Chapter 1

INTRODUCTION

The foundation of linear elastic fracture mechanics (LEFM) is to study the behavior of cracks in machine components like the shaft/beam/plate. Initiation of crack in any structure is not important. However, the growth rate of the crack leads to catastrophic failure of the machine component, which is a function of applied load and geometry of structure. The Stress intensity factor (SIF) is the only parameter that deals with crack growth rate and dictates whether the crack would lead to catastrophic failure. Various analytical methods have been developed to find SIF. Strain energy release rate is one of such methods to find SIF. This method in turn is a function of location and depth of the crack. Apart from conventional methods, non-destructive techniques (NDT) and artificial intelligence technique can be applied efficiently to detect the faults in various dynamic structures in a short time. Researchers across the engineering fraternity have shown a keen interest in the development of methodologies (destructive and non-destructive) to diagnose the damages present in the engineering structures. The modal responses of different structures are being one of such methods/techniques. The method involves monitoring of the vibration spectrum, which includes the frequency and amplitude of vibration. The present chapter illustrates briefly the different methods being used for crack diagnosis. For detailed reading, understanding and the involvement of different factors, this chapter has been described with three different sections; the inspiration for leading the existing investigation, purpose and for plan for the current research along with the comprehensive outline of the thesis.

The performance of any structure is always established on the collectiveness of its individual parts. The breakdown of the structural arrangement makes a disruption of projects, which ultimately leads to both economic declines and loss of human life. Keeping this in mind, it is mandatory to model a system that would investigate the health monitoring of the structure by prescribed means/methods to bypass any woeful failure.

By reviewing the last recorded achievement in the area of structural condition monitoring, it is observed that various SHM techniques are utilized to determine the severity of crack using forward and inverse methods. Most of the analytical methods are
intended by Hilbert transform, Lyapunov theory, Hamilton's variation principle employed the changes in modal characteristics such as mode shapes and natural frequencies using the dynamic flexibility of the structure. Again, the dynamic flexibility of the structure is determined by stiffness error matrix method, Changes in measured stiffness matrix, matrix update method, Eigen structure assignment method etc. Several numerical methods such as the finite element approach, wavelet analysis, artificial intelligence procedures, non-destructive techniques and techniques using for different sensors have been implemented for observing the fitness of complex mechanized structures. Artificial Intelligence (AI) techniques for classification of fault for the multiple crack structure have been intended with an object for active and systematic evaluation of defects existing in the structures.

Almost all structures consist of the beam/shaft / plate to transform the load and to be considered as structural member whose condition has to be monitored from time to time by the scientists using various AI techniques. The methodologies generate in formations concerning the severity of crack in the systems without braking individual members of the whole structure. Hence, the only purpose of improving the accountability for crack diagnosis in design model by AI method is to promote it for identifying crack along with its severities. Inspired by the above objectives, this thesis intends to examine the applicability of AI techniques such as genetic algorithm, artificial neural network, the adaptive neuro-fuzzy-inference system (ANFIS), multiple adaptive neuro-fuzzy inference system (MANFIS) and hybrid methods GA-MANFIS, for multiple crack diagnosis of shafts applied in engineering structures by taking the vibration parameters. Different AI methodologies have been, thus developed and used for damage detection in structural components such as shafts.

A system can be assured to work without risk when it investigates its own fault by using condition-monitoring mechanism. The structures linked with various aerospace / mechanical/civil engineering, needs to be free from cracks for an assured and secured service. Faults in the machine or any engineering equipment may initiate the breakdown of the machine and needs to be identified early.

Many engineering structures are mostly made of columns, shafts, and beams with several end conditions. They are generally open to static and/or dynamic loads. The working period of these components decreases due to the environmental impact. The loss of working period is expected due to the presence of faults in the structure, which changes
the modal pattern of the systems. The stiffness of the structure changes with the severity of crack at different location. A number of mathematical model are developed with respect to different end condition of the structure. By solving these equations, the vibration signatures (frequencies and amplitudes) can be achieved.

In the current analysis, a sincere effort has been made to prepare an intelligent condition monitoring (using AI technique) that can be applied to the different dynamic vibrating structures for damage diagnosis with less error.

Analytical models for the cantilever, simply supported and fixed-fixed shaft have been presented and analyzed in the current analysis. All three types of shafts are the generally handled for the different application. The dynamic responses of the cracked and uncracked shaft have been determined by calculating the compliance matrices. A relationship among the cracked and uncracked the cantilever, simply supported, fixed-fixed shaft have been developed for the dynamic responses and the influence of cracks upon the vibration signatures have been identified.

The AI methods have been extended to predict the crack location and evaluate the severity of cracks existing in the structure by using the decreasing the vibration signatures of cracked shaft and un-cracked shaft. The conclusions collected from the different AI methods have been compared to decide the best reasonable approach of crack prediction and its severity.

In reference to work of different researchers, all have given emphasis in developing models to monitor the presence of cracks in the different structural members such as shaft and beam. In the current research, a wholehearted attempt has been made to develop a fault identification method applying the modal values of a cantilever shaft, fixed-fixed shaft and simply supported shaft adopting the theoretical, finite element, and experimental investigation, along with different AI procedures.

Individual framework of the prevailing analysis are listed below;

Two forward methods such as theoretical and finite element methods are performed to generate the deviation vibration signatures of all three types of shafts with uncracked and cracked conditions. Experimental procedure has been used for authenticating the results obtained from theoretical and finite element analysis. The influencing parameters that
change the vibration characters are frequencies with their mode shape differences obtained from the theoretical, experimental, and finite element method have been assumed as the source for the expression of various AI methods. Skilful methods have been executed to provide the corresponding severity of crack (depth, location) adopting inputs as mode shape differences and the natural frequencies.

This theoretical expression has been accepted for three types of shafts such as the cantilever shaft, fixed-fixed shaft and simply supported shaft with the variety of transverse crack. The main objective is to measure the vibration response of shaft by applying the equations strain energy release rate. The appearance of the crack in the shaft decreases the stiffness and hence, influences the flexibility of the shaft segments with varying end positions. The AI-based procedures are thus applied to obtain the crack parameters (location and depth) using vibration signatures from theoretical, experimental and finite element analysis.

Subsequently, the results from theoretical and finite element model have been the trend up with the AI technique (GA, ANN, ANFIS, and GA-MANIS) and the robustness of technique is checked by comparing with experimental results. From the comparison, it is noted that the outcomes from the modified AI models are an approaching vicinity of each other. Positive results have been obtained from separate techniques being applied in the existing research. The conclusions from the different investigation have been correlated in the present research for legitimacy. The condition monitoring of the shaft with different end condition and multiple cracks at different depths and locations have been described using different AI techniques in eleven chapters.

The introduction part of the thesis presented in Chapter 1 shows the different approaches described by different investigators to classify the crack initiated in assembling systems. The purpose of the research and preparation for leading the current research has also been presented in this part.

Chapter 2 presents the discussion of literature, which outlines a complete report about the recorded performance by several investigators and researchers in the field of condition monitoring and cracks diagnosis of vibrating structures. The classification of different methods applied for crack identification have been performed in the part of this
research and incorporating to communicate the ideas to take the research into the new dimension.

The detail of the theoretical method has been presented in Chapter 3 for the cracked shaft with three different end conditions. The strain energy equation and flexibility matrix have been used to devise the methodologies. These methodologies have been adopted to calculate the natural frequencies and mode shapes of intact and damaged shaft with cantilever and fixed-fixed and simply supported conditions. The comprehensive explanation of the experimental investigation for validating the results of various analyses has been neatly presented in Chapter 4 of the thesis. The experimentations have been carried out broadly on with different end condition the shafts e.g. cantilever, simply supported and fixed-fixed shaft.

Finite element method has been recognized as one of the non-destructive techniques to determine the crack parameters at various end condition of the shaft as demonstrated in Chapter 5. The finite element model of the shaft is taken using ANSIS-14. The material properties of the shaft are considered as same as that of the theoretical analysis for different damage conditions. The result of the finite element analysis has been compared with the theoretical model for cracked and uncracked shafts in the cantilever and fixed-fixed and simply supported conditions.

Chapter 6 outlines the importance of the genetic algorithm to plan for diagnosing the damage for several structures. Developmental procedures using genetic algorithm is introduced and explained in detail. Outcomes for corresponding crack positions with their depths from the genetic algorithm model are correlated with experimental outcomes for testament. Subsequently, the report of the genetic algorithm analysis for crack revelation is presented.

Chapter 7 introduces an inverse analysis, which includes the entire architecture, and the formulation of the artificial neural network (ANN) model to present the prognostication of crack parameters present in the structural system. Feed forward neural network procedure has been used for damage diagnosis in this research. Finally, the results from the ANN have been compared with that of the other techniques to distinguish their effectiveness.
Chapter 8 draws the effective postulates of adaptive neuro-fuzzy inference system (ANFIS) to find out the cracks severity by predicting the positions and depths. Three fundamental natural frequencies with their mode shapes received from the analytical model are taken as input to the adaptive system to train and test the model. Experimental crack locations with depths are used to verify the errors the ANFIS model implemented for condition monitoring of the structure. Again, the prognosticated outcomes of the ANFIS are compared with the outcomes of GA, FEA, and ANN with error analysis.

Chapter 9 illustrates an innovative hybrid model (GA-MANFIS) for the analysis of several cracks present in the shaft. The proposed method consisting of the initial level (Genetic algorithm model) and the final level (MANFIS model). Both the theoretical and finite element analysis provides the information data to the GA-MANFIS structure. The outcomes from GA-MANFIS structure have been supported by the results of the experimental analysis.

The results gathered from the different investigations, e.g. theoretical, experimental, finite element analysis, GA, ANN, ANFIS and MANFIS have been described in Chapter 10 of the thesis. An exhaustive comparison among the outcomes of the different methods has been performed with the results of the experimental investigation.

Chapter 11 represents the conclusion and future scope of the present research. In this chapter the recommendations have been done as of the results of the present research and future scope of the present research is mentioned.