A BEAM USING CROSS-CORRELATION ANALYSIS OF VIBRATION RESPONSE

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ABSTRACT

Now a day STRUCTURAL HEALTH MONITORING (SHM) is a newly evolving technique used from last few decades. The main goal of SHM is to be able to replace current inspection cycles with a continuously monitoring system. The function required in the SHM system during the in-service operation is to identify the load applied to the structure or damage in it. Reducing maintenance costs, increasing civil structures like dam's bridges, and other type of truss structures, Aircraft Availability, Reducing Weight, increasing the strength and Quality control are the primary goals of Structural Health Monitoring. However there are several advantages of SHM over the traditional inspection cycles, such as reduced down-time, elimination of component tear-down inspections and the potential prevention of failure during operation. Civil structures have one of the highest payoffs. For SHM applications since damage can lead to catastrophic and expensive failures, and the vehicles involved undergo regular costly inspections. Currently 27% of an average Materials life cycle cost, both for naturals and composite structures, is spent on inspection and repair which excludes opportunity cost. By the use of SHM it is observed that there is reduction in maintenance and savings up to 75%. New reliable approaches for damage detection such as SHM need to be developed to ensure that the total cost of ownership of critical structures does not become limiting factor for their use. In this thesis cross correlation technique is used to detect and locate the damage in the structure using vibration analysis.

Keywords: *Structural Health Monitoring; Damage Detection; Cross-correlation Functions; Transient Analysis; Vibrational Analysis.*

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1. INTRODUCTION

The three fundamental steps involved in Structural Health Monitoring are Diagnosis, Localization and Prognosis. Diagnosis is a process of detection, identification & assessment of faults and flaws that may affect the performance of the structure in the future. However Localization involves the identification of the location of damages. Prognosis involves the prediction of remaining life of the structural beam or any structures. Now a days the people are more focusing on the detection of the damages which is the most important technique in structural health monitoring. As you know that there are several methods in damage detection techniques but the vibration analysis using cross-correlation technique provides the more perfections, easier, simple as well as cheaper way in damage detections for localizing and quantifying the damage. Cross-correlation function describes the dependence between two sets of amplitude responses. In this analysis the response signals are accelerations. First the beam of composite material is modeled in UGNX and meshed in the ANSYS APDL interface, then the boundary conditions are applied for the case of cantilever and an impulse load is applied, finally the model is simulated for transient setup to obtain the displacement values. The accelerations are obtained from the displacements which are found by using central difference method. In order to determine the damages in the structural beam a proper excitation is given to the beam and the responses are recorded at different degree of freedoms (DOF's). Here the responses may be displacements, velocities or accelerations based on the approach using in the cross correlation technique.

1.1 STRUCTURAL HEALTH MONITORING

Health Monitoring on truss structures is done to collect and analyse specific parameters on the performance of an load to maintain highest loading efficiency and to extend the life of an truss systems. While Health Monitoring on structures are done to detect damage formation prior to component failure so that the repair is cost effective and safety is not compromised. When Health Monitoring is applied to civil structures or aerospace, it is known as Structural Health Monitoring.

1.1.1 Procedure Development

This includes the collection and analysis of information such as material properties, structural design, history of operation, repairs, results of previous history, applied load, operational and environmental conditions.

1.1.2 Sensing

It is a data measurement process. The measured data includes strain, displacement, acceleration, pressure, temperature and any other response depending upon the developed SHM method.

1.1.3 Diagnosis

Diagnosis is a process of detection, identification and assessment of flaws and faults that may affect the performance of the structure in the future. This process requires the modeling and research on the model.

1.1.4 Monitoring

Monitoring is the process of inspection of flaws developed in the structure, evaluation of flaw development rate and conditions of the structure.

1.1.5 Prediction

The primary goals of prediction is to identify the remaining life of structure and detecting the next inspection cycle required based on the previously obtained data.

1.2 Analogy between SHM and Human Body

Structural Health Monitoring is quite analogous to the function of human body. Basic SHM consists of two parts:

1- Interrogator

2- Sensor network.

Brain is known as the central part of body without which human intelligence will fail to take a decision in the similar way interrogator acts as a human brain.

And the Sensor network which includes Sensors and Data processing & Communication is compared to the nervous system in the human body which takes a effective role in transferring signals from brain to other parts of the b rain and vice-versa.

2. LITERATURE REVIEW

C. M. Diwakar, N. Patil, and Mohammed Rabius Sunny [13] In this thesis the traditional threshold-based method of detecting damages from these damage indicators has been observed to be inadequate for the detection of multiple damages. Here, the drawback of threshold-based damage-detection method is overcome by using an artificial netural network.

Le Wang, Tim P. Waters and Zhichun Yang[14] Structural damage detection methods based on vibration responses are appealing for a variety of reasons such as their potential to observe damage from sensor placed remote from an unknown damage site.

Chiu et al.[11] prescribed that structural monitoring in damage detection can be achieved by placing a sensor system on a structure/machine to measure a physical quantity for e.g. vibration signature, impedance, power flow, strain, acoustic emissions, etc.

Habib, Fady[6] described various Structural Health Monitoring Techniques in detecting the damage, they mainly focused on the Acoustic-Ultrasonic(AU), Capacitance Disbond Detection Technique(CDDT) and Surface Mountable Crack Detection System(SMCDS).

Hou, Yan Fang, and Wei Bing Hu[3] introduced the Cross Correlation Function Amplitude Vector(CorV) to detect the damage of a historic timber structure based on the random vibration.

Zhu, Yi, Wang and Sabra[1] had described the application of cross-correlation function for structural damage detection by collecting data by using vibration analysis.

They conducted the laboratory experiment by introducing various Damage Scenarios to validate the damage detection approach. In their experiment they collected the response signals using mobile sensor prototype from the undamaged structure and the structures with three different Damage Scenarios which includes loosened bolts, including extra mass and loss of section area. The mobile sensors which are located at different positions on the structure record the acceleration data at corresponding locations, these acceleration data is used to find the damage indicators. With reference to their experimental work in this thesis damage in the

form of triangular cut which indicates the scenario of loss of section is introduced and numerical study is performed to validate the damage detection approach.

The monitoring and maintenance of structures in the modern society has long been considered to be crucial work. Applying effective approaches to the regular repair of bridges, roads, and other structures is essential for safety of human life. In addition, to keep the buildings and other infrastructures running smoothly and maintaining safety as well as public health is also of great importance.

Now a days, the new technological developments & methods are being utilized as Structural Health Monitoring (SHM) process. Supporter of this emerging capability and understanding the importance of successfully maintaining the civil infrastructures. Today, the government rules and regulations for building and construction, and new mandates as well as required maintenance have also contributed to the development of SHM. This supervene trend has a number of benefits, from improving the safety standards, reducing risks up to the cost effective opportunity.

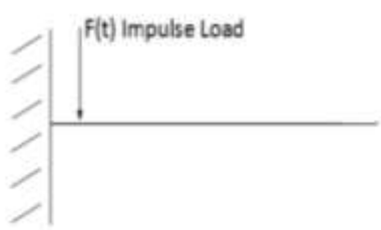
Increased SafetyHowever the greater efforts made to improve SHM, will ultimately work to improve the overall public safety include everything from new policies and guidelines that help to ensure the building and construction safety, due to the development of new technologies.

Advanced SHM methods have greatly improved the ability of engineers to contribute to public safety with the use of sensors, data collection and analysis. This is mainly important with aging structures. The SHM process could involve testing the faltering strength of old buildings, structures, beams, etc.,

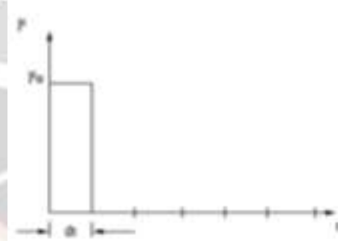
3. RANSIENT ANALYSIS OF A CANTILEVER BEAM

Transient dynamic analysis is a technique used to determine the dynamic response of a structure under a time-varying load. The time frame for this type of analysis is such that inertia or damping effects of the structure are considered to be important. If inertia effects are negligible for the loading conditions being considerd, a static analysis may be used instead.

Transient analysis plays an important role for step or impulse loading conditions where there is a sharp load change in a fraction of time. In this thesis, impact load of 6N is applied at a point .025m from fixed point of the beam. Fig 1(a) shows the cantilever beam and Fig 1(b) shows the loading condition at discrete time step 'dt'. After the application of the load, we track the response of the beam at discrete time points for particular time period.



Cantilever beam with an impulse load



Impulse Load for discrete time step of "dt"

In ANSYS, transient dynamic analysis can be carried out by using 3 methods.

The Full Method: However this method is the easiest of all the method. Here all types of non-linearities are allowed.

The Reduced Method: This method is used to reduce the system matrices which are used to consider only Master Degrees of Freedom (MDOFs). In this method the calculations are much quicker because of the reduced size of the matrices. However, this method used only for linear Problems calculations such as our cantilever case.

Method of The Mode Superposition: This method is a powerful technique for reducing the computational time and requires a preliminary modal analysis, as factored mode shapes are summed to calculate the structure's response. It is the quickest of the three methods, but it requires a good deal of understanding of the problem at hand.

In this study Reduced Method is used for conducting transient analysis. However, if stresses and forces are of interest then we would have to expand the Reduced Solution.

4. DESCRIPTION OF ANALYSIS IN THE ANSYS MECHANICAL APDL

Any finite element analysis involves several steps; all these steps can be categorized into following four sections:

1. Geometric Modelling using UGNX.

2. Meshing using ANSYS MECHANICAL APDL.

3. General pre-processing.

i. Analysis type settings.

ii. Initial conditions.

iii. Boundary conditions.

iv. Load inputs.

v. Load steps.

vi. Solution/Solving.

4. General post-processing.

Following steps explains the whole processes that are involved in the analysis using ANSYS Mechanical APDL.

Step 1:Geometry modeled in UGNX, after that this geometry is imported to ANSYS Mechanical APDL, where we select the type of element that we going to be used in the analysis, in our case element used is a solid type i.e. SOLID 186. Further if there are any real constants, they are added.

Step 2:Then we assign the geometric properties such as young's modulus, poisson's ratio, density and other properties of the material of the model. Further section properties such as thickness in the general plate and ply thicknesses and orientations in case of composite plate and similarly cross section in case of beam etc. are specified.

Step 3:Then comes to the geometric modelling, Geometric modelling involves the modelling of the structure using key points, lines, areas and volumes. Model of the structure can be made using one or many of the above mentioned entities. Basically Geometry Modelling has been done using UGNX.

Step 4:After modeling, the model is meshed using free or mapped mesh, according to model we have choose mesh option such as line mesh, area mesh and volume mesh in the ANSYS Mechanical APDL. For the required accuracy of analysis we can use refinement option.

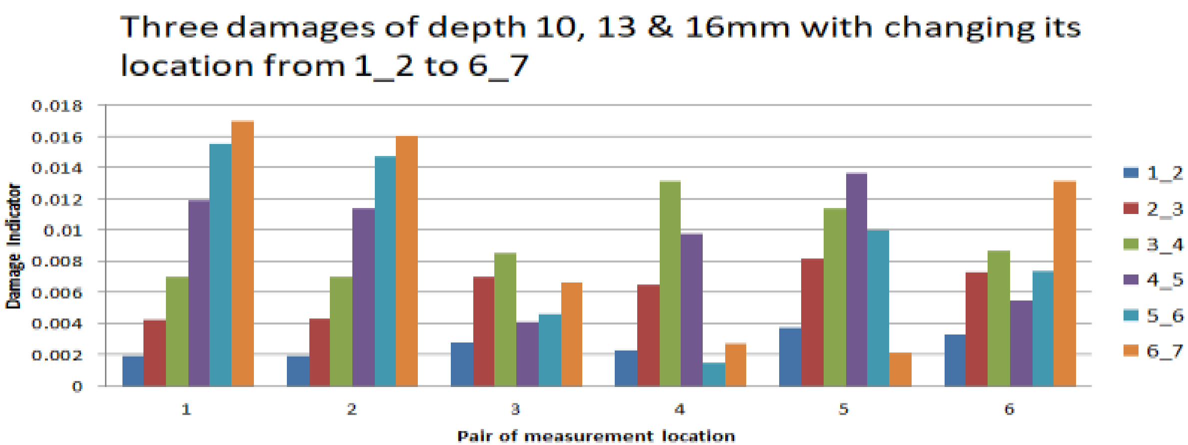
Step 5:Then we choose analysis type such as static analysis, modal analysis, harmonic analysis, transient analysis etc. According to selected analysis type we apply initial, boundary conditions and loads. Load steps are defined in case transient analysis and the analysis type which involves application of loads at different time intervals.

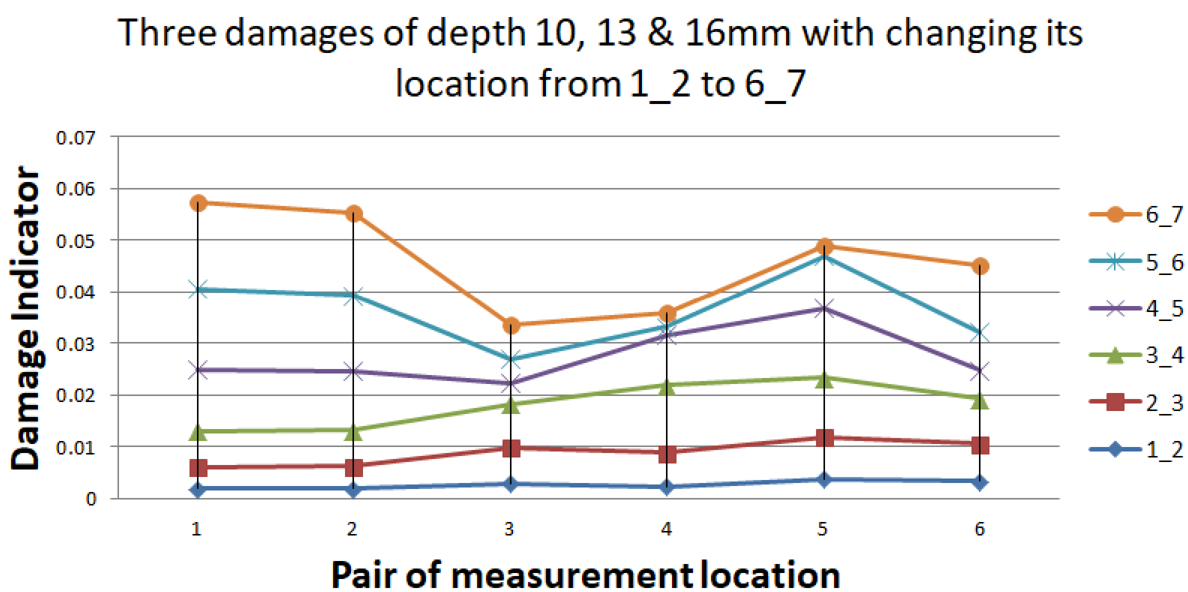
Step 6:Then solution is done using the current file or LS (load step) files.

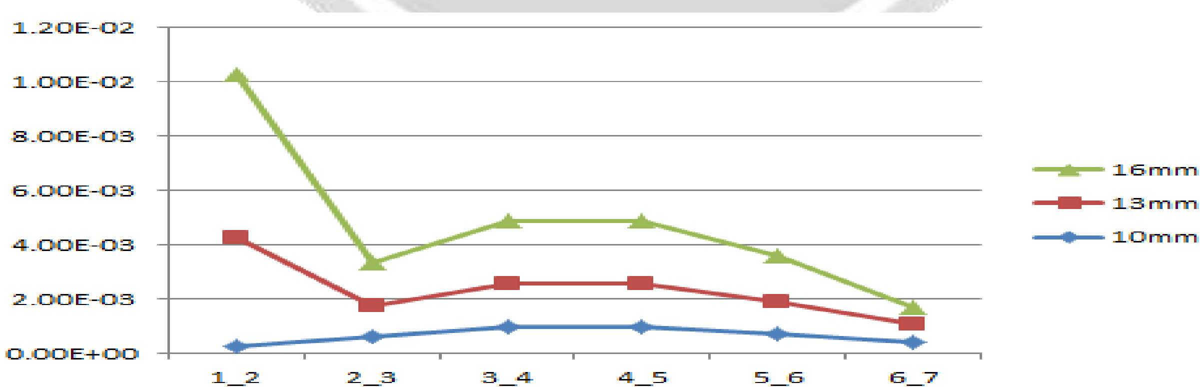
Step 7:Then post processing of the solution is done. Generally post processing involves collection of results, plots and animations of the analysis. The post analysis are done using Microsoft Excel Worksheet and MATLAB. The steps from 1 to 5 are called pre-processing i.e., which are done before solution and involves assigning material & section properties, geometric modelling and meshing. Whereas step 6 is solution step and step 7 is post processing includes the process after the solution which involves acquiring results, plots and animations if any.

Material used	composite	**Length**	0.35m
Young's modulus	70Gpa	**Width**	0.025m
Poisson's ratio	0.3	**Thickness**	0.006m
Density	2700kg/m^3	**Boundary Conditions**	Cantilever beam
Material	Isotropic and elastic	**Applied Load**	Impulse load of 6N for first 1ms time step
Element type	SOLID 186	**Damage**	V-Cut with angle of 45^0,10mm depth

MODEL PARAMETERS, PROPERTIES, BOUNDARY CONDITIONS AND LOAD.


Three damages of depth 10, 13 & 16mm with changing its location from 1_2 to 6_7
Damage Indicator
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
1
2
3
4
5
6
Pair of measurement location
1_2
2_3
3_4
4_5
5_6
6_7


Three damages of depth 10, 13 & 16mm with changing its location from 1_2 to 6_7
Damage Indicator
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1
2
3
4
5
6
Pair of measurement location
6_7
5_6
4_5
3_4
2_3
1_2


1.20E-02
1.00E-02
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
1_2
2_3
3_4
4_5
5_6
6_7
16mm
13mm
10mm

5. CONCLUSIONS

In this damage detection and localizing is validated by using cross-correlation function through vibration analysis. Comparison of maximum absolute values of normalized cross correlation functions between the undamaged and damaged beam indicates the effect of damage between the pairs of location. And the damage is located between the pairs of measurement nodes where the maximum values of Damage Indicators obtained. Later the damage depths are increased from 10mm to 13mm and 16mm and observe that increase in the values of Damage Indicators due to the effect of increase in damage.

Further multiple damages are introduced and observed that the peak values of Damage Indicators shows all the locations of the damage. By this it has seen that this numerical study of Vibration Response Using Cross correlation Analysis working well in detection of single and multiple damages. Also this can be extended for multiple excitations, hoping so the method followed in this thesis may give an appropriate results for multiple unknown excitation.

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