Chapter-1
INTRODUCTION

1.1. THEME OF THESIS

Damage is one of the important aspects in structural analysis and engineering. Damage analysis is done to promise the safety as well as economic growth of the industries. Generally damage in a structural element may occur due to normal operations, accidents, deterioration or severe natural events such as earthquake or storms. Nowadays the plants as well as industries are running round the clock to achieve the industrial goal. During operation, all structures are subjected to degenerative effects that may cause initiation of structural defects such as cracks which, as time progresses, lead to the catastrophic failure or breakdown of the structure. The inspection for quality assurance of manufactured products is thus very much important. To avoid the unexpected or sudden failure, earlier crack detection is essential. Taking this ideology into consideration crack detection is one of the most important domains for many researchers. The most common structural defect is the existence of a crack in a machine member. The presence of a crack could not only cause a local variation in the stiffness but it could affect the mechanical behavior of the entire structure to a considerable extent.

The use of composite materials as construction elements has been increased substantially over the past few years. The composite materials are subjected to various types of damage, mostly cracks and delamination. The crack in a composite structure may reduce the structural stiffness and strength, redistribute the load in a way that the structural failure is delayed, or may lead to structural collapse. Therefore, crack is not necessarily the ultimate structural failure, but rather it is the part of the failure process which may ultimately lead to loss of structural integrity.

Non-destructive testing is preferable over a destructive testing for damage/crack detection in Fiber Reinforced Composite (FRC) beams. Many non-destructive methodologies for crack detection have been in use worldwide. However, the vibration based method is fast and inexpensive for crack/damage identification. Vibration based methods can be classified into two categories: linear and nonlinear approaches. Linear approaches detect the presence of cracks in a target object by monitoring changes in the resonant frequencies in the mode shapes or in the damping factors. Depending on the assumptions, the type of analysis, the overall beam characteristics and the kind of loading
or excitation, a number of research papers containing a variety of different approaches have been reported.

Cracks or other defects in a structural element influence its dynamical behavior and change its stiffness and damping properties. Consequently, the natural frequencies and mode shapes of the structure contain information about the location and dimensions of the damage. Open crack models are considered as crack remains open during vibration. The assumption of an open crack leads to a constant shift of natural frequencies of vibration. Numerous methodologies investigated over last few decades indicate that a real fatigue crack opens and closes during vibration.

1.2. COMPOSITES MATERIALS

Composite materials can be defined as the combination of two or more materials on a microscopic scale to form a useful material. The reinforcing phase is in the form of fibers sheets or particles, and are embedded in the other materials is called the matrix phase. The reinforcing material and the matrix material can be metal, ceramic, or polymer. Composites as structural material are being used in aerospace, military and civilian applications because of their tailor made properties. The ability of these materials to be designed to suit the specific needs for different structures makes them highly desirable.

1.2.1. Classification of Composite Materials

Based on Dispersed phase: composites are classified into three types

1. Particle-reinforced composites
2. Fiber-reinforced composites
3. Structural composites

Based on Matrix phase: composites are classified into three types

1. Ceramic Matrix Composites
2. Metal Matrix Composites
3. Polymer Matrix Composites

Fiber-reinforced composites are used in the present work. Fibers are the principal constituent in a fiber-reinforced composite material. In a composite matrix the fibers are surrounded by a thin layer of matrix material that holds the fibers permanently in the desired orientation and distributes an applied load among all the fibers. Glass fibers with
polymeric matrices have been widely used in various commercial products such as piping, tanks, boats and sporting goods. E glass is available as continuous filament, chopped strand mat and random fiber mats suitable for most methods of resin impregnation and composite fabrication. Glass is by far the most widely used fiber, because of the combination of low cost, corrosion resistance, and in many cases efficient manufacturing potential. It has relatively low stiffness, high elongation, and moderate strength and weight, and generally lower cost relative to other composites.

1.3. DAMAGE THEORY

Damage identification methods are classified according to the type of measured data and the technique to gather that data. They are mainly based upon the change in natural frequencies or dynamically measured flexibilities and changes in mode shapes. The four levels of damage identification are:

1. Determination of the damage that is present in the structure, level 1
2. Determination of the geometric position of the damage, level 2
3. Quantification of the severity of the damage, level 3
4. Prediction of the remaining service life of the structure, level 4

There are two types of problems related to damage structures namely, forward (direct) problem and inverse problem. The forward problem is to find out the effect of damages on the structural dynamic properties. For example, calculating natural frequency shifts of a structural component due to a known type of damage. In such problems, damage is modeled mathematically, and then the measured natural frequencies are compared to the predicted ones to determine the damage. The inverse problem, on the other hand, consists of detecting, locating and quantifying damages present on a structural component. For example, damage parameters, such as crack size and position are calculated. This present work is to determine geometric position and quantification of severity of FRC beams. This problem can be classified as level 3 damage identification in composite materials and not considered prediction of the remaining service life of the structure.
1.4. NON-DESTRUCTION EVALUATION FOR CRACK DETECTION

Crack is a narrow opening without complete separation of parts. One of the most common incipient losses of structural integrity in mechanical structures is the development and propagation of cracks. There are various types of cracks, for example transverse crack, longitudinal cracks, open cracks, breathing crack, gaping cracks, slant cracks and subsurface crack, etc. Non-Destructive Evaluation (NDE) is preferable over a destructive testing for damage/crack detection. The NDE process flow chart (ASTM E1316–13) is shown in Fig.1.1.

Fig: 1.1. Overview of the NDE
Non destruction evaluation process involves measuring and interpreting the response of object to be examined with a proper non destructive stimulus. This stimulus-piece interaction leads to an indication to be interpreted. The results are distinguished between relevant, non-relevant and false indications. The relevant indications are evaluated and decided whether the object has to be rejected, accepted or repair (if possible).

A typical scheme of vibration-based non-destructive evaluation process is summarized as follows: first, the vibration response of the structure is measured. For a forced vibration test both the input excitation force and output structural response is measured. Secondly, modal analysis is performed to get modal parameters such as natural frequency, mode shapes and damping ratios from measured time histories. Thirdly, a non destructive detection algorithm is applied to identify crack using previous estimated model parameters. An analytical model of the structure and its predicted response may also be used as a base line in the detection process.

The field of nondestructive damage methods is very broad and covers many techniques, such as, Liquid penetrate test, Ultrasonic testing, Eddy currents, Magnetic particles, Vibration methods, Acoustic method and Radiography etc. Some of the major methods are compared to vibration methods and their advantages are displayed in Table 1.1.

1.5. VIBRATION METHOD FOR CRACK DETECTION

When a system is displaced from its static equilibrium position and then released, it vibrates freely with a frequency that depends upon the mass and stiffness of the system. Vibration usually refers to a periodic motion in an elastic structure about an equilibrium position. Vibration based techniques have been proved a fast and inexpensive means for crack identification. The lowest frequency of vibration is called the fundamental frequency and the highest frequencies are termed harmonics. Any linearly elastic continuum will have natural frequencies that can be investigated by considering the mass and stiffness of beam. The differential equation of motion for a system in which structural damping or viscous damping is either not present or considered insignificant and also the applied force being zero written in a compact form.
<table>
<thead>
<tr>
<th></th>
<th>Ultrasonic testing</th>
<th>Eddy currents</th>
<th>Liquid penetratnt</th>
<th>Magnetic particles</th>
<th>Vibration methods</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost of instrumentation</strong></td>
<td>Average-High</td>
<td>Low</td>
<td>Low</td>
<td>Average</td>
<td>Average</td>
</tr>
<tr>
<td><strong>Cost of consumables</strong></td>
<td>Very Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Very Low</td>
</tr>
<tr>
<td><strong>Accessibility</strong></td>
<td>Important</td>
<td>Important</td>
<td>Important</td>
<td>Important</td>
<td>Important</td>
</tr>
<tr>
<td><strong>Detectable defects</strong></td>
<td>Internal</td>
<td>Surface breaking and sub surface</td>
<td>Surface breaking</td>
<td>Surface breaking and sub surface</td>
<td>Surface breaking and sub surface</td>
</tr>
<tr>
<td><strong>Sensibility</strong></td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td><strong>Influence of material</strong></td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Average</td>
</tr>
<tr>
<td><strong>Operator’s skill</strong></td>
<td>High</td>
<td>Average</td>
<td>Low</td>
<td>Low</td>
<td>Average</td>
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**Peculiar advantages**
- Deep penetration into the material, single side access, provides distances information,
- Probe contact is not required, minimum part preparation
- Large areas inspected rapidly, indication given directly on the part
- Large areas inspected rapidly, indication given directly on the part
- Response are measured directly

**Peculiar limits**
- Surface roughness, need for couplant, defects parallel to sound beam are not detected, reference standards are needed
- Limited depth of penetration, defects parallel to coil are not detected
- Needs care in preparation of the surface, non-porous materials, post cleaning etc.,
- Proper, alignment of magnetic field and defect is critical, paint can affect sensitivity, demagnetization is usually needed
- Needs care in preparation of the experiment because Sensitivity of instrument is high.
The equation represents the general form formulation of wide range of problems in dynamics for free un-damped system. A crack in a structure induces a local flexibility which affects the dynamic behavior of the whole structure to a considerable degree. It results in reduction of natural frequencies and changes in mode shapes, stiffness of the beam. An analysis of these changes makes it possible to determine the position and depth of cracks. The Fast Fourier Transforms (FFT) algorithm and digital computers in the laboratory test systems are development of techniques. The advances in these areas in turn allowed researchers to investigate the possibilities for quantitatively measuring the state of a structure by inspecting its vibration characteristics.

1.6. SCOPE OF PRESENT WORK

Engineered materials such as laminated composites are widely used in automotive and aerospace industry due to their excellent strength-to and stiffness-to-weight ratios and the possibility of tailoring their properties in optimizing their structural responses. But the presence of crack in a structure causes sudden change its material properties. The aim of present work is to determine geometric position and quantification of severity of damage in FRC beams using vibration analysis.

1.7. ORGANIZATION OF THE THESIS WORK

The chapter 1 introduces the background of this thesis and depicts the research problem in the area of crack identification in composite materials. An attempt is made to present in the form of a prerequisite understand the thesis i.e., crack, composite materials and vibration methods. Chapter 2 presents an overview of literature available with reference to the present work and regard to the crack detection methods in composite and isotropic materials. Different vibration and non vibration techniques are discussed. Chapter 3 presents mathematical modeling of un-cracked and cracked composite beam using finite element modeling. Eigen nature of beam is also discussed. Chapter 4 presents the preparation of composite beams and its mechanical properties of the beam. Free and forced vibration experimentation is conducted on FRC beams. Chapter 5 presents theoretical and experimental natural frequency with respect to crack depth and length. Chapter 6 presents concluding remarks and future scope of the thesis.