DEVELOPMENT OF DamageCALC APPLICATION FOR AUTOMATIC CALCULATION OF DAMAGE INDICATOR

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ABSTRACT

This paper presents development of DamageCALC application for automatic calculation of Damage Detection and Relative Quantification indicator - DRQ. DamageCALC is developed using Visual Basic 6 and enables automatic graphical interpretation of the damage indicator. The method based on DRQ indicator uses frequency response functions as the characteristics of dynamics response of the mechanical system. The DamageCALC automatically reads the measurement results, previously obtained from modal testing of the beam structure, calculates the value of the corresponding coefficients and forms a chart for graphical interpretation of the damage indicator values. By following the trend of calculated DRQ indicators for several successive measurements of the structure, one can determine the existence of damage at the structure and its propagation.

Keywords: Damage indicator, FRF, Modal testing, Automatic calculation

1. INTRODUCTION

In the most general terms structural damage can be defined as changes introduced into a system that adversely affect the current or future performance of that system. Implicit in this definition is the concept that damage is not meaningful without a comparison between two different states of the system, one of which is assumed to represent the initial and often undamaged state, [1].

Damage may also be defined as any deviation in the structure’s original geometric or material properties that may cause undesirable stresses, displacements, or vibrations on the structure. These weaknesses and deviations may be due to cracks, loose bolts, broken welds, corrosion, fatigue, etc. All of them should cause a decrease in the structure’s stiffness, and some will also affect its mass and damping properties.

Therefore, structural damages should always, at a sufficient level of severity, cause a change in a structure’s vibration behaviour, described by modal properties: natural frequencies, damping loss factor and mode shapes.

Since the changes on the dynamic characteristics can be measured and studied, it is possible to trace what structural changes have caused the dynamic characteristic to change, thus identifying damage, [2].

Sampaio and Maia in [3] present some new development of the Detection and Relative damage Quantification (DRQ) indicator method, concerning the detection, localization and the relative severity of damage. This method belongs to the class of methods using the change in the frequency response functions to detect, locate and relatively quantify the damage. The main advantages of the method are: 1) it is not necessary to perform modal identification; 2) there is no need for any analytical or numerical model of the structure; 3) it uses all measured data in the form of frequency response functions, without further treatment. This method is also suitable for automatic calculation. Therfore, the DamageCALC application for automatic calculation of DRQ indicator and automatic graphical interpretation of the damage indicator is developed using Visual Basic 6.
2. THEORETICAL DESCRIPTION OF DAMAGE DETECTION METHOD

The Response Vector Assurance Criterion (RVAC) is defined in paper [4] as:

\[
RVAC_d(\omega) = \frac{\sum_{i=1}^{N} \alpha_i(\omega) \alpha_i(\omega)}{\sum_{i=1}^{N} \alpha_i(\omega)^2 \sum_{i=1}^{N} \alpha_i(\omega) \alpha_i(\omega)} \tag{1}
\]

where \(\alpha_i(\omega)\) is element of the system receptance matrix and corresponds to an individual frequency response function, FRF. For only one applied force, receptance matrix turns to be just a vector, so \(\alpha_i(\omega)\) is a single FRF for \(i\)-th co-ordinate or measuring point, and \(N\) is the total number of measuring points. The element \(\alpha_i(\omega)\) corresponds to the undamaged structure, while the superscript \(d\) stands for damaged structure.

The Detection and Relative damage Quantification indicator is formulated in paper [3] as:

\[
DRQ_d = \frac{\sum_{\omega} RVAC_d(\omega)}{N_{\omega}} \tag{2}
\]

where \(N_{\omega}\) is the number of frequencies and, so, DRQ varies between 0 and 1.

The DRQ indicator is able to detect and relatively quantify the damage that is to recognize the pattern of damage variation.

3. EXPERIMENTAL INVESTIGATION

In the aim to obtain the experimental FRFs of undamaged and damaged structure, the steel beam of dimensions 400x10x10 mm was modal tested [5]. A crack of 0.5 mm width was introduced by wire-cut. The beam was suspended with common strings to simulate free-free conditions (Fig. 1).

An impact hammer (Endevco type 2230) generated excitation on the each of 17 nodes uniformly arranged along the beam. An accelerometer (B&K type 4507) was attached to node 5 to capture the vibration signals. The signals were fed into Multi-channel Data Acquisition Unit Portable PULSE (B&K type 3560 C) and analyzed in Labshop 9.0 Pulse software, in the frequency range of 0-3200 Hz. Modal test was repeated for eight level of damage: \(d=1, 2, 3\) correspond to undamaged beam, \(d=4, 5, 6, 7, 8\) correspond to a crack depth of 1-5 [mm]. The first three natural frequencies for different damage levels are given in Table 1. Figure 2 shows the overlaid FRFs measured at the 5th measurement location for 8 damage levels. There is some frequency shift due to increasing of the damage, that is frequencies move to the left (decreasing) due to of decreasing of the stiffness of the beam (when damage increasing). After calculation the Response Vector Assurance Criterion (eq. 1.) and the Detection and Relative damage Quantification indicator (eq. 2.), results are graphically interpreted as follow in Figure 3. It is obvious that DRQ indicator shows decreasing trend as the level of damage increasing.
4. DEVELOPMENT OF DamageCALC APPLICATION

Structural health monitoring procedures based on the Detection and Relative damage Quantification (DRQ) indicator method can be done using some automated procedure through the following steps:

1. Measure the FRF at a certain number of locations on the undamaged structure by modal testing.
2. Load FRFs as a text file into the Damage CALC application.
3. Extract the FRF values for the selected frequencies to calculate the RVAC and DRQ indicators.
4. Start the calculation of RVAC and DRQ indicators.
5. Graphically display the calculated value of the damage indicators.
6. Repeat the entire procedure for each measurement to assess the structural health.

The Detection and Relative damage Quantification indicator method is suitable for automatic calculation. The DamageCALC application for automatic calculation of DRQ indicators and automatic graphical interpretation of results of calculation is developed using Visual Basic 6 [6].

The application automatically reads the measurement results (FRFs) previously obtained by modal testing of beam structure. After reading the results of measurements, application calculates values of the RVAC coefficients for the selected frequency, and calculates the DRQ damage indicator for each measurement. Finally, application designs the graph for visual interpretation of measurement results.

![Fig. 3. DRQ recognize the pattern of damage variation](image3.png)

![Fig. 4. Developed DamageCALC application](image4.png)
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For the development of applications, standard objects offered in Visual Basic 6\textsuperscript{th} are used. The drop-down menus for the frequency selection, a text fields for input and correction of data, and objects for writing and selection of data are placed at the basic form of application.

The program code of application and objects on the basic form enable the calculation for the ten levels of damage of the structure, into the three measuring points and for three natural frequencies.

It is also possible memorizing of the calculated data and drawing diagrams on the basis of previously memorized information from the damaged structure. The frequency response functions measured in the experiment, as input data for the application, need to be preserve in the form of text documents with .txt extension. The program code of application finds path to the appropriate text documents and loading them into a working memory of a computer. Developed application DamageCALC is shown in Figure 4.

The application consists of several modules:
1. Input frequency module,
2. Module for the selection of documents with information about the measurement of the undamaged structure,
3. Module for the selection of documents with information about the measurement of the damaged structure,
4. Module with the command buttons for the data calculation and memorizing,
5. Module for printing the results,

The module (diagram) for the graphical displays the results.

4.1. Input Frequency Module

At one measurement, the FRF measured location contains 3200 data that are discrete values of the measured FRF in the range 0-3200 Hz, with a resolution of 1 Hz (Fig. 5).

For the calculation of RVAC coefficients only three certain frequencies, between 3200 values, are required. Therefore, the application must choose frequencies for which the measured FRF values are read. This is done from the drop-down menu, with pre-selected any document that contains the measured data (Fig. 6) and the values of selected frequency in [Hz] are automatically printed in the text fields.

4.2. Modules for Selecting Documents with Information about the Measurement of the Undamaged and Damaged Structure

After selecting the frequency, the documents with FRFs data measured on the undamaged structure at the three measurement locations are selected. The path to selected documents is automatically printed by pressing the button "Load paths". On the basis of the printed path, the data from a given document are listed by pressing the button "Load Data". Loading can be done only if each of three documents with the data of measurements at three locations are selected.

Especially a separate module for the selection of documents containing measurement information from the undamaged structure and module for the selection of documents containing measurement inform of damaged structures in the three points are given as separated, Figure 7.
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4. Modules for Printing the Results and for Graphical Display the Results

The calculated values of DQR indicator can be memorized in a separate document that can be re-loaded into the application and used for graphical analysis. The entire process of analysis for the next measurement (next level of damage) begins with pushing the button "new level of measurement", where currently memorized data be deleted and the user gets the possibility to select data documents again.

The output data obtained by calculation are printed in a separate module, Figure 9. By pressing the button "Diagram DQR", the application shows the graph of the calculated value of the indicators DQR.

5. CONCLUSION

The DamageCALC application is developed in a way that all operations are carried out by simply selection of data and documents, which makes it easy to handle. The application is simply for transfer and requires no installation. Documents containing the measurement data are copied to the folder containing the application, or the application itself is copied into the folder with the corresponding documents.

Structural health monitoring procedures based on the Detection and Relative damage Quantification (DQR) indicator method can be done using DamageCALC application through the following steps:

1. Measure the FRF at three locations on the undamaged structure by modal testing.
2. Load FRFs as a text .file into the Damage CALC application.
3. Extract the FRF values for the selected frequencies to calculate the RVAC and DQR indicators.
4. Start the calculation of RVAC and DQR indicators.
5. Graphically display the calculated value of the damage indicators.

6. Repeat the entire procedure for each measurement to assess the structural health.

DRQ indicator is able to detect and relatively quantify the damage that is to recognize the pattern of damage variation. So, one can follow the trend of change of DRQ indicator by graph displaying all calculated DRQ for a series of measurements.

REFERENCES