SELECTION OF NATURAL FREQUENCY METHOD FOR DETECTING CRACK IN BEAM

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ABSTRACT

Damage is defined as any deviation introduced to a structure, which adversely affects the current or future performance of that system. Cracks are among the most encountered damage types in the structures due to fatigue or manufacturing defects. Crack will initiate in a structure when the stresses near the crack tip will exceed the permissible limit. Cracks found in structural elements may arise due to fatigue cracks that take place under service conditions, such as mechanical accidents, fatigue, erosion, as well as environmental attacks. These are issues that can lead to a crack in a mechanical structure. The presences of crack in a component can failure the whole system. Crack changes the physical characteristics of a structure. It is very important to monitor the changes in the parameters. For safety, performance, structural integrity damage detection is very important. Visual inspection for damage detection is time consuming also not reliable. Internal cracks cannot find by visual inspection. There are some destructive and non-destructive methods for damage detection. Non –destructive methods are favorable as compared to destructive methods for detection of crack. A wide variety of highly effective local non-destructive evaluation tools are available. However, damage detection based upon changes in vibration characteristics is one of the few methods. These methods monitor changes in the structure on a global basis. Damage detection using vibration test data is best methods. Damage detection by measuring natural frequency is easy and applicable to any size and shape.

Keyword: - *Damage, Crack, Non-destructive method, Vibration*

1. INTRODUCTION

Cracks are potential source of catastrophic failure in mechanical machines, civil structures and in aerospace engineering. To avoid the failure caused by cracks, many researchers have performed extensive investigations over the years to develop structural integrity monitoring techniques. Most of the techniques are based on vibration measurement and analysis because, in most cases, vibration based methods can offer an effective and convenient way to detect fatigue cracks in structures. It is always require that structures must safely work during its service life, however damage initiates a breakdown period on the structures. It is unanimous that cracks are among the most encountered damage types in structures. Crack in structures may be hazardous due to their dynamic loadings. So crack detection is important for structural health monitoring applications. As beam type structures are being commonly used in steel construction and machinery industries.

1.1. Types of cracks

Based on the geometries of cracks, they can be broadly classified as follows:

- Transverse cracks: - Cracks perpendicular to the beam axis are known as “transverse cracks”.

- Longitudinal Cracks: - Cracks parallel to the beam axis are known as "longitudinal cracks".
- Slant cracks: - "Slant cracks" are cracks at an angle to the beam axis.
- Breathing Cracks: - Cracks that open when the affected part of the material is subjected to tensile stresses
- Gaping Cracks: - Cracks that always remain open are known as "gaping cracks".
- Surface cracks: - Cracks that open the surface are called "surface cracks".
- Subsurface Cracks: - Cracks that do not show on the surface are called "subsurface cracks".

2. NECESSITY OF CRACK DETECTION

Mechanical structures in real service life are subjected to combined or separate effects of the dynamic load, temperature, corrosive medium and other type of damages. Cracks in a structure may be hazardous due to static or dynamic loadings, so that crack detection plays an important role for structural health monitoring applications. Crack detection is important because of following reasons:

- Fatigue cracks are potential source of catastrophic structural failure.
- It is required that structures must safely work during its service life.
- Damages initiate a breakdown period on the structures.
- Presence of cracks in structures or in machine members leads to operational problem as well as premature failure.
- Cracks present a serious threat to proper performance of structures and machines.
- The aging phenomena, i.e. more and more structures are getting older while the load they have to carry is either not changing or getting heavier.
- The importance of an early detection of cracks appears to be crucial for both safety and economic reasons.
- Cracks in structural elements may indicate a fatigue problem, mechanical defects or others fault from the manufacturing process. In any case they represent a threat to the reliable behavior of this part or structural element. So its detection is an important issue.
- The propagation of incipient cracks in mechanical structures can cause catastrophic failures.
- Monitoring and identification of crack damage is an important concern to engineering communities.

One approach for reducing inspection related shutdown time and associated cost is to provide a mechanism with an early warning failure device. Such a device monitors, online, crack-related irregularity in the behavior of a system. If the device gives a sound signal that a crack is present, a message is given out to the operator to shut down the machine and have to be checked. For the development of such early warning devices, knowledge of the dynamics of cracked structures is important. A crack in a structure may be realized from the local divergence in structure stiffness affecting the global dynamic behavior of the structure. Also, a crack may manifest its presence in a beam-like structure through the change in natural frequency and mode shape of the system. These indicators may also be used to measure the extent of the damage and to determine its location.

3. CRACK DETECTION METHODS

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 shifts in natural frequencies or dynamically measured flexibilities and changes in mode shapes.

One damage identification system commonly classifies four levels of damage assessment.

- Level 1: Determining the presence of damage.
- Level 2: Locating the damage.
- Level 3: Quantifying the damage severity.
- Level 4: Prediction of the remaining serviceability of the structure.

Structural damage detection has gained increasing attention from researchers in last few decades. The ability to monitor a structure and detect damage at the earliest possible stage is of outmost importance in the mechanical, civil and aerospace engineering communities. Most of the failures are due to material fatigue. For this reason methods allowing early detection and localization of cracks have been the subject of intensive research for investigations. Since the last two decades a number of experiments and theories have been developed to expose the phenomenon and determine the crack initiation and propagation conditions.

3.1. Non-destructive methods

Non-destructive evaluation is widely used in industry to evaluate the structural integrity of civil and mechanical structures. Non-destructive testing (NDT) methods are often employed for detection of cracks in machine and structural components. The evaluation is performed by an NDE specialist and is generally performed on a routine maintenance schedule when the structure is out of service. Many NDE methods are available and are currently being used commercially. The difference between NDE and structural health monitoring (SHM) is that SHM is an online system that is intended to be performed while the structure is in service.

Commonly used NDE methods include visual or localized experimental methods such as ultrasound, thermal wave, Eddy Currents, surface waves, and acoustic emission, X-ray, magnetic field methods, and radiograph. Monitoring techniques are applied to structures such as airframes, bridges, and turbo machinery. All of these experimental techniques require that the location of the damage is known a priori and that the portion of the structure being inspected is readily accessible. Their adoption becomes uneconomical for long beams and pipelines which are widely met in power plants, chemical plants and offshore oil installations, etc. These methods are costly and time consuming for long components, e.g. railway tracks, long pipelines, etc. In order to detect a crack by any of these methods, the whole component requires scanning. This makes the process tedious and time consuming, and the cost involved may make the application prohibitive Subjected to these limitations, these experimental methods can detect damage on or near the surface of the structure. The drawbacks of traditional localized NDT methods such as high cost and long consuming time has motivated development of global vibration based damage detection methods.

The conventional methods have been well developed, implemented in widely marketed equipment, and accepted by industry and regulatory agencies as practically applicable non-destructive evaluation methods. The Vibration-based method of crack detection is considered to be a potential candidate and a lot of efforts are now directed in this direction.

3.2. Vibration based methods

The global damage identification methods, on the other hand, quantify the condition of a structure by examining deviations of its global structural characteristics. Vibration-based damage assessment which is the mostly used global damage identification method is usually carried out in three steps:

- Data collection.
- Extraction of condition index.
- Assessment of structure condition through the analysis of indices.

A fundamental issue with the use of vibration-based damage assessment methods is to seek some damage indices that are sensitive to structural damage. The damage indices that have been demonstrated with various degrees of success include natural frequencies, mode shapes, mode shape curvatures, modal flexibility, modal strain energy.

The methods based on vibration for detection of cracks can offer some advantages over the traditional methods. They may enable determination of location and size of a crack from the vibration data collected from a single or at most a few, points on the component. In local methods, it is required that the neighborhood of the damage is known a priori and part of the structure under inspection is readily accessible. Visual, acoustic, magnetic field and eddy current techniques are some examples for local methods. These methods are rather limited in the information they provide and can be inaccurate. Generally, conventional methods can only tell that the structure is damaged. In order to determine the location of the damage, many sensors are necessary. With vibration based methods it may be possible to acquire global damage assessment using a single sensor. Using fewer sensors is less costly in terms of initial cost and maintenance costs. Using these methods it may be possible to not only determine that the structure is damaged, but also the location and severity of the damage.

All of these methods are based on variation of structural dynamic properties caused by damage. According to the process to treat the measured data, the vibration-based damage identification methods can be classified as model based and non-model based. The model-based methods identify damage by correlating an analytical model, which is usually based on the finite element theory, with test modal data of the damaged structure. Comparisons of the updated model to the original one provide an indication of damage and further information on the damage location and its severity. However, the construction of the finite element model usually gives rise to model errors from simplified assumptions. To detect the damage, a high quality finite element model that could accurately predict the behavior of the intact structure is required but is often difficult to achieve. Non model based damage detection methods are relatively straightforward. The changes of modal parameters between the intact and damaged states of the structure are directly used, or correlated with other relevant information, to develop the damage indicators for localizing damage in the structure. Early works of such methodologies make use of the natural frequency and mode shape information.

4. SELECTION OF NATURAL FREQUENCY AS CRITERION

It is well known that when a crack develops in a component it leads to changes in its vibration parameters, e.g. a reduction in the stiffness and increase in the damping and a reduction in the natural frequency. These changes are mode dependent. Hence it may be possible to estimate the location and size of the crack by measuring the changes in vibration parameters. The vibration parameters could be structural parameters (i.e. mass, stiffness and flexibility) or modal parameters (i.e. natural frequencies, modal damping values and mode shapes). The vibration based methods of crack detection utilize one or more of these parameters as the basis for crack detection. The technique using changes in natural frequencies as the crack detection criterion has received considerable attention. This is perhaps because the natural frequencies can be measured easily and monitoring is possible from any location on the component. The determination of natural frequencies for a given crack location and size is a straight forward problem, but the corresponding problem of determination of crack parameters from the knowledge of natural frequencies is rather difficult because of the lack of uniqueness. If these difficulties can be overcome it can be cast into a nondestructive testing technique offering tremendous scope for its exploitation in practice.

Some of the approaches use finite element method as a tool for analysis and they are iterative and require an initial guess. As a result the error in the solution is remarkably influenced by the initial guess. The choice of using the natural frequency as a basis in the development of NDE is most attractive. This is due to the fact that the natural frequencies of a beam can be measured from one single location on the beam, thus offering scope for the development of a fast and global NDE technique**.** There are now considerable efforts being made in this direction to make the method useful in practice. There are many applications e.g. Rails of railway tracks, pipelines anchored at regular/irregular intervals, etc., where the supports have flexibility. The analysis based on the open crack model can be used to give a quick and initial estimate of location and size. Their use lead to a considerable saving in time, labor and cost for long beam like components, such as rails, pipelines, etc. The beams are considered to be slender so that shear deformation and rotational inertia can be neglected. Damping in the beam is neglected. The method of modeling is restricted to open normal edge cracks. Frequencies can be measured more easily than mode shapes, as they are less affected by experimental errors.

In practice the natural frequencies of structures are measured most easily and accurately in comparison with all other parameters such as the mode shapes. Using the other parameters, which are more contaminated by measurement noise, is not sure to improve the result of the damage identification. Among many possible crack identification methods, vibration measurements where natural frequency as basic criterion offer the potential to be an effective, inexpensive, and fast tool for non-destructive testing.

A major disadvantage of using mode shape based technique is that obtaining accurate mode shapes involves arduous and meticulous measurement of displacement or acceleration over a large number of points on the structure before and after damage. The accuracy in measurement of mode shapes is highly dependent on the number and distribution of sensors employed. On the other hand, measurement of natural frequencies is more reliable, repeatable and more accurate. Also, natural frequency measurement can be accomplished with a single sensor.

Besides natural frequencies the use of curvature mode shapes for detection of location and size of cracks has also been suggested. The methods based on structural parameters mainly utilize changes in stiffness or flexibility matrices of the system. These methods have one drawback, that they require measurement at many points on the component. Modeling through the rotational spring has emerged as a simple and attractive analytical tool for slender beams where the shear deformation can be neglected. The approach has been applied to mostly normal edge cracks. Slender components are encountered in many practical applications, e.g. rails, crane girders, brackets; long intermittently supported pipelines, etc. The varieties are enormous. The beam can be on multiple supports. The section can be variable.

5. CONCLUSIONS

Natural frequency as a basic criterion for detection of crack over other method is due to

- The natural frequencies can be measured easily and monitoring is possible from any location on the component.
- Frequencies can be measured more easily than mode shapes, as they are less affected by experimental errors.

- Measurement of natural frequencies is more reliable, repeatable and more accurate.
- Natural frequency measurement can be accomplished with a single sensor.

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