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Condition Monitoring of Robust Damage of Cantilever Shaft using Experimental and Adaptive Neuro-fuzzy Inference System (ANFIS)

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Abstract

Presently most of the failures encountered by machines are due to material fatigue. Therefore crack detection and localization is the main topic of discussion for various researchers across the globe. The dynamic behaviour of a whole structure is affected due to the presence of a crack as the stiffness of that structural element is altered. The cracks in the structure change the frequencies, amplitudes of free vibration and dynamic stability areas to an inevitable extent. In this work the effect of an open crack on the modal parameters of the cantilever shaft subjected to free vibration is analyzed. The results obtained from the experimental approach have been verified with the results obtained from finite element analysis using ANSIS 13.
A methodology has been developed to predict fatigue crack propagation life of mild steel shaft. It has been assessed by adopting Adaptive Neuro-fuzzy Inference System (ANFIS), a novel soft-computing approach, suitable for non-linear, noisy and complex problems like fatigue. The proposed hybrid neuro-fuzzy system combines the learning capabilities of neural networks with fuzzy inference system for nonlinear function approximation. A single-output Sugeno-type Fuzzy Inference System (FIS) using grid partitioning has been modelled in this work. After comparing the output, it has been found that the proposed model has proved its efficiency quite satisfactorily.

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Keywords: Shaft; Natural Frequency; ANFIS; Crack Location; Crack Depth.

1. Introduction

The use of high strength materials is common in aircrafts, ships and offshore structures which are sensitive to flaws and defects. Those tiny flaws or imperfections are present to some extent during manufacturing as fabrication defects

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or material defects (in the form of inclusions or second phase particles) or localized damage in service. They eventually coalesce and develop into larger cracks and subsequently grow to a critical size leading to catastrophic failure of the structure. The structural components are often designed for some degree of damage tolerance to ensure survival in the presence of growing cracks. The basic need of damage tolerance design philosophy is to establish a timely inspection schedule so as to give the inspector the ample opportunities to detect a growing crack. It helps in recommending the repair or replacement of the affected component in order to prevent failure, injury or loss of life and thus reduce any associated financial loss. These all need a reliable life prediction methodology.

In different engineering systems (e.g. steel structures, industrial machinery) shafts are commonly used as structural members and are subjected to static and dynamic loads. Typical examples where this type of load interaction occurs are airplane flying under gust spectrum, ships and offshore structures coming under high loads for a certain periods, etc. Due to the loading and environment effect they may experience cracks, which drastically reduce the life cycle of the structural system. The cracks present in the system may be considered to develop the analytical model to study the effect of cracks on the modal response of the system [1, 2]. The damage in the shaft member introduces the stiffness, which can be used along with the prevailing boundary conditions to formulate the vibration characteristic equation to obtain the mode shape, natural frequency of vibration, crack parameters such as relative crack depths and relative crack positions [4]. Chenget et al [4] investigated effect of the crack location and size, rotation speed and hub radius on vibration characteristics of a cracked rotating tapered beam and analyzed by the spatial wavelet transform based approach to detect the crack location. Han and Chu [6] proved that the open crack seems to have greater influences upon the asymmetric rotor system. Karaagac et al [7] investigated the effects of crack ratio and crack positions on the fundamental frequencies and the critical (the lowest) buckling loads of cracked cantilever beams numerically and experimentally. They stated that for small crack ratio, the reduction in fundamental frequency and buckling loads are small, becoming progressively greater at larger crack ratios. The higher drops in fundamental frequency and buckling loads are observed when the crack locates near the clamped end.

Chenget et al [4] formulated p-FEM for vibration analysis of cracked rotating tapered beams. Gunda et al [5] proposed that the boundary conditions considered are both classical for which the large amplitude free vibration behaviour apparently for the first time. The ends of the beam have been treated as immovable axially which leads to the Von-Karman type of nonlinearity represented by the homogeneous doffing equation.

Atternezad et al [2] showed the merit of the new method is indeed blending the pure concept of structural mechanics and mathematical techniques to elaborate the finite element method and present a suoer convergent element for free vibration analysis. Bannerjee [3] showed that the dynamic stiffness method is used for exact free vibration analysis of beams carrying spring mass system. The method is applied with a particular reference to the Wittric-Williams algorithm. Davey et al. [8] studied the modal analysis and natural frequencies of fractal structures such as rods and beam. They constructed beams and rods taking composite material for testing purpose. The verification of parameter for composite beams and rods satisfy the initial condition of kinetic and strain energy within the fractal displacement.

Kohan et al [9] presented a general algorithm, based in the variational Raleigh-Ritz method, for the analysis of thick beams with various complicating effects. Paul. They validated that the general algorithm compares the natural frequencies calculated with exact and approximated results. Mohebpour et al [10] investigated a dynamic analysis of the laminated composite plates transverse by a moving oscillator. They observed finite element method based on the first order shear deformation where the stiffness, mass and force coefficient are defined for a= 1, 2,..., 5. Yu et al [11] presented an analytical evaluation on free vibration of naturally curved and twisted beams with uniform cross-sectional shapes.

With the recent advances in the field of soft-computing technology, crack propagation life is now being simulated with the existing experimental data so as to avoid more difficult, time-consuming and costly fatigue tests. Out of different soft-computing methods such as artificial neural network (ANN), genetic algorithm (GA), fuzzy-logic, and adaptive neuro-fuzzy inference system (ANFIS), ANFIS is one of the recent developed methods to handle fatigue problems successfully [12, 13, 14, 17]. Although ANN has been frequently used by several researchers in modelling and analyzing different types of fatigue problems during last 10 years, the application of other soft-computing techniques are quite rare. As far as the application of adaptive neuro-fuzzy inference system (ANFIS) in the field of fatigue is concerned, very limited work has been reported in literature. Damage in a cracked structure has been dissected using genetic algorithm technique by Taghi et al [15]. They presented a cantilever beam to determine the natural frequency through numerical method. To monitor the possible changes they utilized genetic algorithm. Zheng