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Damage methodology approach on a composite panel based on a combination of Fringe Projection and 2D Digital Image Correlation

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ABSTRACT

The recent improvement in accessibility to high speed digital cameras has enabled three dimensional (3D) vibration measurements employing full-field optical techniques. Moreover, there is a need to develop a cost-effective and non-destructive testing method to quantify the severity of damages arising from impacts and thus, enhance the service life. This effect is more interesting in composite structures since possible internal damage has low external manifestation. Those possible damages have been previously studied experimentally by using vibration testing. Namely, those analyses were focused on variations in the modal frequencies or, more recently, mode shapes variations employing punctual accelerometers or vibrometers.

In this paper it is presented an alternative method to investigate the severity of damage on a composite structure and how the damage affects to its integrity through the analysis of the full field modal behaviour. In this case, instead of punctual measurements, displacement maps are analysed by employing a combination of FP + 2D-DIC during vibration experiments in an industrial component. In addition, to analyse possible mode shape changes, differences between damaged and undamaged specimens are studied by employing a recent methodology based on Adaptive Image Decomposition (AGMD) procedure. It will be demonstrated that AGMD Image decomposition procedure, which decompose the displacement field into shape descriptors, is capable to detect and quantify the differences between mode shapes.

As an application example, the proposed approach has been evaluated on two large industrial components (car bonnets) made of short-fibre reinforced composite. Specifically, the evolution of normalized AGMD shape descriptors has been evaluated for three different components with different damage levels. Results demonstrate the potential of the presented approach making it possible to measure the severity of a structural damage by evaluating the mode shape based in the analysis of its shape descriptors.

1. Introduction

Nowadays, the application of composite materials in mechanical components is increasing since they offer several advantages compared to conventional isotropic materials as metal or plastic which are especially appealing for low weight and

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good structural behaviour. However, they also presents some disadvantages compare to those isotropic materials. Among others, it is highlighted the susceptibility of laminated composites to impact damage, due to its lack of plastic deformation and inherent anisotropic nature [1]. This aspect could be one of the most sensitive issues since the surface appearance is not representative of the possible internal damage induced by either static or dynamic loads [2] leading to barely visible impact damages (BVID). This factors leads to an interesting research field related to the identification of delamination or damages in composite specimens after suffering impacts [1].

Different non-destructive damage assessment techniques have been employed along recent years in composite specimens for impact damage detection. Some of them have been focused on image analysis as ultrasounds, Shearography, X-ray or thermography [3–6]. Nonetheless, each of those techniques has specific applications. Ultrasonic and X-ray [7] testing allows the determination of the depth of the defect while Shearography presents more capability to measure different damage grades as well as it is simple [8]. It could be concluded that the complexity of damage mechanisms in composite materials requires from different methodologies to completely characterize the damage.

Moreover, it is observed that those methodologies allow characterizing the damage but they do not offer any information about possible variations in the structural integrity of the whole component. To overcome this drawback, vibration analysis has been one of the most widespread approaches for damage identification and integrity analysis. The basis of this approach is that the vibration response of a component is defined by the parameters of resonance frequency and the specimen mode shape which are directly related to its physical and structural properties, i.e. mass, stiffness and damping [1]. Hence, a change in the integrity of the specimen due to an impact could be detected as a change in its resonance frequency and/or mode shape [9,10]. Based on this statement, several experimental approaches can be found in the literature. Among them, there exist three main experimental approaches for damage identification, namely the natural frequency method, where a shift in the resonance frequency is only monitored; the mode-shape method, where a change in the mode-shape is expected to happen if a damage is present, and the curvature mode shape method where the spatial derivate of the mode shape is studied [11–13]

There exists several contributions related to vibration tests for damage identification with different approaches to determine if damage has affected to the integrity of the specimen and at which level [1]. The aim of the present study is to demonstrate that the natural frequency method is not always a good option for accurate damage assessment against the mode-shape method which offers more reliable information as presented by Perez et al. [1]. Nonetheless, in contrast to previous studies [9,11–23], a full field optical technique based on a combination of Fringe Projection (FP) and 2D Digital Image Correlation (2D-DIC) is adopted instead of punctual transducers for the quantification of the structural damage and its effect over the mode shape.

Experiments employing contact transducers such as accelerometers or strain gauges present the disadvantage of being fixed to the surface of the component, which could introduce a substantial modification of its modal behaviour due to the mass-loading effect [24]. In addition, these are point-wise measurement systems and partial mode shape information could be lost. Hence, if whole surface is desired to analyse, it is required a large number of simultaneous transducers or an excessively long sequential test for a complete spatial characterization of the component.

To overcome these drawbacks and to accomplish the mode-shape methodology, the attention has been focused on the implementation of full-field optical techniques on vibration analysis [25–37]. These optical techniques are non-invasive (requiring no contact with the analysed component) and provide quantitative information on a whole surface simultaneously. Some of the most extensively employed optical techniques are Digital Shearography and Electronic Speckle Pattern Interferometry (ESPI) [26,38], Scanning Laser Doppler Vibrometry (SLDV) [25,38,39], Fringe Projection and Moiré techniques [33,34,37,40] and more recently Digital Image Correlation Technique (DIC) [28–32,35,36,41].

Among the techniques mentioned, SLDV technique are considered the most accurate and most widely employed together with accelerometers [39]. This technique employs a punctual laser vibrometer to analyse a specific point at the specimen surface, in this way, mass-loading effect is eliminated. Nevertheless, it has the disadvantage of providing only punctual measurements, as well as the introduction of errors inherent to the system, such as those due to rigid solid motion or desynchronization [24]. For this reason, several authors have attempted to apply full field optical techniques for the analysis of the Forced Normal Mode (FNM) tests, where the component is sinusoidal excited to one of its natural frequencies. In this sense, it should be noted that DIC technique is one of the most widespread and most progressive for the analysis of dynamic events. Nevertheless, to perform a 3D-DIC in a vibration test it is necessary to employ two high speed cameras perfectly synchronized.

To accomplish the aim of this paper, it has been employed a full field optical technique for damage severity quantification based on mode-shape analysis that integrates Fringe Projection [42] and 2D-Digital Image Correlation [43]. It is a low-cost alternative to 3D-DIC employing a single camera and a simple projector instead of a stereoscopic camera system. This reduces the economic cost and the complexity of the set up as well as it makes it possible to easily obtain simultaneous 3D displacements measurements [40,44] during vibration experiments [37].

The specimens under analysis were three large industrial components with different degree of damage. Although they were manufactured in an automatized procedure, it is not possible to ensure exactly the same thickness and weight, and hence, variations in the resonance frequency are not always due to a damage that affects to its integrity. To analyse the severity of damage, they were subjected to constant frequency sinusoidal vibration tests and their resonance frequency and mode shapes were analysed to compare natural frequency method and mode shape method. In particular, the industrial composite components were three car bonnets of approximately 1.8×0.8 m provided by Centro Ricerche Fiat, Italy. One of