



A BEAM USING CROSS-CORRELATION ANALYSIS OF VIBRATION RESPONSE

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Abstract: *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. This work involves the analysis of a composite beam which has been modelled in UGNX and simulation analysis has been done in ANSYS APDL to validate the damage detection approach. The responses of undamaged and damaged beam are recorded and used in cross correlation approach to compare the cross correlation functions, where the cross correlation functions are determined using the impulse responses which are obtained through the above analysis. These impulse responses correspond to the inherent dynamic properties of the structure, therefore by comparing the cross correlation functions of undamaged and damaged beam, damage can be identified.*

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

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.

1.2 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.

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.

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.

Monitoring

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

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.

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 brain 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 neural 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.

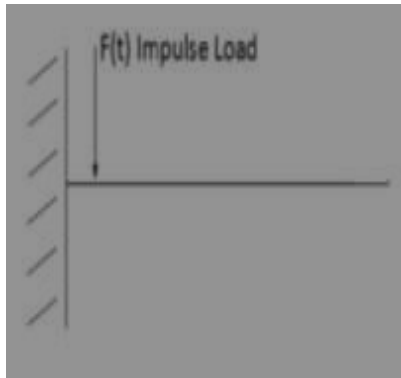


Fig.1

Increased Safety. However 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 considered, 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. It 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.

Three damages of depth 10, 13 & 16mm with changing its location from 1_2 to 6_7

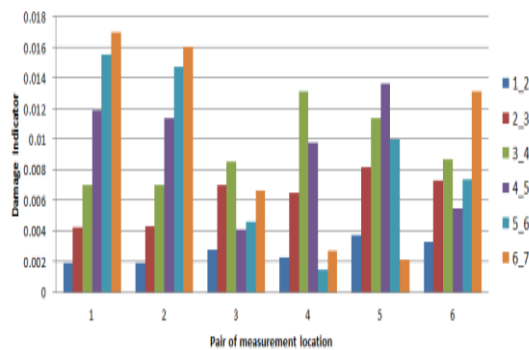


Fig.2

Three damages of depth 10, 13 & 16mm with changing its location from 1_2 to 6_7

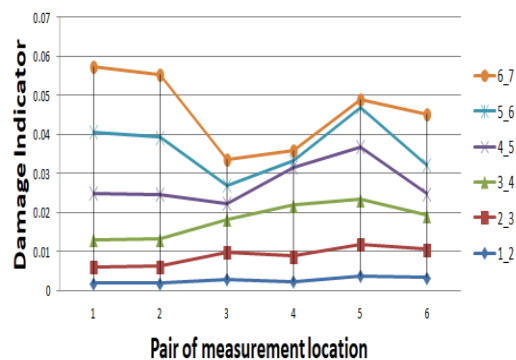


Fig.3

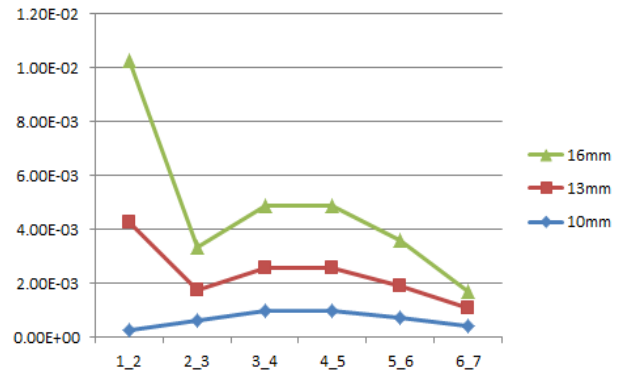


Fig.4

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.

References

[1] Zhu, Dapeng, et al. "Structural damage detection through cross correlation analysis of mobile sensing data." Proc. of the 5th World Conference on Structural Control and Monitoring, USB. (2010).
[2] Lei, Jia Yan, Qian Feng Yao, and Ying Lei. "Structural Damage Detection with Cross Correlation Function of Vibration Observations." Advanced Materials Research. Vol. 163. (2011).
[3] Hou, Yan Fang, and Wei Bing Hu. "Damage Detection of Historic Timber Structure Based on Cross Correlation Function Amplitude



- Vectors."Advanced Materials Research. Vol. 368. (2012).
- [4] Yan, Y. J., et al. "Development in vibration-based structural damage detection technique." *Mechanical Systems and Signal Processing* 21.5: pp. 2198-2211. (2007).
- [5] Bjorkmon, Mikael. "Evaluation of finite element tools for transient structural dynamic simulations of firing systems." (2010).
- [6] Schallhorn, Charles Joseph. "Localization of vibration-based damage detection method in structural applications." (2012).
- [7] Habib, Fady. *Structural Health Monitoring of Adhesively Bonded Composite Joints*. (2012).
- [8] Wang, Le, Zhichun Yang, and T. P. Waters. "Structural damage detection using cross correlation functions of vibration response." *Journal of Sound and Vibration* 329.24: pp. 5070-5086. (2010).
- [9] Guemes, Alfredo. "SHM Technologies and Applications in Aircraft Structures." *Proceedings of the 5th International Symposium on NDT in Aerospace, Singapore*. (2013).
- [10] W. Staszewski, C. Boiler, and G. Tomlinson, *Health monitoring of aerospace structures: smart sensor technologies and signal processing*. Hoboken, NJ, USA: J. Wiley. (2004).
- [11] Sohn, Hoon, and Charles R. Farrar. "Damage diagnosis using time series analysis of vibration signals." *Smart materials and structures* 10.3: pp. S446. (2001).
- [12] Chiu, W.K.; Koh, Y.L.; Galea, S.C.; Rajic, N. "Smart structure application in bonded repairs" *Composite Structure*. Vol. 50, pp. 433-444. (2000).
- [13] C. M. Diwakar, N. Patil, and Mohammed Rabius Sunny "Structural Damage Detection Using Vibration Response Through Cross-Correlation Analysis: Experimental Study". 2018
- [14] Le Wang, Tim P. Waters and Zhichun Yang "structural Damage detection using cross correlation functions of vibration response". 2010
- [15] Sohn et al , " A review of Structural Health Monitoring literature : 1916-2001, rep.LA13976-MS, Los Alamos National Laboratory, Los Alamos NM, USA, 2004