in the rotating hollow shaft in gas turbines. fatigue is induced by high temperatures and stresses that come due to operations. There are many parts may affect by the affections of temperature and stresses such as blades, shafts and other components [10]. Generally, high temperature has a great effort to increase the mechanical performance of turbines but it has another side affection such as creep and other disadvantage. Therefore, several factors should be taken in account during the design of gas turbines such as materials properties and etc. Usually material pretreat before using in gas turbine, they are treating by heat treatment and other kinds of treatments.
Many researchers have stated that coating usually use to decrease the damage that caused by thermal affection and there is another reason for coating is to minimize the oxidization. Coating is made from zirconium dioxide-based and ceramics. The uses of thermal protection of coating can limit the exposure of temperature on gas turbines components [11-12].
The main objective of this study is to investigate the possibility of cracks occurring in hollow shafts that use in aircraft by using FEM approach along with Fuzzy Logic approach. Structural analysis by ANSYS has been used with hybrid membership functions in MATLAB. These tools are combined together to give precise result for cracks positions and locations.

THEORY

Shear stresses and pairs equation approach have been assumed for both MATLAB analysis and finite element method FEM that is employed by ANSYS. The crack in this special case is considered to be an open crack and as well as in this case damping has not been considered in this theory. Single transverse crack is considered for the formulation.

GOVERNOR EQUATIONS

Total Equivalent Stresses

Generally, when opposite forces or a torque are applied on the shaft, they are leading to make shear stresses in the shafts. The value of shear stresses between zero in the centre of the shaft to the maximum on the surface of the shaft[13].
The general shear stress formula for the circular shaft can be written as:

$$\tau = T\, r / J$$

where
τ = shear stress (Pa)
T = twisting moment (Nm)
r = distance from centre to stressed surface in the given position (m)
J = Polar Moment of Inertia of Area (m4)
The angular deflection of a torsion hollow shaft can be written as:

$$\alpha = 32\, L\, T / (G\, \pi\, (D4 - d4))$$

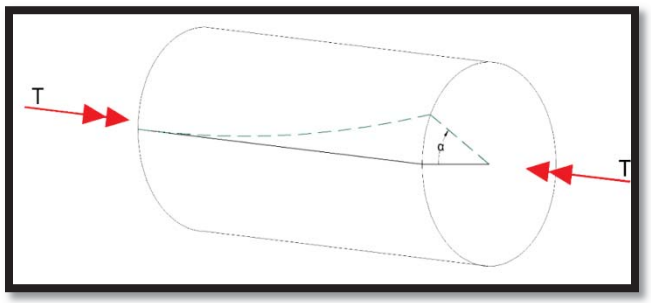

FIGURE 1. explanation of stresses determination

PARIS' LAW

The (Paris-Erdogan equation) is a crack growth equation that gives the growth rate of the cracks of fatigue. The intensity of stress factor characterizes the load around a crack tip and the rate of crack growth is experimentally shown to be a function of the intensity of stresses for the specific range seen in a loading cycle [14-15].
Life prediction of the cracks that caused by fatigue has simplified to use in different aspects of engineering. , in 1960 Paris [16-23] showed that there are a range of the range of intensity of stresses and there is a factor (K) characterize the cracks initiations under the mechanical loading such as fatigue loading . This factor is responsible to characterize the critical cracks than can lead to make fracture in future. During the examination of a number of different kinds of alloys , he make a graph that can rep-resent the growth of cracks against intensity stress to show a straight line with consideration of the factor K as follow :

$$log\frac{da}{dN} = mlog(\Delta K) + \log C$$

By taking out the logs gives:

$$\frac{da}{dN} = C\Delta K^m$$

firstly, there is a way to find a method to predict the residual cycle life of the critical cracks of a different sizes . the simplification of this process needs limits for the integration of the size of cracks which can be investigated by final shape of the size. There is a relation between the size of cracks and the fractures' in the follow:

$$K = Y\sigma\sqrt{\pi a}$$

There is a range of the variables of (a) and (N) . substitution for the range of intensity of stresses can be substituted for equivalent equation by consideration the stresses and size of cracks .

FUZZY LOGIC ANALYZING THEORY

The Fuzzy logic refers to a computing-based approach that considers quantity of truths without assigning numerical for true or false i.e. (1,0). This approach uses specific functions for its linguistic variables. Fuzzy logic has wide area of applications ranging from control theory to artificial intelligence. Traditional computing makes use of precise data with certainty but soft computing can use imprecise data and can compute to generate precise output. Fuzzy logic employs words rather than numbers for defining certain mapping rules.

FUZZY LOGIC MODEL

Fuzzy logic, has been considered one of the rare methodologies that intuitive and could be smoothly used.. The model of fuzzy logic, usually consists of output and input variables. The Variables of input Can be categorized into Area and Ratio. The variable of output is Class for the objects. In research of [17] 0 and Rare were the affective range of the variables. There are 2 or more fuzzy subset of each variable. Furthermore, membership functions have been employed in a trapezoidal form for output and input variables. The using of membership function is limited on before and after interval. [18] higher accuracy of cracks location can be discovered by using Membership function as well as it has been used for the predictions.

In this paper inference system has been conducted for the of the fuzzy logic formulation. inference of steps is represented in 'IF-THEN' statements, the 'IF' part is explained to as 'antecedent' while the 'THEN' part is named the 'consequent.' The parameters could be combined together by using the op-erators of fuzzy 'AND,' 'OR,' and 'NOT.'. The membership value will be considered as output of each one of these rules.

MATLAB (CODING) SET UP

MATLAB software has been performed to analyze input data by using fuzzy logic tool and input data as follow :
First angular velocity = "FAV"
Second angular velocity = "SAV"
Third angular velocity = "TAV"
For the output of fuzzy logic controller process, following terms has been used

Crack depth = “CD”
Crack length= “CL”
[19] According to the fuzzy logic subset the rules fuzzy are known with a general code as follows:

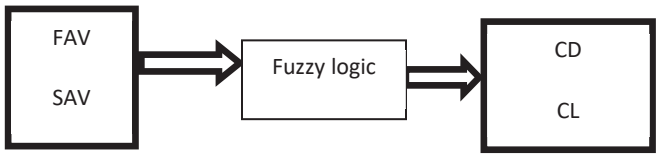

FIGURE 2. Flow chart of the process

“If (FAV is FAi and SAV is SAj and TAV is TAk) then (CD is CDijk and CL is CLijk) Where i= 1to 9, j=1 to 9, k=1 to 9 (13)” Because of “FAV”,“SAV”,“TAV” there are nine functions. Two kinds of rules could be written “If (FAV is FAi and SAV is SAj and TAV is TAk) then CD is CDijk (14 a) If (FAV is FAi and SAV is SAj and TAV is TAk) then CL is CLijk”

ANSYS SOFTWARE SET UP

Finite element method has been employed in ANSYS 16.1 software to simulate the crack location in hollow shafts by depending on angular velocity. Paris law and stresses equations have been considered as governor equations for the finite element method (FEM).

GEOMETRY AND MESH SETTING

The hollow shaft with a cross crack is subjected to moment 0.5 KN.m, free at lift end and has regular shape with constant square cross section of 50 mm. Drawing has been done by using Design Modular in ANSYS. software . The meshed model uses the elements of Tri type pave in complicated areas and Quad type paves in the rest areas. ANSYS provides a complete mesh flexibility with amorphous meshes the solution and it may be polished or roughened the grid depending on the solution Once the grid had been read into ANSYS [20].

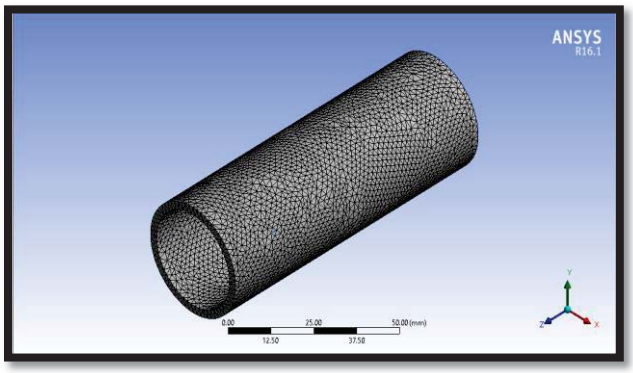

FIGURE 3. mish generation

PRIMARY BOUNDARY CONDITIONS

Three different values of angular frequencies will be conducted in this study as follow :
First angular frequency = FAV
Second angular frequency = SAV
Third angular frequency = TAV

The assumption is 5mm crack located at distance L1 from clamped end . With a anti clockwise moment that subjected at the free end of shaft (0.5 K N.m) the magnitude of moment is considered based aircraft recording [20] . By vivification with the with results that taken by MATLAB, can find the correct location of the crack. The table 1 shown mechanical properties of steel that required for the simulation.

TABLE 1. Mechanical properties of the hollow shaft

Item	Value
Young's Modulus of Elasticity	200GPa
Density of material	7800kg/m3
Passion ratio	0.25

RESULTS AND DISCUSSION

Grid Independent Study

Grid independent study is commonly used for numerical studied to insure precise results [22] .Based on the outcomes, it is seen that the angular velocity is proportionate to the number of elements,. Moment has been set has been sat 0.5 KN.m for four different the angular velocities ,the first attempt is was set 1500 rpm when number of elements was 261794. moreover, there is no change in frequency when the number of elements increasing to 282893 at both 2000,2500 rpm .therefor 282893 elements are considered for this study.

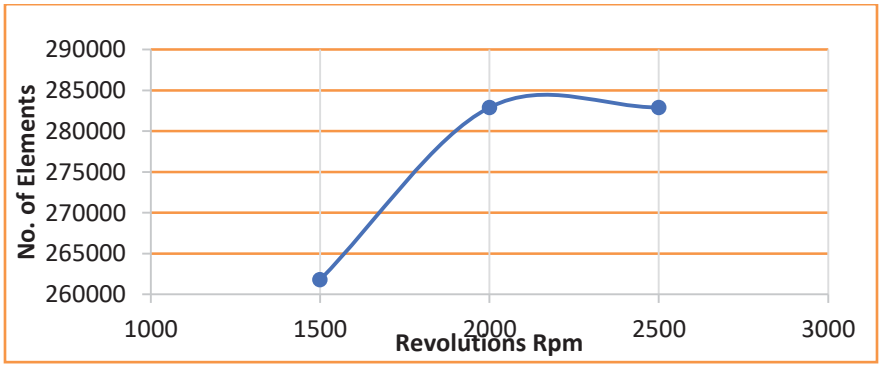

FIGURE 4. The grid independent study

Crack Investigation

Three different of angular velocities 1500,2000, and 2500 rpm have been considered to simulate in ANSYS structural. In order to perform simulations process to get precise results, crack Assumption should be taken in account. Assumption is a crack depth is 5 mm and locate at distance L1 from one end. Figures follow show the simulation result for those different frequencies .structural analysis has been done in ANSYS for total deformation that is done by frequency. The following figure 5,6,7 have been gotten by ANSYS structure analysis. Results are shown that the total deformation at three different angular velocities 1500,2000, and 2500 rpm with moment 0.5 KN.m. these calculations help in predicting the cracks.

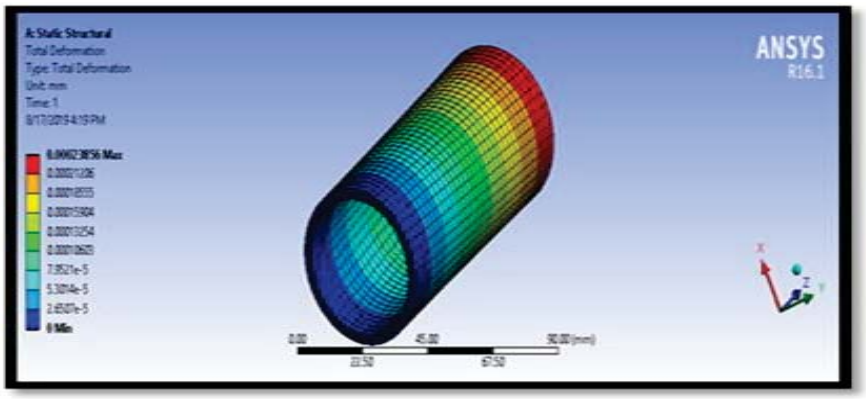

FIGURE 5. Shows total deformation in hollow shaft at 1500 rpm

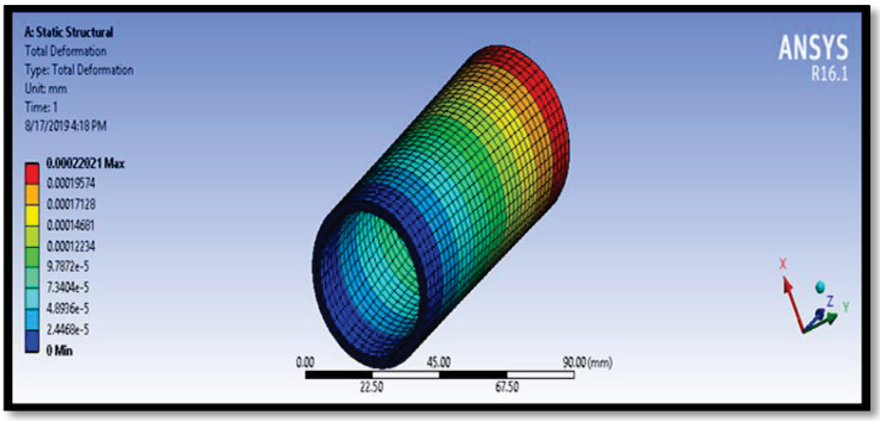

FIGURE 6. Shows total deformation in hollow shaft at 2000 rpm

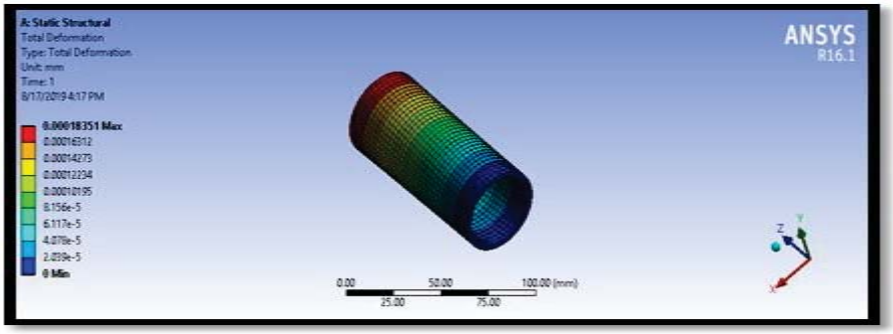

FIGURE 7. Shows total deformation in hollow shaft at 3000 rpm

CONCLUSION

The main target of current study is to confirm result that is collected by using MATLAB analysis with the FEM simulation by using ANSYS. In this research , numerical analysis has been carried out using structural analysis tool in ANSYS 16.1 software for the angular frequencies and modes of simply supported continuous section of hollow shaft with crack and without crack of material structural steel. It is showed that when the angular velocities are slightly increase, the crack depth of the shafts is increase. In other hand MATLAB analysis is used by using Fuzzy logic tool to detect the location and depth of crack. Both approaches of these methods are governed by same rotation equation which totally depending on stresses and Paris's law . These can be applied in gas turbine that used in aircraft. Three different angular velocities

1500, 2000, and 2500 rpm were conducted to perform the simulation process. torque has been fixed at 0.5 KN.m with these velocities. Same boundary conditions have been employed in MATLAB to carry out the analyzing process. Results have been evaluated for both approaches.

NOMENCLATURES

τ	shear stress (Pa)
T	twisting moment (Nm)
r	=distance from canter to stressed surface in the given position (m)
J	Polar Moment of Inertia of Area (m4

ABBREVIATIONS

CD	Crack depth
CL	Crack length
FAV	First Angular Frequency
SAV	Second Angular Frequency
TAV	First Angular Frequency

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