ACCURACY OF VIBRATION BASED IDENTIFICATION TECHNIQUE USED FOR DAMAGE DETECTION

M. Wesolowski, S. Rucevskis, E. Barkanov and A. Chate
Institute of Materials and Structures, Riga Technical University,
Kalku St. 1, LV-1658, Riga, Latvia

1. INTRODUCTION

During the last two decades structural damage identification has become an important research area for civil, mechanical, and aerospace constructions. A great variety of methods have been proposed for damage detection by using dynamic structure parameters. Most of them require modal data of the healthy state of structure as a reference. In the present paper an identification technique for damage detection which utilizes mode shape curvatures obtained from vibration analysis of damaged laminated composite beam is proposed. Since the present procedure uses only the experimentally measured natural frequencies and their corresponding mode shapes, high accuracy of the vibration sensing is needed for the modal data. Therefore the damage detection is preceded by an investigation of experimental errors influence on dynamic characteristics of a beam. Examples of the detection of damage introduced by low-velocity impact are described.

2. ERRORS INFLUENCE AND SOURCES

The experimental dynamic characteristics of a structure are mostly disturbed by the errors due to badly simulated boundary conditions, additional mass from exciting or sensing devices, and measurement noise influence. Application of the POLYTEC Laser Scanning Vibrometer (PSV-400B) provides noncontact vibration sensing and thus eliminates the additional mass of sensing devices. Moreover, the PSV-400B equipped with the Digital Decoder VD-07 provides the signal-to-noise correction as well as very high accuracy of vibration velocities sensing, which vastly eliminates the undesired noise from measurement data. In order to determine the errors caused by boundary conditions, several experiments have been carried out for different arrangements of free-free and clamped beams. To study an influence of additional mass of excitation devices, a number of experiments has been performed using different excitation techniques employing PZT actuators, modal shaker, impact hammer and loudspeaker.

3. DAMAGE DETECTION

Two phenomena are used in the proposed identification technique for damage detection. The first is that the following relation between mode shape curvature and flexural stiffness of a beam holds and allows exhibiting its local changes caused by the flexural stiffness reduction,

$$\frac{\partial^2 w}{\partial x^2} = \frac{M}{EI} \tag{1}$$

where w is a transverse displacement, (EI) is a flexural stiffness of beam and M is an applied moment. The location of damage is assessed by the largest magnitude of the mode shape curvature. The second is the fact that damage as a combination of different failure modes in the form of a local stiffness reduction in the structure affects its dynamic characteristics, i.e., natural frequencies and corresponding mode shapes. Therefore in the present study the first phenomenon is applied for damage location and size characterization, and the second - for identification of the beam stiffness reduction by using mixed numerical-experimental (inverse) technique.

Damage induces reduction of the flexural stiffness of a structure subsequently causing an increase in the magnitude of mode shape curvature. The present study focuses on the identification of damage location and size in a laminated composite beam by extracting mode shape information obtained from vibration experiments. A low-velocity impact is used in order to introduce damage into beam. Then an experimental modal analysis is performed using the PSV-400B system. The mode shape curvature is computed from experimentally measured mode shape using central difference approximation. The location and size of damage (Fig. 1) is estimated by application of the mode shape curvature square magnitude damage index expressed as follows

$$MSCSM = \frac{1}{N}\sum_{n=1}^{N}\left(\left(\frac{\partial^2 w}{\partial x^2}\right)^2_{(i,j)}\right)_n \tag{2}$$

where N is a total number of mode shapes, i and j a number of measurement points in x and y direction, respectively. Finally, the beam stiffness reduction is identified via natural frequencies by using mixed numerical-experimental technique. The method is based on the minimization of discrepancy between the numerically calculated and experimentally measured frequencies. The numerical frequencies are calculated by employing a finite-element model for beam with introduced stiffness reduction. Further by using the response surface approach, a relationship between the modal frequencies and damage extent is constructed. The damage extent is obtained by solving the optimization problem.

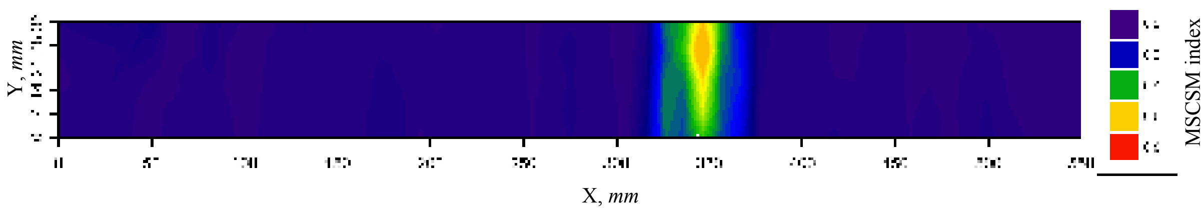

Fig. 1. Damage location in the laminated composite beam.

4. CONCLUSIONS

The present investigations gave the possibility to find sources of experimental errors and their influence on the structural dynamic characteristics. The acquired experience in reducing the errors influence on dynamic characteristics has been successfully applied to the noncontact damage detection procedure, so that the location and size of damage in a composite beam have been successfully estimated based on the mode shape curvature square magnitude damage index. Using the inverse technique, an extent of the damage has been found giving an information about beam stiffness reduction.

ACKNOWLEDGEMENTS

This work was supported by the European Commission under FRAMEWORK6 program, contract No. MRTN-CT-2005-019198, project “Multidisciplinary Research and Training on Composite Materials Applications in Transport Modes” - MOMENTUM, and by the Latvian Council of Science under MATERA program, project “Advanced Dynamic Modelling of Adaptive Multifunctional Materials and Structures” - ADYMA.