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On Damage Detection in Beams based on Dynamic Tests and Transitory Analysis

This study is covered by Structural Health Monitoring Concept - SHMC, and deals with some basic problems regarding the diagnosis of the current health status during exploitation. The detection of a potential area of structural damage supposes a great volume of bulky investigations performed on each structure element. Dynamic tests can provide a relative simple method to obtain some relevant information regarding both qualitative and quantitative levels of structural capability in order to maintain the initial performances during its regular working regime. In this paper is shown the influences of a certain crack which is developed in a simple beam upon the dynamic characteristic. The essential information about the linkage between the crack parameters and the dynamic evolution is also presented. A main concluding remark reveals a good correlation of the damage characteristics with the dynamic capability performances, supplying an appropriate way to estimate the structural health level based on a regular set of dynamic instrumental investigations.

Keywords: *health monitoring, dynamic instrumental tests, structural damage detection, transfer function, transitory analysis.*

1. Introduction

This research was started from a practical requirement to analyze and characterize the capability level of a certain structure to provide its functional statements during the exploitation cycle. Main applications was developed for vibration isolation devices and systems used in passive control of dynamic actions. The study contains and continues a series of theoretical and practically analysis regarding performances level prediction, methods, maintenance, monitoring, and damage detection, both of the author [7] and of the other research scientists in the nearest area [1-4, 6, 9]. Based on theoretical approaches and using instrumental analysis on laboratory stands the author was developed multiple experimental studies onto various structural elements. In this paper is briefly presents the results of one of these analyses which denote the opportunity and the performances of dynamic investigations for damage detection and structural health characterization for beam elements.

2. Basic theoretical approaches

The entire analysis was supply with the basic hypothesis according with the the rigidity changes can be evaluated when the shifting of natural frequencies are known and supposing the null changes of masses [5]

$$\Delta\Omega = x^T \, \Delta K \, x \,, \tag{1}$$

where the stiffness matrice is denoted by K, the displacement vector by x, the natural frequency by Ω, and the changes of these parameters by delta symbol ahead of.

Taking into account a large structure, and using the specific strain energy expression for the system at initial and current states respectively, it can be considered the damage parameter of the j element denoted by β_j as follows [8]

$$\beta_j = \frac{k_j}{\tilde{k}_j} = \frac{1}{2}\left(\frac{\tilde{\delta}_{ij}}{\delta_{ij}} + 1\right), \tag{2}$$

where the notations $\delta_{ij} = \dfrac{(\varepsilon_{ij})^2}{\sum_{p=1}^{n} (\varepsilon_{ip})^2}$,

respectively $\tilde{\delta}_{ij} = \dfrac{(\tilde{\varepsilon}_{ij})^2}{\sum_{p=1}^{n} (\tilde{\varepsilon}_{ip})^2}$ are used.

In the previous eqn. (2) the k_j denotes the stiffness of the j element, ε_{ij} denotes the deformation of the j element corresponding to the i mode, n is the total number of the structural elements, and the symbol "~" upward the essential parameters indicates the damage structure.

The evaluation of a single point output for a multiple input points distributed on the entire structure or on a certain structural element practically involves an extended measurement procedure and sometimes an expanded experimental system. Besides this it involves a long real-time acquisition and analysis.

The author proposes a dynamic analysis based on transitory state evaluation of beam behaviour. Using the excitation signals applied on fixed point and acquiring the acceleration signal for a single point on the beam it can be evaluate the global behaviour of the beam dynamics. Short pulse signals had been used to provide the transitory evolutions of the considered element. Hereby the MISO (Multiple Input Single Output) technique is replaced with SISO (Single Input Single Output) technique with relevant advantages.

The method presented in this paper assumes the most significant spectral components in acquired signal and follows the evaluation of those components frequencies for each damage situation. Stochastic analysis will also be used to perform the frequencies shifting with respect in crack dimension.

3. Instrumental tests

For a practical example was used a 330 mm length cantilever steel beam with rectangular cross section (24 x 0.8 mm). The excitation point was assumed nearby the free end of the beam and the measurement fixed point at 50 mm from the input. The free length of the beam between fixed and input points was 300 mm.

In Fig. 1 was depicted a general view of the instrumental setup used for this example analysis and evaluation.

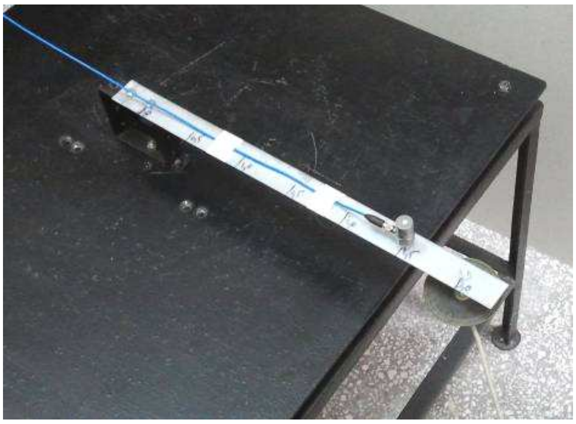


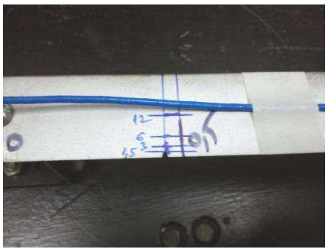
Figure 1. Instrumental setup - general view

The damage of the beam was supposed to appear at 45 mm from the fixed end. This damage consists by a linear crack cross-sectional induced into the beam with variable depth between 0% and 75% from the width.

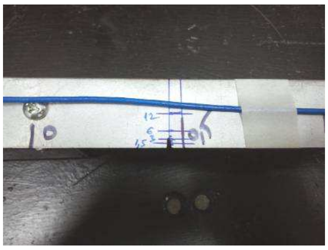
The pictures in Fig. 2 present the evolution of the damage for each step used in analysis. It has to be mentioned that the crack was developed continuously by one side of the beam, and taking into account the strong asymmetrical loading for the last step of analysis was performed a second crack from the other side of beam (see Fig.2.g).

A PCB-CCP-ICP-320C34 accelerometer and NI-USB-9233 digital acquisition device were used for experimental analysis. Excitation pulses were induced with the help of a small laboratory electro-dynamic actuator driven by the NI-USB-6218 DAQ device and a power amplifier. Both digital acquisition devices were leads from a single virtual instrument developed into NI-LabVEW software thus that it was assured a unitary acquisition-analysis-presentation (AAP) environment with a single operational interface.

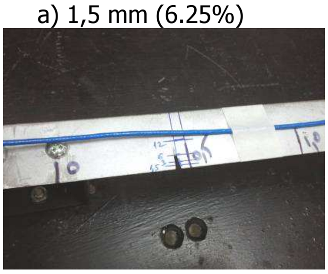
The virtual instrument had implemented a routine for evaluation of the transitory state thus that it was able to perform multiple pulses for the same measurement and to evaluate every singly response. The number of the pulses per measurement can be varied but for this example it was used ten consecutive pulses for each damage case.



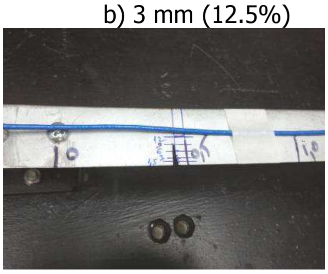
a) 1,5 mm (6.25%)



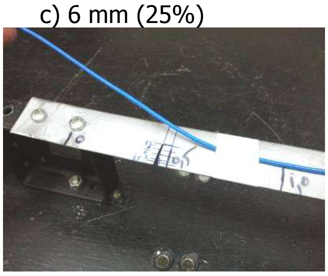
b) 3 mm (12.5%)



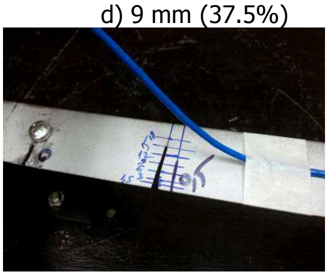
c) 6 mm (25%)



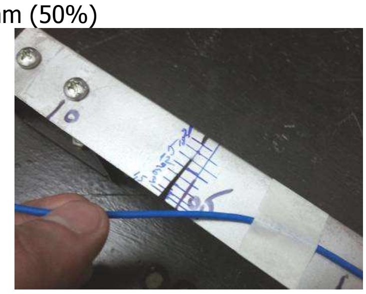
d) 9 mm (37.5%)



e) 12 mm (50%)



f) 15 mm (62.5%)



g) 18 mm (75%)

Figure 2. The crack evolution in beam during the instrumental tests

4. Results and discussions

The first five harmonics was considered for acquired signal analysis. For every spectral component were evaluated the variance trend and the results denoted a diminishing tendency with increasing of the crack depth. The extreme values of the frequencies for all estimated harmonics are presented in Table 1. The last column in Tab. 1 contains the variances of the harmonics frequencies. A comparative analysis of these values reveals that basic spectral component provide less information than the others. For convenience in Fig. 3 were depicted the evolution of the first harmonic in respect with the damage depth. It was shown only the trend line of the frequency variance (and the acquired values with dots). It can be observe a good approximation between the real values and the variance trend line. For the others four spectral components this approximation acquires greater magnitudes thus that a concluding remark denote an appropriate evaluation of the linkage between frequency shifting and crack depth must be based on the first essential harmonics in order to reduce the global error.

Table 1. Extreme values and variances of spectral components

Harmonic	Frequency		Variance
	max. [Hz]	min. [Hz]	[%]
1st	3.483	3.271	6.5
2nd	6.933	6.333	9.5
3rd	10.400	9.633	8.0
4th	14.000	12.900	8.5
5th	17.667	16.267	8.6

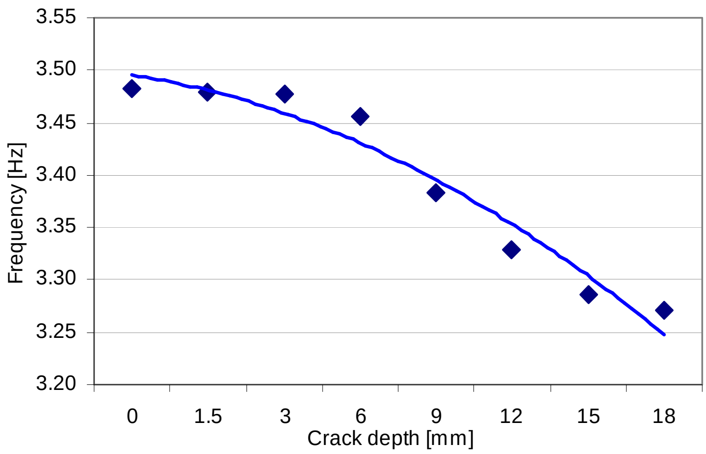


Figure 3. Evolution of the first harmonic in respect with the crack depth (regression analysis with continuous line; acquired values with dots)

5. Conclusion

The previously presented results dignify the opportunity of this method for structural damage evaluation. A good strategy for test points preparation and an appropriate techniques used for computational analysis obviously imply the increasing of the method accuracy and effectiveness. The main conclusion of this work can be formulate as follows: by changing the multiple inputs with a single excitation point and taking into account that the instrumental tests usually require more time than computational analysis, results that the disadvantage of the relative reduced input data, for this proposed method, are suitable balanced by the total evaluation time diminishing.

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