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AN APPROACH TO DAMAGE DETECTION IN A BEAM LIKE STRUCTURES FROM EXPERIMENTALLY MEASURED FRF DATA

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ABSTRACT:
The method based on damage detection and relative quantification indicator is investigated in this paper, in order to detect, locate and quantify the damage of the beam like structure. This method uses frequency response functions as the characteristics of dynamics response of the mechanical system, from which the damage detection and relative quantification indicators are calculated. The goal of investigation is to determine effectiveness of the method based on damage detection and relative quantification indicator to detect, locate and quantify damage of the beam, from the standpoint of independency of the method to the previously built FEM or analytical model and for different boundary conditions.

KEY WORDS:
Damage detection, experimental FRF data, modal testing.

1. INTRODUCTION

Structural damage can be defined as changes introduced into a system that adversely affect the current or future performance of that system. If one is focused on the study of damage identification in structural and mechanical systems, than 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. It is obvious that concept of damage detection is based on comparison between two different states of the system, one of which is assumed to represent the initial and often undamaged state. The structural damage detection can be divided into four levels, based on the amount of information provided regarding the damage state. According to Rytter [7] these four levels are: 1) identification of damage existence in a structure; 2) identification of damage existence in a structure and location of damage; 3) identification of damage existence in a structure, location of damage and quantification of damage severity; 4) identification of damage existence in a structure, location of damage and quantification of damage severity and prediction of the remaining service life of the structure.

The interest in the ability to monitor a structure and detect damage at the earliest possible stage is pervasive throughout the civil, mechanical and aerospace engineering communities during last three decades. At present, using non-destructive techniques to detect damage status of engineering structures is put into a focus of engineering interests. Non-destructive techniques are the means by which structures may be inspected without disruption or impairment of serviceability. Generally, structural damage detection methods can be classified as local damage detection methods and global damage detection methods [11]. Local damage detection techniques refer to non-destructive testing such as acoustic and ultrasonic methods, magnetic field methods, radiography, eddy-current methods, etc., is mainly used to detect local damage in structure. All these methods require that the vicinity of the damage is known and that the portion of the structure being inspected is accessible, and can detect damage on or near the surface of the structure. Local damage detection methods utilise only data obtained from the damaged structure. Baseline data and theoretical models of the undamaged structure are not used. These are the main advantages of local damage detection, which is very effective for small and regular structures, such as pressure vessels.

However, for the large and complex structures, for the structures in invisible or closed environment, it is very difficult to detect damage using local damage detection methods, because local damage detection methodology can only be used to inspect some special and accessible components of a structure. In order to detect damage throughout the whole structure, especially some large, complicated structure, a methodology called global vibration based structural damage detection has been developed. Its basic principle is explained previously, and in a nutshell, when some damage emerges in the structure then structural parameters will change and frequency response functions (FRF) and modal parameters of the structural system will also change. So, the change of the structural FRF's and modal parameters can be taken as the signal of early damage occurrence in the structural system. Such an approach has been introduced for several years in fields like automotive, aeronautical, mechanical and civil engineering.

2. THE BRIEF SURVEY OF VIBRATION-BASED DAMAGE DETECTION APPROACH

Structural damage detection using measured vibration data has been a subject of much practical interests and research efforts and received considerable attention in the literature.

First very detailed survey of the technical literature to determine the state of the art of the damage-detection field using modal analysis procedures was presented by Richardson [6]. The survey focused on structural integrity monitoring for nuclear power plants, large structures, rotating machinery, and offshore platforms, with by far the largest amount of literature associated with rotating machinery. The author stated that while monitoring of overall vibration levels for rotating machinery had become commonplace, attempts at relating structural damage to measured modal changes was still in its primitive stages.

Next survey of the structural health monitoring studies that have appeared in the technical literature until 1996 was presented by Doebling, *et al* [1]. That report first categorizes the methods according to required measured data and analysis technique. The analysis categories include changes in modal frequencies, changes in measured mode shapes (and their derivatives), and changes in measured flexibility coefficients. Methods that use property (stiffness, mass, damping) matrix updating, detection of nonlinear response, and damage detection via neural networks are also summarized. The applications of the various methods to different types of engineering problems are categorized by type of structure and are summarized. The types of structures include beams, trusses, plates, shells, bridges, offshore platforms, other large civil structures, aerospace structures, and composite structures. The report describes the development of the damage-identification methods and applications and summarizes the current state-of-the-art of the technology.

Sohn, *et al* [9] presents detailed report which is an updated version of the previous literature review report by Doebling, *et* al. That report contains new technical developments published between 1996. and 2001. in the discipline of structural health monitoring. The authors have organized reviewed articles following the statistical pattern recognition paradigm reported in [2]. This paradigm can be described as a four-part process: (1) Operational Evaluation, (2) Data Acquisition, Fusion, and Cleansing, (3) Feature Extraction and Information Condensation, and (4) Statistical Model Development for Feature Discrimination. The reviewed articles are then categorized by type of applications, which include beams, truss, plates, bridges, aerospace structures, and composite structures.

Yan, et al. [11] presents general summary and review of state-of-the-art and development of vibration-based structural damage detection methods based on structural dynamics characteristic parameters. They divide vibration-based structural damage detection methods into traditional-and modern type. The traditional type refers to detection methods for structural damage only utilizing itself mechanical characteristic of structures, such as natural frequencies, modal damping, modal strain energy or modal shapes, etc. This kind of method generally requires experimental modal analysis or transfer function measure, and the authors find it not convenient for online detection of structures in service, because these experimental measures often need multifarious instrument or manual operation. The modern type refers to detection methods for structural damage based on online measured response signal of structures in service. Among the modern type methods for structural damage detection, the representative ones include Wavelet analysis, Genetic algorithm and Artificial Neural Network, etc.

The cited authors pointed out the main topics for the future research in damage detection based on measured vibration response of a structure:

- Minimizing the dependence on prior analytical models and/or prior test data for the detection and location of damage.
- Developing of methods that have ability to account for the effects of nonlinear structural response.

- Optimization of the position and number of measurement sensors.
- Construction and extraction of feature index for small structural damage from structural vibration response.
- Ability of discrimination of changes in the modal properties resulting from damage from those resulting from variations in the measurements (resulting from changing environmental and/or test conditions and from the repeatability of the test)
- Reducing the dependence upon measurable excitation forces, using vibrations induced by ambient environmental or operating loads for the assessment of structural integrity.
- Comparison of different damage detection methods by application to a common set of data.
- Integration of local nondestructive inspection and global vibration testing.
- Damage prognosis which estimates the remaining service life of a structure.

3. CLASIFICATION OF DAMAGE IDENTIFICATION METHODS

In order to detect structural damage from structural dynamic response signal, the first problem is to select damage feature index to be constructed. The physical variable used to identify damage may be a global one, but the physical variable used to determine damage location is better to be local one and must be sensitive to structural local-damage. Determination of structural damage location is equivalent to determining a region where structural stiffness and loading capacity decreases using a measurable quantity. The key factor of vibration based damage detection is to establish the calculation model and to estimate the vibration parameter to be measured.

Doebling [1] and Farrar [2] categorize damage identification methods according to:

- the type of measured data (feature) used
- the techniques used to identify the damage from the measured data.

Common features used in vibration based damage detection studies are: 1) modal frequencies, 2) frequency response functions, 3) mode shapes 4) mode shape curvatures 5) modal strain energy 6) dynamic flexibility, etc.

The techniques used to identify the damage from the measured data can be classified as: 1) methods based on frequency changes (forward or inverse problem methods) 2) methods based on mode shape changes 4) methods based on mode shape curvature changes 3) methods based on dynamically measured flexibility: comparison of flexibility changes, stiffness error matrix method, effects of residual flexibility, changes in measured stiffness matrix, 4) matrix update methods, 5) neural-network based methods, 6) time-history and spectral pattern methods, 7) nonlinear methods, 8) statistical pattern recognition methods, etc. He [4] classifies damage detection methods as:

- Damage detection using experimental data only. Damage detection without a readily available spatial model of the undamaged structure is an approach departed completely from model updating path. Usually, the data available are the experimental data before and after damage occurred. As a result, we are dealing with two sets of modal or FRF data. The comparison of these two sets should yield the information about the existence and location of damage. The main question is how to relate the differences between modal and FRF data before and after damage to the spatial stiffness changes that resulted in the differences.
- Damage detection using modal data and analytical data. Damage detection using modal data is an approach that was largely adopted from model updating. Its algorithm aims to determine damage by using the modal data from a damage structure and an analytical model for its counterpart. Although many model updating methods utilizing modal data can be adopted directly for damage detection, method based on modal force vector is more convenient and efficient.
- Damage detection using FRF data. Using measured FRF data for damage detection has many advantages over the traditional methods using modal analysis data: 1) any numerical errors inherent in modal analysis results caused by inaccurate curve fitting and unavailable residual terms are avoided; 2) no more efforts is needed to process FRF data in order to derive modal data; 3) the most significant advantages of using measured FRF data over derived modal analysis data lies in the fact that FRF data provide abundant information on the dynamic behavior of a structure. Modal analysis data lose much of the information that FRF data have, due to the necessary numerical process to extract them.

4. ONE APPROACH TO DAMAGE DETECTION USING FRF DATA

Sampaio and Maia [8] present some new development of the Detection and Relative damage Quantification indicator, concerning the detection, localization and the relative severity of damage.

This method belongs to the class of methods that use 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.

Theoretical description: The equation of motion of a multiple-degree of freedom system with hysteretical damping, which is often used in describing of complex structure's dynamics [5], is:

$$[M]\{\ddot{x}(t)\} + i[D]\{x(t)\} + [K]\{x(t)\} = \{f(t)\} \tag{1}$$

If the excitation is harmonic, the realtion between the response and the excitation at each frequency of the analysis is given by:

$$\{X\} = [\alpha(\omega)]\{F\} \tag{2}$$

where

$$[\alpha(\omega)] = ([K + iD] - \omega^2 [M])^{-1} \tag{3}$$

is the system receptance matrix, containing all the inforamtion about the dynamic characteristic of the system. Each element $\alpha_{jk}(\omega)$ of the matrix corresponds to an individual FRF describing the relation between the response at a particular coordinate *j* and a single force excitation applied at coordinate *k:*

$$\alpha_{jk}(\omega) = \frac{X_j}{F_k} \qquad F_i = 0, i = 1 \ldots N; i \neq k \tag{4}$$

The column vector, *k*, of the receptance matrix, $\{\alpha_k(\omega)\}$, describes the shape (in space) exhibited by the structure at each excitation frequency ω, given by the responses normalized by the applied forces.

When a structure is damaged its stiffness and damping change and, in consequence, so does the receptance matrix:

$$[{}^d\alpha(\omega)] = ([{}^dK + i\,{}^dD] - \omega^2 [M])^{-1} \tag{5}$$

where the superscript *d* stands for damaged.

It is reasonable to assume that the smaller the degree of correlation between the column vectors, $\{\alpha_k(\omega)\}$ and $\{{}^d\alpha_k(\omega)\}$, the larger the damage.

To measure the degree of correlation between two vectors, R. Pascual *et al.* [5,6] proposed the Frequency Domain Assurance Criterium (FDAC):

$$\mathrm{FDAC}_{\mathrm{jk}}\_\mathrm{d}(\omega_1, \omega_2) = \frac{\left|\sum_{j=1}^{N} {}^d\alpha_{jk}(\omega_2)\overline{\alpha_{jk}(\omega_1)}\right|^2}{\sum_{j=1}^{N}\left[{}^d\alpha_{jk}(\omega_2)\overline{{}^d\alpha_{jk}(\omega_2)}\right]\sum_{j=1}^{N}\left[\alpha_{jk}(\omega_1)\overline{\alpha_{jk}(\omega_1)}\right]} \tag{6}$$

where — represents the conjugate operator and *N* is the total number of co-ordinates or measuring points.

W. Heylen *et al.* [7] defined a simplified form of FDAC, known as RVAC or Response Vector Assurance Criterion (RVAC) (see Figure 1), with only one applied force (so that the receptance matrix turns to be just a vector):

$$\mathrm{RVAC}\_\mathrm{d}(\omega) = \frac{\left|\sum_{j=1}^{N} {}^d\alpha_j(\omega)\overline{\alpha_j(\omega)}\right|^2}{\sum_{j=1}^{N}\left[{}^d\alpha_j(\omega)\overline{{}^d\alpha_j(\omega)}\right]\sum_{j=1}^{N}\left[\alpha_j(\omega)\overline{\alpha_j(\omega)}\right]} \tag{7}$$

The Detection and Relative damage Quantification indicator is formulated as [8]:

$$DRQ_d = \frac{\sum_{\omega} RVAC_d(\omega)}{N_\omega} \tag{8}$$

where N_ω is the number of frequencies and, so, DRQ will vary between 0 and 1.

The procedure described previously is the strategy for damage detection that is level 1 according to Rytter's classification of the structural damage detection.

The similar procedure can be further applied to the localization stage, that is level 2 according to Rytter. A comparison between shape vectors can be taken as before, but now taking consecutive pairs of coordinates (p and p+1) along the structure, instead of doing it for all the coordinates simultaneously (whole structure) . The calculation is entirely similar and the "local" RVAC is defined as

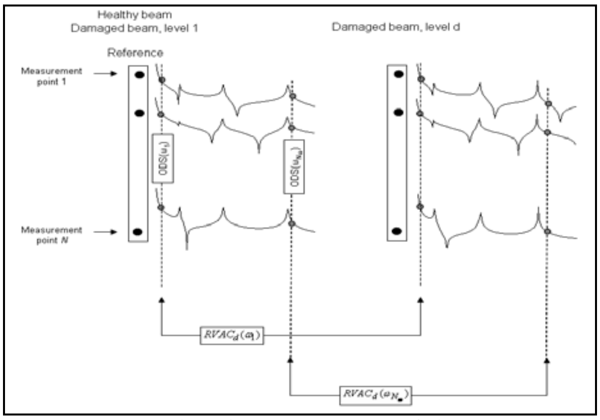

Figure1. Graphical presentation of the RVAC [8]

$$\mathrm{RVAC\_d}\,(p,\omega)=\frac{\left|\sum_{j=p}^{p+1}{}^{d}\alpha_j(\omega)\overline{\alpha_j(\omega)}\right|^2}{\sum_{j=p}^{p+1}\left[{}^{d}\alpha_j(\omega)\overline{{}^{d}\alpha_j(\omega)}\right]\sum_{j=p}^{p+1}\left[\alpha_j(\omega)\overline{\alpha_j(\omega)}\right]} \tag{9}$$

For the sake of comparison with the proposed method, one shall also compute the Generalized Damage Index, in terms of shape vectors, defined as:

$$\beta_{ij}(\omega)=\frac{\left({}^{d}\alpha_{ij}''^{2}(\omega)+\sum_{i=1}^{N}{}^{d}\alpha_{ij}''^{2}(\omega)\right)}{\left(\alpha_{ij}''^{2}(\omega)+\sum_{i=1}^{N}\alpha_{ij}''^{2}(\omega)\right)}\frac{\sum_{i=1}^{N}\alpha_{ij}''^{2}(\omega)}{\sum_{i=1}^{N}{}^{d}\alpha_{ij}''^{2}(\omega)} \tag{10}$$

The developed indicators can also give information about the relative extent of the damage, i.e., it can be used as relative damage quantifiers, which satisfy level 3 of structural damage detection according to Rytter.

5. EXPERIMENTAL DAMAGE DETECTION ON THE BEAM LIKE STRUCTURE

Sampaio and Maia stated in [8] that there is no need for any analytical or numerical model for structural damage detection based on the Detection and Relative Damage Quantification indicator. They showed numerical performance of the method and its experimental application on the example of the free-free supported beam, exciting it by shaker and collecting responses with 21 uniformly distributed accelerometers along the beam.

Figure 2. Two boundary conditions: the freely supported beam and the cantilever beam

However, it was interested to investigate how proposed method operates in the case of impulse excitation and the limited number of accelerometers on disposal. Thus, we decided to experimentally investigate performance of the proposed method applying it to the freely supported beam and cantilever beam, Figure 2. Modal testing was performed by means of hammer excitation, using two different testing methods: “roving hammer method” and “roving accelerometers method”. It was necessary to collect FRFs for chosen number of DOFs from the undamaged beam and from the damaged beam for a few levels of damage. The damage was simulated introducing a cut at a certain location of the beam, and the damage was propagated by deepening the cut for 1 mm at every level of damage.

5.1. An equipment used for modal testing

Measurement data were collected using the Multi-channel Data Acquisition Unit Portable Pulse, Bruel&Kjaer type 3560 C, and analyzed in the Pulse LabShop 9.0 software, in the frequency range of 0÷3200 Hz, Figure 3. An impact hammer Endevco type 2302-10 generates excitation, while the responses were captured by modal accelerometer, B&K type 4507, attached to the structure. Both signals were weighted by some window functions: the excitation signal by transient window function and response signal by exponential window function. Frequency resolution was chosen to be 1 Hz, and the number of averaging was 5 per DOFs.

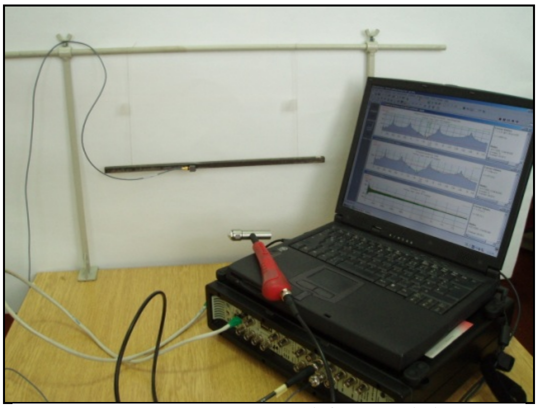
Figure 3. Equipment used for modal testing

5.2. Damage detection of the freely supported beam

The steel beam of dimensions 400×15×15 mm was used for experimental investigation. The crack of 1 mm width was introduced by wire-cut. The beam was suspended with common strings to simulate free-free conditions. Two test were done with two different modal testing procedure:

- test 1: so called “roving hammer” test with fixed response measurement position
- test 2: so called “roving accelerometer” test with fixed hammer excitation position.

In the “roving hammer” test the accelerometer was attached to node 5 to capture the vibration response signals, while the impact hammer generates excitation on the each of 17 nodes uniformly arranged along the beam, Figure 4. In the “roving accelerometer” test the excitation position was fixed at nod 8, but the accelerometer was moved along the 17 DOF of beam to capture the vibration response signals, Figure 5. To avoid the loading mass effect due to local added transducer mass, 16 dummy transducers were used during test, Figure 6a and 6b. The dummies were systematically replaced by the real transducer for the measurement, until all of the measurement locations have been covered. Thus the systematic error incurred as a result of moving the transducer around on the structure during test was turned into single error by the use of dummy transducer. The beam was cut with 7 depths in the middle of location 14 and 15, Table 1. As one can see from table 1 the beam was measured in 10 conditions: the undamaged (or reference), two undamaged but different from reference state, and 7 levels of damage at certain location.

Table 1. Levels of damage of the free-free beam

Level of damage „d“	1	2	3	4	5	6	7	8	9	10
Depth of cut [mm]	0	0	0	1	2	3	4	5	6	7

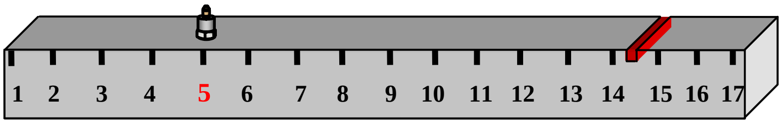

Figure 4. Location of damage and response measurement location for the “roving hammer” test

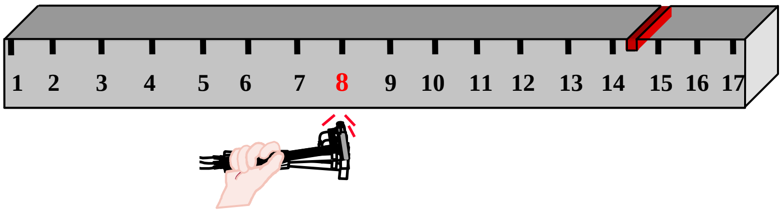

Figure 5. Location of damage and excitation position for the “roving accelerometer” test

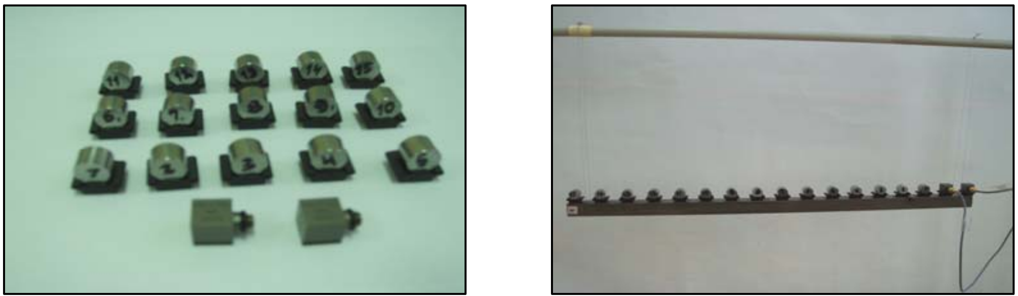

Figure 6. Dummy transducers used in the “roving accelerometer” test and the free-free beam equipped by dummy transducers

were done, all FRFs measured at location 5 were ov at there is some frequency shift due to increasing of th creasing) due to of decreasing of the stiffness of the be requencies for 10 levels of damage and two modal tes

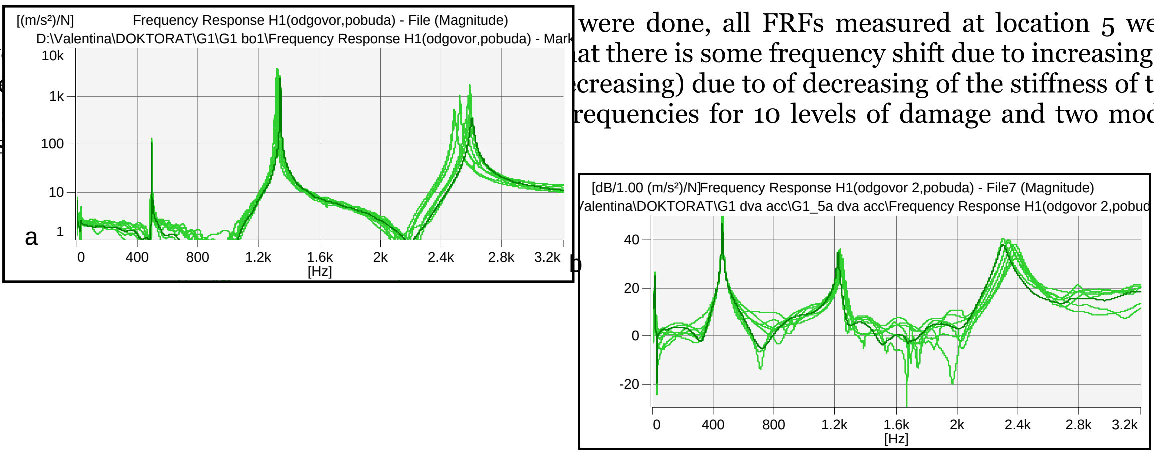

Figure 7. Overlapped FRFs measured for 10 levels of damage:
a. ”roving hammer” test, b. “roving accelerometer” test

Table 2. Values of modal frequencies for undamaged and damaged beam

		Modal frequencies (Hz)								
		Level of damage "d"								
		1	2	3	4	5	6	7	8	9
Test 1	f1	493	493	493	493	493	492	492	491	489
	f2	1339	1339	1339	1337	1334	1327	1318	1305	1286
	f3	2600	2600	2600	2587	2574	2557	2520	2483	2425
Test 2	f1	459	459	459	459	460	459	458	458	456
	f2	1246	1246	1246	1245	1245	1238	1230	1219	1201
	f3	2389	2389	2389	2384	2377	2357	2334	2299	2249

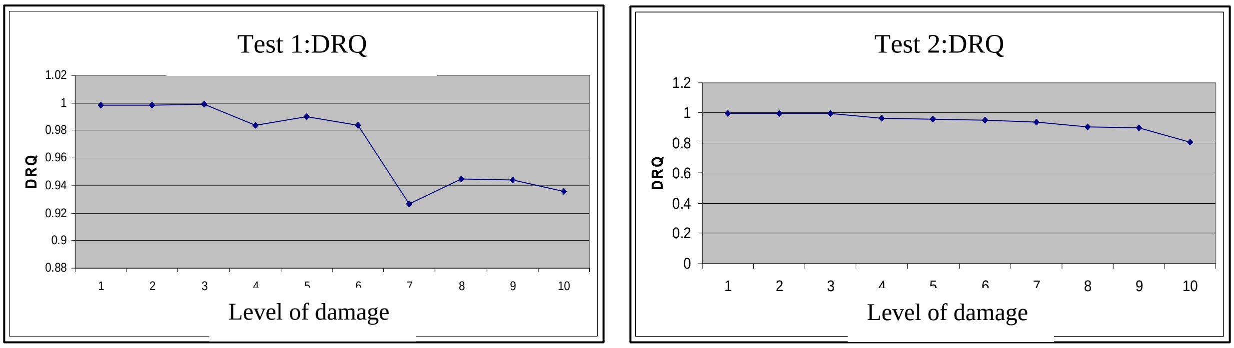

Figure 8. Detection and quantification of the damage using the DRQ indicator for two modal tests

After calculation the Response Vector Assurance Criterion (eq.7.) and the Detection and Relative damage Quantification indicator (eq.8.), results are graphically interpreted as follow on Figure 8. It is obvious that DRQ indicator shows decreasing trend as increasing the level of damage, for both modal tests. However, “roving accelerometer” test shows better tendency of decreasing the DRQ indicator value as the level of damage increasing. Generally, it can be stated that the DRQ indicator is able to detect and relatively quantify damage, which satisfy the level 1 and the level 3 of damage detection according to Rytter.

For the purpose to locate damage, much better results showed the General Damage Index - GDI (eq. 10) than the local RVAC indicator (eq.9). To calculate GDI, some correction has been done to the index defined with the equation as follows:

$$\beta_d(p,f)=\frac{\left({}^d\alpha_j''(f)\overline{{}^d\alpha_j''(f)}+\sum_{j=1}^{N}{}^d\alpha_j''(f)\overline{{}^d\alpha_j''(f)}\right)}{\left(\alpha_j''(f)\overline{\alpha_j''(f)}+\sum_{j=1}^{N}\alpha_j''(f)\overline{\alpha_j''(f)}\right)}\,\frac{\sum_{j=1}^{N}\alpha_j''(f)\overline{\alpha_j''(f)}}{\sum_{j=1}^{N}{}^d\alpha_j''(f)\overline{{}^d\alpha_j''(f)}} \qquad (11)$$

However, GDI defined from equation 11 was still not enough sensitive to a low level of damage, so that the new index, named cumulative GDI was proposed [3]. The Cumulative GDI was calculated by successive adding the values of GDI for the each level of damage. Some measurement inaccuracies occurred on the certain locations during testing could be averaged, but it is supposed that GDI should increase continuously on the location on damage. Figure 9 shows cumulative GDI indicating the location of damage between measurement location 14 and 15, for both modal tests.

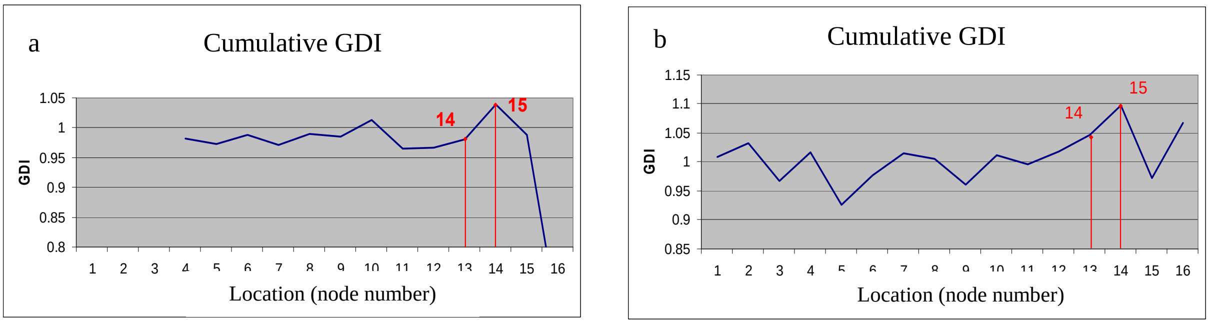

Figure 9. Location of damaged element using the GDI indicator:
a) “roving hammer” test, b) “roving accelerometer test

5.3. Damage detection of the cantilever beam

The steel beam of dimensions 400×10×10 mm was used for experimental investigation. The beam was clamped at one end, forming bracket of 300 mm length, Figure 10. An impact hammer generates excitation on the each of 14 nodes uniformly arranged along the beam. An accelerometer was attached to node 11 to capture the vibration response signals. The damage was simulated by cut of 0.5 mm width introduced the middle of location 4 and 5, with 5 level of depths, Table 2. As one can see from Table 3 the cantilever beam was measured in 7 conditions: the undamaged (or reference), one undamaged but different from reference state, and 5 levels of damage at certain location.

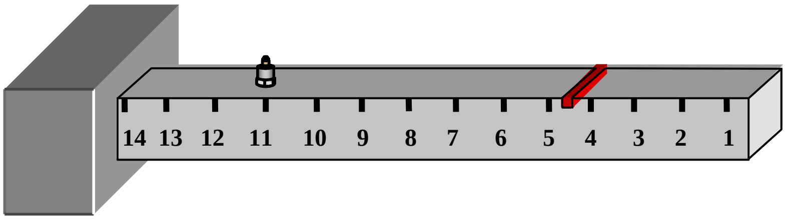

Figure 10. Location of damage and response measurement location of the cantilever beam

Table 3. Levels of damage of cantilever beam

Level of damage „d“	1	2	3	4	5	6	7
Depth of cut [mm]	0	0	1	2	3	4	5

After 7 modal tests of the cantilever beam were done, all FRFs measured at location 11 were overlapped, Figure 11. It is obvious from figure 11, that 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 level of damage increasing). Modal frequencies for 7 levels of damage are shown in Table 4.

Table 4. Values of modal frequencied for undamaged and damaged beam

	Modal frequencies (Hz)						
	Level of damage "d"						
	1	2	3	4	5	6	7
Mode1: f1	88	88	83	81	81	81	80
Mode 2: f2	527	527	519	523	518	509	500
Mode 3: f3	1465	1465	1469	1454	1422	1375	1322
Mode 4: f4	2849	2849	2868	2831	2784	2736	2684

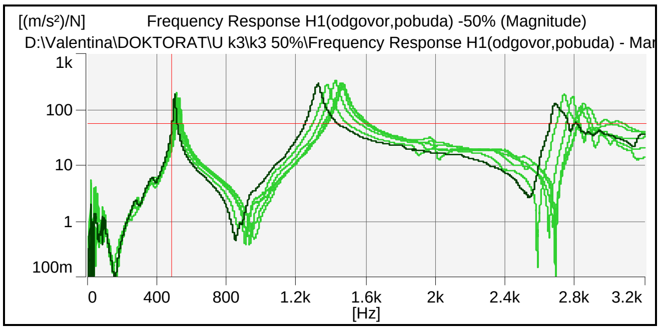

Figure 11. Overlapped FRFs measured for 7 levels of damage

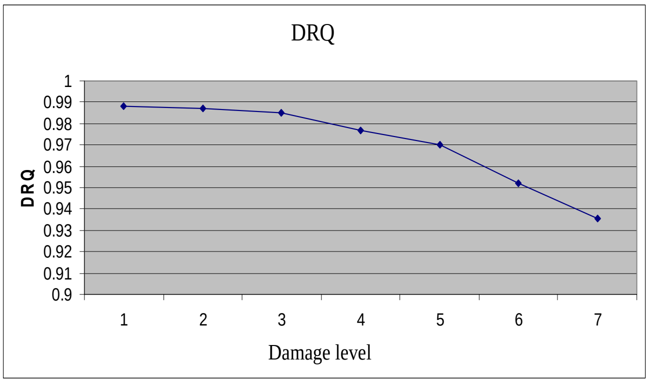

Figure 12. Detection and quantification of damage using the DRQ indicator

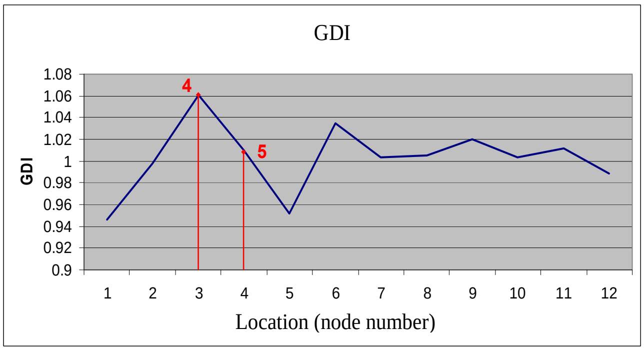

Figure 13. Location of damaged element using GDI indicator

After calculation the Detection and Relative damage Quantification indicator, results are graphically interpreted as follow on Figure 12. It is obvious that DRQ indicator shows decreasing trend with increasing the level of damage. Therefore, the DRQ indicator is able to detect and relatively quantify damage.

As previously mentioned for the freely supported beam, to locate the damage much better results showed the General Damage Index (GDI) than the local RVAC indicator. The Cumulative GDI was calculated by successive adding the values of GDI for the each level of damage. Figure 13 shows cumulative GDI indicating the location of damage between measurement location 4 and 5 of cantilever beam.

6. CONCLUSIONS

This paper presents one approach in damage detection using frequency response functions data. It is point out that using measured FRF data for damage detection has many advantages over the traditional methods using modal analysis data, especially that FRF data provide abundant information on the dynamic behavior of a structure. By reviewing accomplishment in damage detection methods based on vibration responses, one of the observed tasks for future development and advancing of damage detection methods is minimizing the dependence on prior analytical models and/or prior test data for the detection and location of damage. So, the method based on Detection and Relative damage Quantification indicator is investigated and approved. Experimental investigation was conducted on the free-free beam and the cantilever beam, using hammer excitation and “roving hammer” method of modal testing. The results of experiments show that DRQ indicator is able to detect and relatively quantify the damage that is to recognize the pattern of damage variation. It was found that Generalized Damage Index gave better location of damage than local RVAC indicator. As certain measurement inaccuracies happened on the certain locations during testing it could be averaged by successive adding the values of GDI for the each level of damage. However, it is supposed that GDI should increase continuously on the location on damage. So, some improvement of the GDI indicator is proposed that is the Cumulative GDI. Proposed damage detection method showed good performance even for the hammer excitation and one response transducer available, which is important considering the practical implementation of the method in the frugally equipped laboratories.

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