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A Study of the Effect of the Simulation of the Boundary Condition on Dynamic Response of Composite Structures

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Abstract: The aim of this research is to evaluate the effect of the boundary conditions uncertainties on the structure's response, using the change of the dynamic characteristics. The experimental models used and the correlation by the Frequency Domain Assurance Criterion (FDAC) allowed an explication of the change in the dynamic characteristics. The application of this strategy to stratified composite structures (glass/polyester) has given satisfactory results.

Key words: Composite, experimental, dynamic, boundary conditions

INTRODUCTION

Damages that appear in composite structures are not often visually detectable. By monitoring such structures it is possible to predict, minimize the consequences and anticipate a fracture which can endanger the structure. Therefore the necessary repairs thereafter, will be less costly and carried out at an appropriate time. Nowadays, structural mechanics favors systems monitoring which present an undeniable scientific interest for damage detection. During the past years significant efforts have been made to improve the use of non destructive methods in the control of structures and detection of damages. Due to their sensitivity to any change in the structure, the variations in the dynamic characteristics are used as indicator to formulate algorithms for the detection and identification of damages as reported in the abundant literature, (Salawu, 1997; Neild *et al*., 2003).

Measurements by vibration (natural frequencies) are excellent tools for the evaluation of damage and allow an easy access to the monitoring of structures. The Frequency Response Function (FRF) has been used as a mean to identify damages in steel structures by Huynh *et al*. (2005) and Davis (2002). The control by vibration measurements makes it possible in general to follow up the general state of the structure. Many researchers tried to identify the damage in composite materials through the variation of the dynamic parameters, either by rotations of the shape functions (Abdo and Hori, 2002) by the analysis of the modal deformation (Yam and Leung, 1996) by the experimental deformation test (Hwanga and Kim, 2004; Kessler *et al*., 2002), or by the changes in the Eigen frequency values and measured static displacement (Wang *et al*., 2001). However, fewer were interested in the influence of the experimental conditions. An evaluation of modal parameters and detection of the damages could be influenced by many factors. The understanding and determination of the amount of the variation in the dynamic characteristics due to the used experimental procedure are very important in practice.

The sensors which are sensitive to any damage are also sensitive to other sources such as those linked to the experimental procedure. Mastering the conditions of the measurements is necessary to the automation of the control technique, which can define the thresholds of the variation that can make the structure in danger. The identification of the sources that are responsible for the changes in the dynamic behavior is a promising technique for the diagnosis and monitoring of structures. Some rare studies have been able to show the influence of the test procedure and its environment on the dynamic response of the structure (Salawu, 1997; Alampalli, 2000; Landrein *et al*., 2001; Kam *et al*., 1998; Doebling and Farrar, 1997; Cornwell *et al*., 1999). The choice of the techniques for the separation of sources is justified on the one hand by the fact that the control of structures could not be instrumented in such a way as to isolate the generated vibration by specific sources and on the other hand by error measurements. In this study, separation source, which is based on a two level approach, is used. It consists of evaluating the influence of the experimental simulation of the boundary conditions and those of the damage. The validation of the algorithm is mainly based on the repeatability of the tests. The correlation techniques used for the FRF values will help then in the identification of the characteristic variation level.

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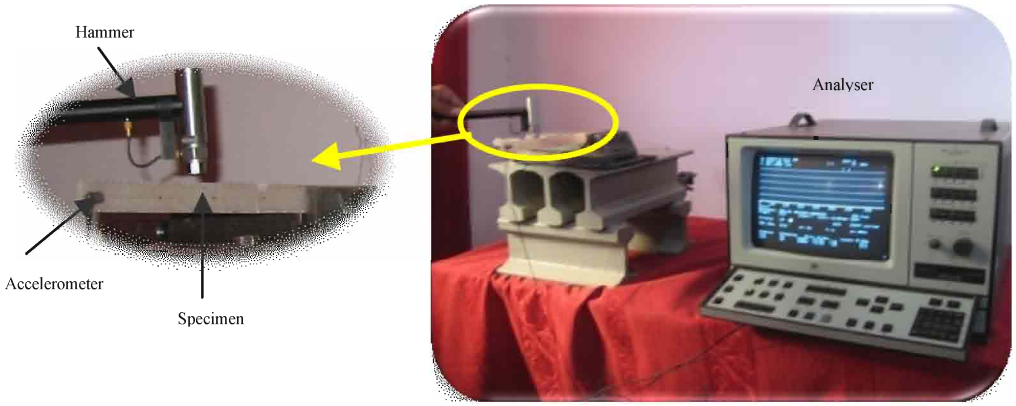

Fig. 1: Overall set up of testing (built in free condition)

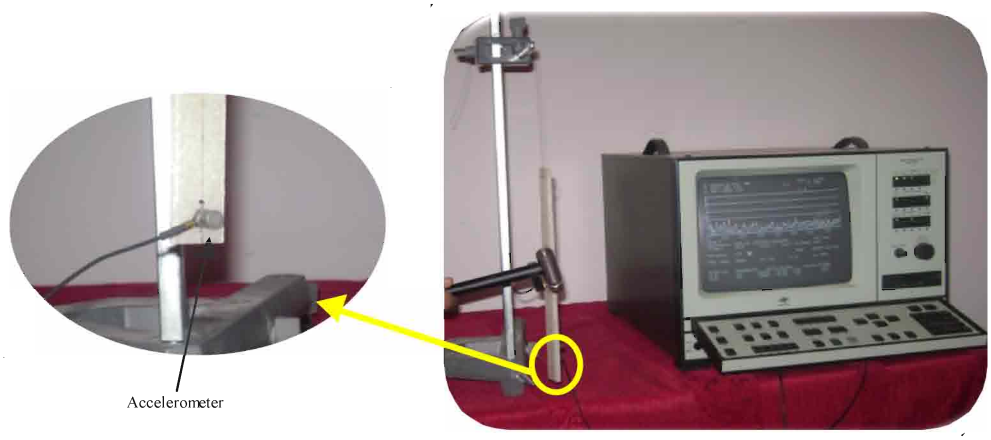

Fig. 2: Overall set up of testing (free-free condition)

EXPERIMENTAL PROCEDURE

A composite beam with two different boundary conditions is subjected to pulse loading introduced by an impact hammer. Figure 1 and 2 shows the apparatus used to perform the vibration tests. It consists of an accelerometer, an impact hammer and a bi canal signal analyser (type 2035) for the acquisition of the data. The impact hammer (type 8202) is connected to the first input in order to identify the excitation. The accelerometer is fixed on the specimen to receive the signal through the other channel which measures the response of the structure by Frequency Response Function (FRF).

Since generally two boundary conditions were found in the literature (Hwanga and Kim, 2004) these were used for validation purposes. In order to simulate experimentally these two boundary conditions, experimental devices based on two simplified models are used. The first consists in suspending the beam with a very flexible string (free-free) as shown in Fig. 3. A mechanical system is used to realize (built in-free) boundary (Fig. 4).

The tested beam is elaborated from a composite material (glass/polyester) with eight layers. The reference layer is in a form of short fibers (glass E) randomly distributed in the plane. The thickness of the reference layer is 0.27 mm. The volume fraction (V_f) is 35%, young modulus E = 8.798 GPa, the density $\rho = 1355$ kg m^{-3}. The dimensions of the beams are for free-free (337×19×5.4 mm) and for the cantilever (250×19×5.4 mm).

The structure is installed in its montage as indicated in Fig. 3 and 4. The montage is simple to ensure a careful repetition of the tests. The variation in the FRF is considered as an indicator for all changes in dynamic characteristics. In the order to visualize the picks of the three first modes, the three testing points are chosen outside the vibration nodes.

Fig. 3: Experimental simulation of the free-free boundary condition

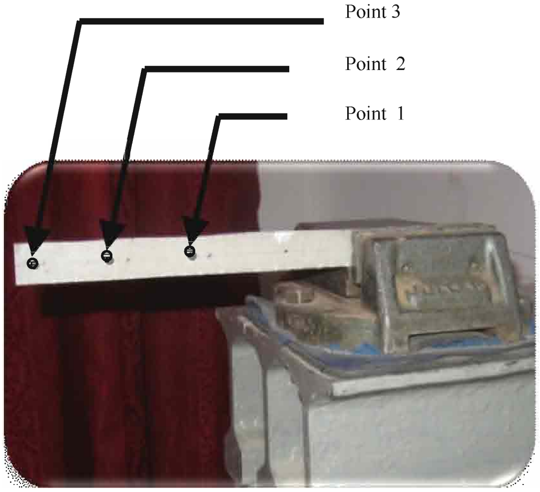

Fig. 4: Experimental simulation of the boundary condition (built in-free)

In order to quantify the influence of the simulation of the boundary conditions on the dynamic behaviour of the beam, the correlation between repeated tests is proposed. The correlation is then calculated for the response of the intact and damaged beam so as to compare and separate the influence of the simulation of the boundary conditions from those of the damage.

The developed strategy is based on two axes. In a first step the structure is tested three times for each simulated boundary condition. The FRF are measured on the basis of an average value from five excitations. In a second step the beam is damaged in its middle by a 3 mm crack, responses have been estimated to a coherence superior to 0.9.

Correlation: With a frequency band of 800 Hz (800 spectral lines), the first three natural frequencies were swept. The complete data for the FRF of each test is stocked in the corresponding vectors T_i (i is the test number). The Frequency Domain Assurance Criterion (FDAC) is used as a measure of correlation. The FDAC used in this study is given by Davis (2002). The FDAC is able to separate the different sources of variation of the FRF.

$$\mathrm{FDAC}(\omega_k)=\frac{\left[\sum_{n=1}^{N}\{T_1(\omega_k)\}\{T_2^*(\omega_k)\}\right]\left[\sum_{n=1}^{N}\{T_2(\omega_k)\}\{T_1^*(\omega_k)\}\right]}{\left[\sum_{n=1}^{N}\{T_1(\omega_k)\}\{T_1^*(\omega_k)\}\right]\left[\sum_{n=1}^{N}\{T_2(\omega_k)\}\{T_2^*(\omega_k)\}\right]} \qquad (1)$$

$$\mathrm{FDAC}=\begin{cases}1 & \text{Perfect correlation}\\ 0 & \text{No correlation}\end{cases}$$

Where:

ω_k : Desired frequency, ω_k = 1, 800 Hz with a step of 1 Hz
T_1, T_2 : The data for the first and second tests of the FRF to correlate
T_1*, T_2* : The conjugate of T_1 and T_2
n : Testing point, n = 1-3
N : Total number of testing points, N = 3

RESULTS AND DISCUSSION

For all Fig. 5-12, the FDAC curve which is obtained from Eq. 1 is superposed with the corresponding FRF curves. A simple examination of the different FRF curves does not show clearly the difference between the three responses of the structure although the test conditions were identical. However, when the correlation function is consulted, one discovers differences between the test results.

Figure 5-7 show the correlation between the three tests that were carried out on the beam structure. The FDAC curves show a good correlation between the different tests. This correlation is of the order of 0.92 and can be higher for a certain frequency bands. For this boundary condition simulation (free-free) the test results were repeatable with acceptable correlation and were close to those found in the literature (Davis, 2002).

Figure 8-10 show correlation between the three tests carried out on the structure of Fig. 4, the FDAC curves show for this case some dispersion. The results indicate

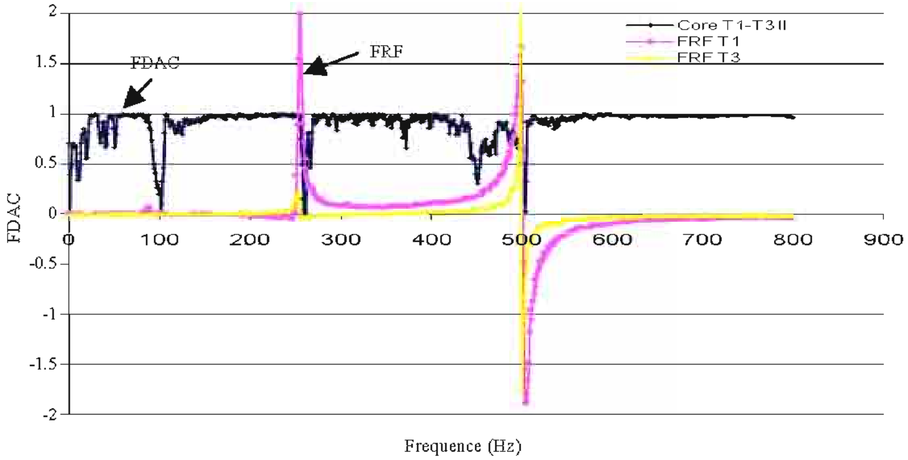

Fig. 5: Curve of correlation between FRF of Test 1 and Test 2 of undamaged beam

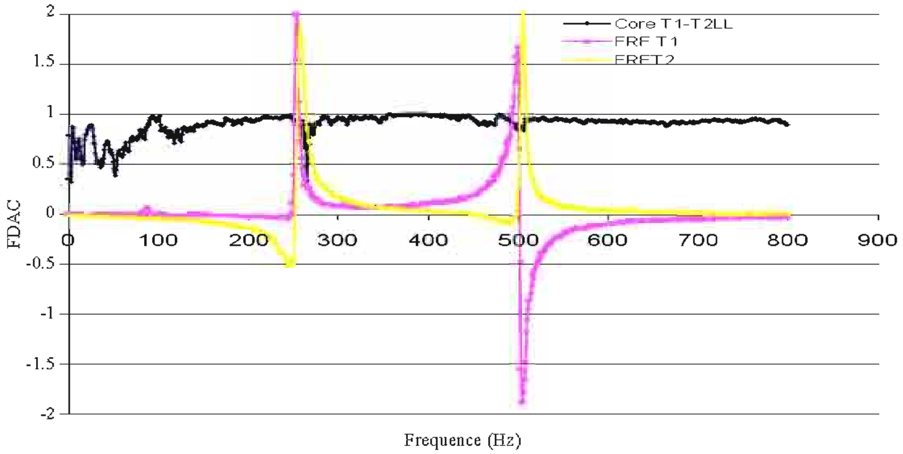

Fig. 6: Curve of correlation between FRF of Test 1 and Test 2 of undamaged beam

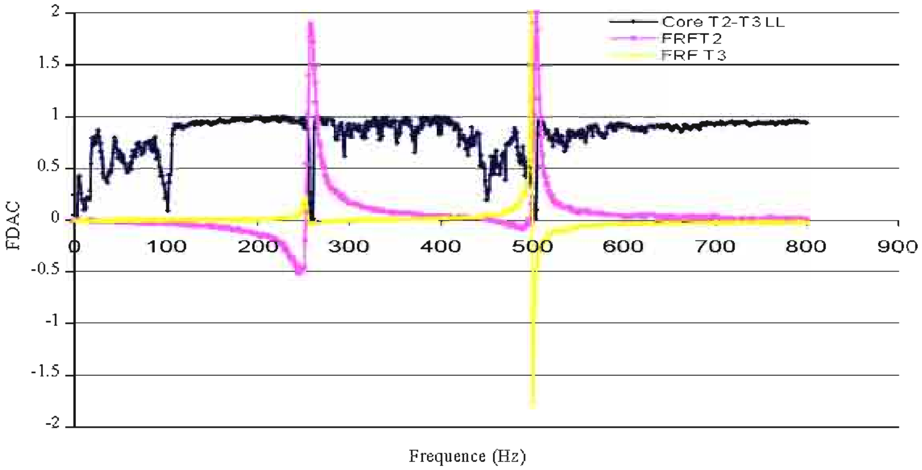

Fig. 7: Curve of correlation between FRF of Test 2 and Test 3 of undamaged beam

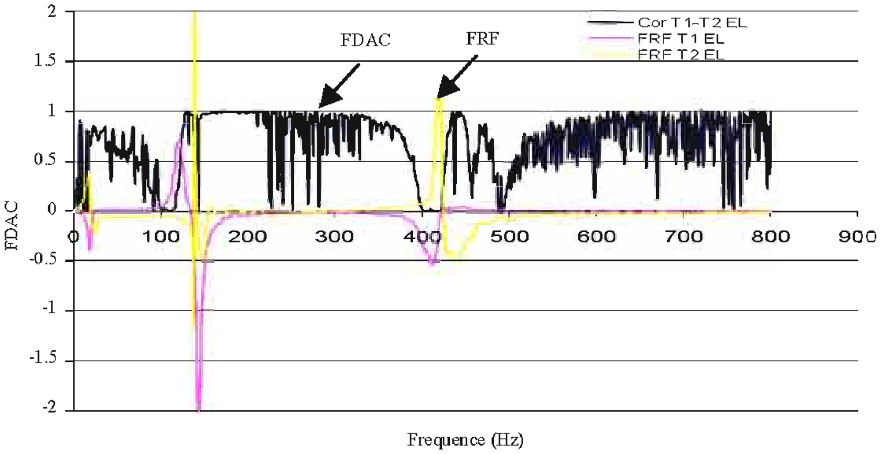

Fig. 8: Curve of correlation between FRF of Test 1 and Test 2 of undamaged beam

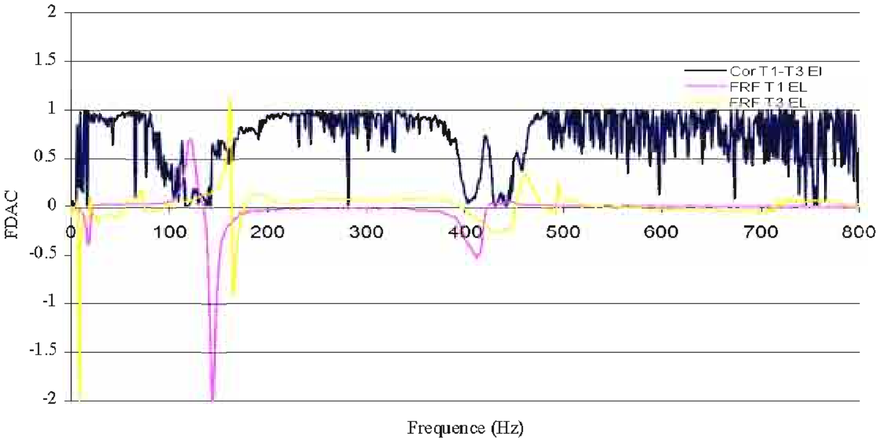

Fig. 9: Curve of correlation between FRF of Test 1 and Test 3 of undamaged beam

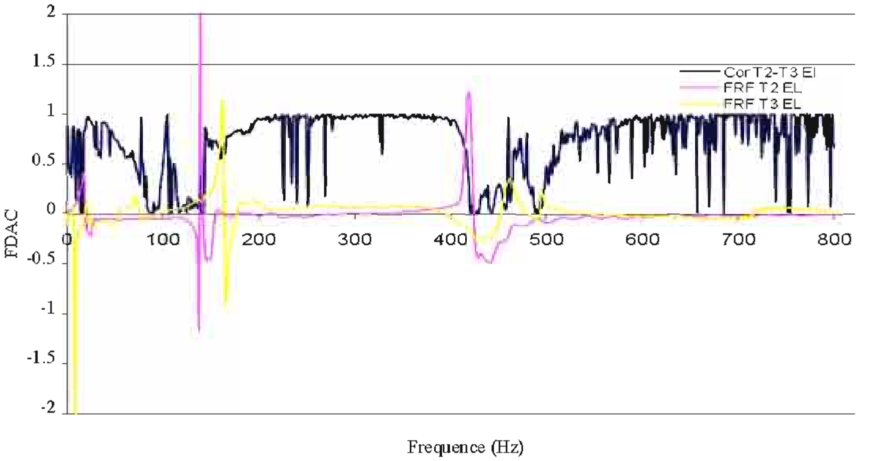

Fig. 10: Curve of correlation between FRF of Test 2 and Test 3 of undamaged beam

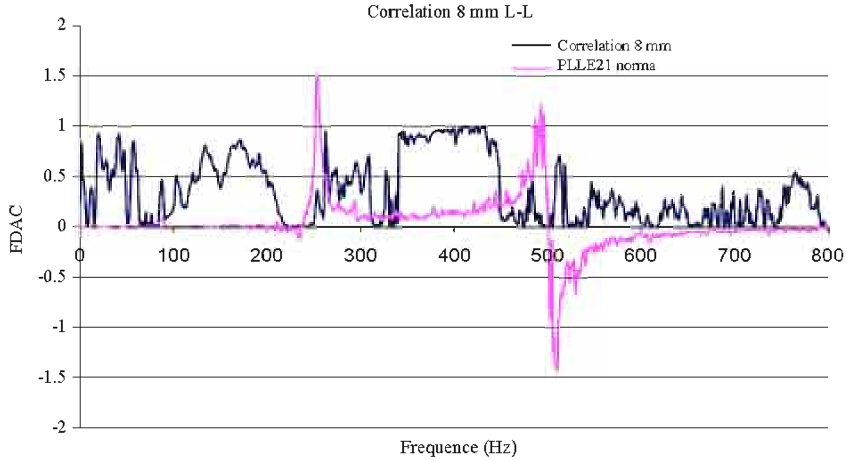

Fig. 11: Curve of correlation between damaged and undamaged beam (free-free)

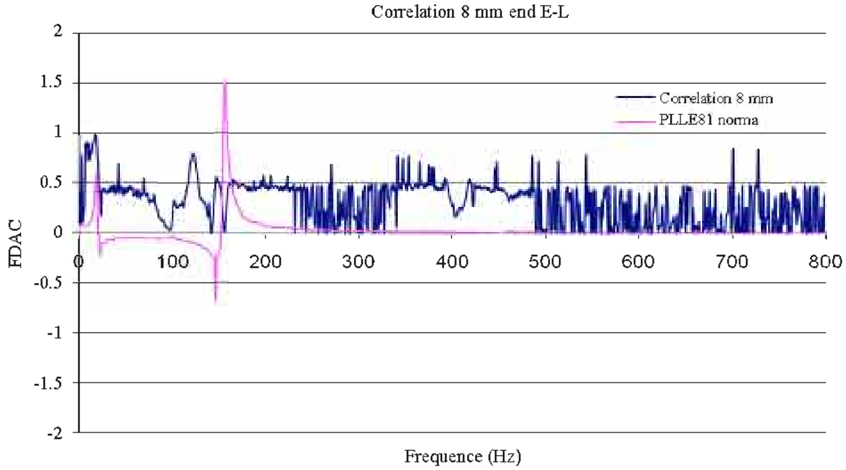

Fig. 12: Curve of correlation between damaged and undamaged beam (cantilever)

the existence of a great probability of the influence of the boundary conditions. This is showed by the drop in the value of correlation which is around (0.71) and is not easily seen. These variations in the value of the correlation can be due to the manual handling during the tests or to the apparatus used to simulate the boundary conditions. Hence particular attention must be given in the choice of the techniques used in the boundary conditions simulations.

A comparison between the intact and damaged structure illustrated in Fig. 11 and 12 shows that the results are less correlated with a FDAC value around (0.20). In fact, the variations of the FDAC are higher and can bring the value of the correlation to zero. This perturbation is due to deterioration in the dynamic characteristics.

CONCLUSION

It be concluded through this study that the errors due to the simulation of the boundary conditions are detectable and result from the uncontrollable testing conditions. The evaluation of the variation in the response depends partially on the uncertainties linked to the tolerance in the simulation of the boundary conditions.

Although the variations in the FRF due to the simulation of the boundary conditions are insignificant as compared with those due to damage, they can influence the final result. Through the FDAC correlation, it has been shown that the influence of the measurement can be neglected for the free-free boundary condition, whereas the simulation of the fixed end boundary condition; could have an impact on the dynamic behavior. However by introducing damage in the structure we have shown that its effect is more important compared to that of the experimental errors, moreover fixed end boundary condition is more sensitive to damage in comparison to the free- free boundary condition.

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