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Damage Detection by Laser Vibration Measurement

The technique based on the vibration analysis by scanning laser Doppler vibrometer is one of the most promising, allowing to extract also small defect and to directly correlate it to local dynamic stiffness and structural integrity. In fact, the measurement capabilities of vibrometers, such as sensitivity, accuracy and reduced intrusively, allow having a very powerful instrument in diagnostic.

Keywords: *laser, vibration, detection, damage*

The issues related to structural damage detection have been widely investigated in recent years, because of the large impact that safety and reliability have on many fields, in particular in industry (aeronautics, automotive, etc.). Several are the requirements that an experimental technique must satisfy: it must be non-destructive, easy to be used, rapid enough for on-line monitoring and with much reduced uncertainty in the response, which should be clear and of accessible interpretation. In general, two are the main steps constituting a diagnostic procedure: the experimental measurement and the data processing. It is evident that, for each measurement technique, a dedicated signal processing strategy should be designed and employed, although in some cases common elements can be found.

Other diagnostic techniques largely studied and applied are those based on vibration measurements, since they allow non-destructive evaluation of the structure under investigation. In this field, several strategies for structural excitation, vibration measurement and data processing have been presented, but results seem to be not yet completely satisfactory, in particular concerning the precise evaluation of the damage location. The usual approach consists in the determination of modal parameter changes due to the presence of the defect. However, this approach may give problems in dealing with thin and light structures, as panels of composite materials, where, if the defect is small, natural mode shapes may mask the local vibration pattern induced by the fault.

The average spectrum of the Frequency Response Functions (FRFs) measured over the whole structure are reported superimposed to the FRFs measured on the superficial and the deep delamination respectively. Considering the average FRF as measured over a generic non-defected point of the panel (the defect is small and localized, therefore it does not influence the global behavior of the structure), one should be able to decide whether the considered point is defected or not and to give a judge concerning the depth. It is evident that this is almost impossible: the spectra are very complex and it is not possible to extract information directly by peak analysis or frequency shift.

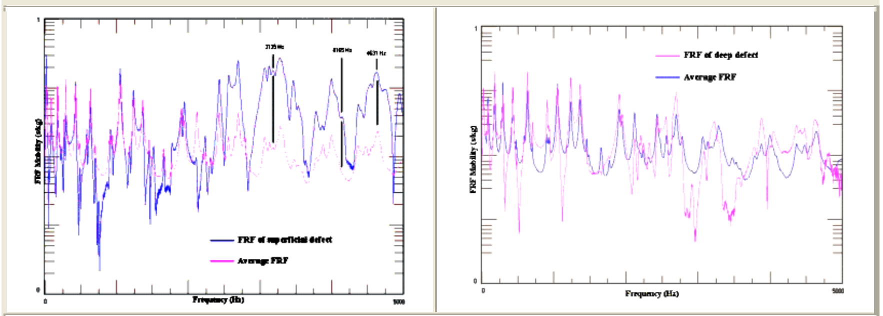

Figure 1. Comparison between the Frequency Response Functions (FRFs) measured over the superficial and the deep defects and the average FRF for the whole structure.

Damage detection techniques based on vibration analysis are usually based on the assumption that the presence of defects in a structure determines variation on its dynamic behavior. In some works the assessment of such variation is obtained by comparing references structures (usually non-defected ones or numerically generated) with the analysed structure.

As already discussed by the authors in previous works, such approaches may give satisfactory results, but are not always feasible because of the need of a reference structure, sometimes not available or not completely representative of the healthy status.

The proposed technique is based on the hypothesis that only small defects are present on the structure (for large defects a detailed analysis is not necessary), without alterations of its global dynamic behavior. Therefore the spatially averaged spectral response of the structure can be used as a good reference, being the effects of the damages diluted on a large number of non-defected points.

The data obtained both from the FE model (and later from the experimental tests) were processed using Matlab routines, in order to extract synthetic information about the presence and the characteristics of the defects.

The first step of the process is the organisation of data. In fact, in order to transfer the large amount of data (Spectral response or FRF in each point of the grid) produced by a Scanning Laser Doppler Vibrometer (SLDV), the Universal File Format was used. On the other hand, also data from numerical codes have to be re-arranged. In fact, the FE model produces vibration information in each node of the mesh, which in this case presents a different density across the structure (a fine mesh on the defect, a coarse mesh elsewhere). For such reason the statistical weight of defected and non-defected points is artificially different, and it is difficult a comparison with experimental data obtained, generally, in a regular matrix. For these reason FE spectra have to be interpolated in a regular grid.

The second step is the normalisation of the spectra. The α -trimmed average (α =5%) is calculated, frequency by frequency, for all the points of the structure and the obtained spectrum is used as norm in order to obtain a dimensionless spectrum, as shown in (1):

$$FRF_{(i)norm}(\omega) = \frac{FRF_{(i)}(\omega)}{FRFaverage(\omega)} \qquad i=1, 2, \ldots, 290 \qquad \omega=[0,200]\ \text{kHz} \tag{1}$$

where i=1, 2, ..., 290 denotes the index relative to the node (or to the measurement point for the experimental data).

The $FRF_{(i)norm}$ oscillates usually around a unitary value, if relative to a non-defected point in the structure. If no defects were on the panel, a variation with respect to the unitary level could be due only to different factors of modal participation between different FRFs or to noise in the single measurements. The α -trimmed average is employed to have a $FRF_{average}$ similar for defected or non-defected panels, according to the hypothesis of small damages. In fact, this kind of average allows reducing the effects of "extreme" data (i.e. of data significantly dispersed with respect to the average value), and thus of defects, even if some residual effect is present. Because of this reason, theoretically, the $FRF_{(i)norm}$ presents a reduced dependence also by resonance or anti-resonance peaks, and therefore a elevated value should correspond to a high dynamic behavior, i.e. to a defect.

. Conclusion

In damage detection and characterization, the non-contact measurement techniques are gaining an increasing interest, as they offer large potentials, in particular to:

- perform test not only in laboratory, but also in operative conditions (e.g. maintenance of airplanes);

- eliminate induced damages or other secondary effects on the structure (e.g. water penetration and corrosion in traditional ultrasonic tests);
- perform non-destructive testing with easy experimental set-up and reduced time for the object preparation.

Among the different techniques, one of the most promising seems to be the one based on the vibration analysis by Scanning Laser Doppler Vibrometry. In fact, this measurement technique allows the extraction of dynamic information on the defect with powerful performances in term of sensitivity, reduced intrusivity, high spatial resolution and capability to measure on the field.

However, an "intelligent" signal post-processing procedure must designed and applied to the measured data, in order to highlight and extract the relevant information.

In this work the recent advances in the signal processing strategy are presented, with the aim of further improving reliability, easiness and readability of the output of the diagnostic procedure and to reduce the amount of the relevant data to be managed. In particular, a new algorithm for data processing and defect characterization is discussed and tested using both numerical (FEM) and experimental data. The results, achieved on a fiber-glass panel excited by a piezoelectric actuator, showed that the proposed procedure can be successfully employed: the delaminations of the panel are correctly localised, their depth identified and the "pseudo-defects" due to other interfering inputs (e.g. energy near the driving point, measurement noise, etc.) minimized.

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