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Experimental analysis of the linear and nonlinear behaviour of composites with delaminations

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ABSTRACT

An analysis of the linear and nonlinear vibration responses of composites with delaminations is presented. The effect of delamination size on the linear and nonlinear vibration response is studied. The composite material used in this paper is a glass fibre reinforced plastic (GFRP) having delaminations at the plies interfaces. The experimental procedure consists in inducing the specimen on its resonance flexural modes with different excitation levels (amplitudes) for six bending modes and for each delamination length. The presence of the nonlinearity introduced by the delamination was clearly identified by the variation of natural frequencies for increasing excitation levels. Then, nonlinear elastic parameters for progressive delamination length were determined and discussed for the first six bending modes. The linear and the nonlinear elastic parameters were compared in their sensitive modes.

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1. Introduction

Delamination is the major observed failure mode in reinforced composite structures. It is usually barely visible from external view since the delaminations are frequently embedded within the composite structures. Delaminations may arise during manufacturing, such as incomplete wetting, or during service, such as low-velocity impact. The presence of delamination reduces the structural stiffness which changes the dynamic response of the structures. It leads to changes in natural frequencies, modal shapes, damping ratios, flexibility and modal strain energy [1–3].

The use of modal analysis testing to detect internal damage is one of the most famous detection technique used in the last few decades. The shift in frequencies is generally investigated to identify the presence of delamination. This method provides reliable and accurate data [4–6]. Natural frequencies can be measured with a single sensor, and can be monitored with greater accuracy, easily and with high reliability [7]. El Mahi et al. [8] investigated the effect of damage on the vibration behaviour of sandwich materials. Experimental analysis of damaged sandwich materials was performed using beam test specimens and impulse technique. A numerical model was implemented. Recently, Zhang et al. [9] used the graphical approach to assess the location, the size and severity of delamination in composite beams from measured frequency shifts. This approach has been validated using numerical simulations as well as experimental data from modal testing conducted on simply supported cantilever beams.

Resonance method presents accurate results in the linear domain. This method is being improved to become more sensitive, when the material behaves nonlinearly, by investigating the nonlinear vibration procedure. Experiments based on nonlinear resonance technique have been used by Meo et al. [10] and Zumpano et al. [11] to detect the micro-damage and the barely visible damage in composites. It consists in exciting the specimen around one of its bending resonance modes with different excitation levels. Under resonance conditions when the amplitude excitations are increased, a resonance frequency shift is observed. The resonance frequency shift and loss factor variation are analyzed as a function of the strain amplitude. Nonlinear dissipative and nonlinear elastic parameters are determined from the down shift of the resonance frequency as well as the diminution of the quality factor with increasing strain amplitude is described by Idriss et al. [12] for sandwich materials. It is often observed that the measurement of nonlinear parameters from these nonlinear processes are more sensitive to the presence of damage than the linear elastic parameters measured through linear method [12–14]. Therefore this method was applied by Polimeno et al. [15] for complexes shape structures. The majority of work which

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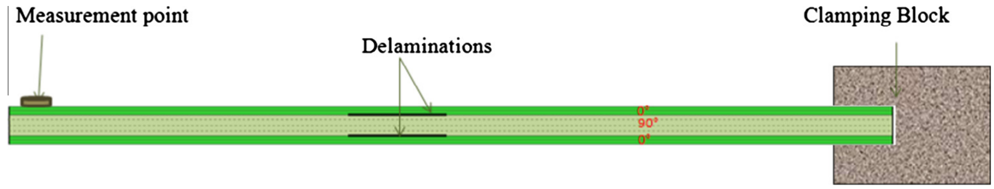

Fig. 1. A composite beam with delaminations.

investigate the nonlinear methods are related to the study of micro debonding in metals material [16,17], granular material or rock, ceramic, concrete, synthetic slate [18]. The investigation of nonlinear methods in composite structures is still limited [19].

This paper aims to investigate nonlinear resonance vibration in laminate composite having interlaminar delaminations. An attempt is made to examine the effect of delamination size on the linear and nonlinear dynamic behaviour of composites. To this end, firstly, a short description of the nonlinear theoretical background is presented. Then, experimental findings of linear and nonlinear vibration are presented in order to characterize the elastic behaviour of delaminated composites. Then, the evolution of nonlinear elastic parameters for progressively delamination length is presented and discussed for several bending modes. Finally the sensitivity of this method is discussed.

2. Experimental set up

The composite materials used in this study is the glass fibres reinforced plastic (GFRP) consisting of unidirectional layers of E-glass fibres and epoxy matrix, with the stacking sequence $[0_2/90_2]_s$. Laminates were prepared by hand lay-up process using SR 1500 epoxy resin, SD 2505 curing agent and unidirectional glass fibres. At room temperature and using vacuum moulding process, composite plates are carried out under 30 kPa pressure. Double superposed delaminations are artificially introduced using Teflon tape during the lay-up at the interfaces between plies having different stacking directions. Obtained specimen has 250 mm length, 20 mm width and 2.5 mm depth. The centres of the cracks are always located at 95 mm away from the clamped end of the beam (Fig. 1). Specimens having increasing delamination length from 0 to 130 mm were tested in linear and nonlinear resonant experiment. Three specimens were tested for each delamination length.

The resonance method is implemented by inducing the specimen with a flexural wave. The experimental equipment employed in this present paper, shown in Fig. 2, is similar to the configuration used in earlier works [12,20,21]. The test specimen is supported horizontally as a cantilever beam. At the clamped end, a BK480 shaker excites the beam into flexural vibrations. The beam response is measured using an accelerometer [of practically negligible mass], BK 352c22 fixed at the free end of the beam. A Stanford Research Systems SR785 analyzer is used to generate the excitation signal which is amplified by a Power Amplifier PA25E with constant gain. The accelerometer with sensitivity 9.75 mV/g is connected to a conditioner with a constant

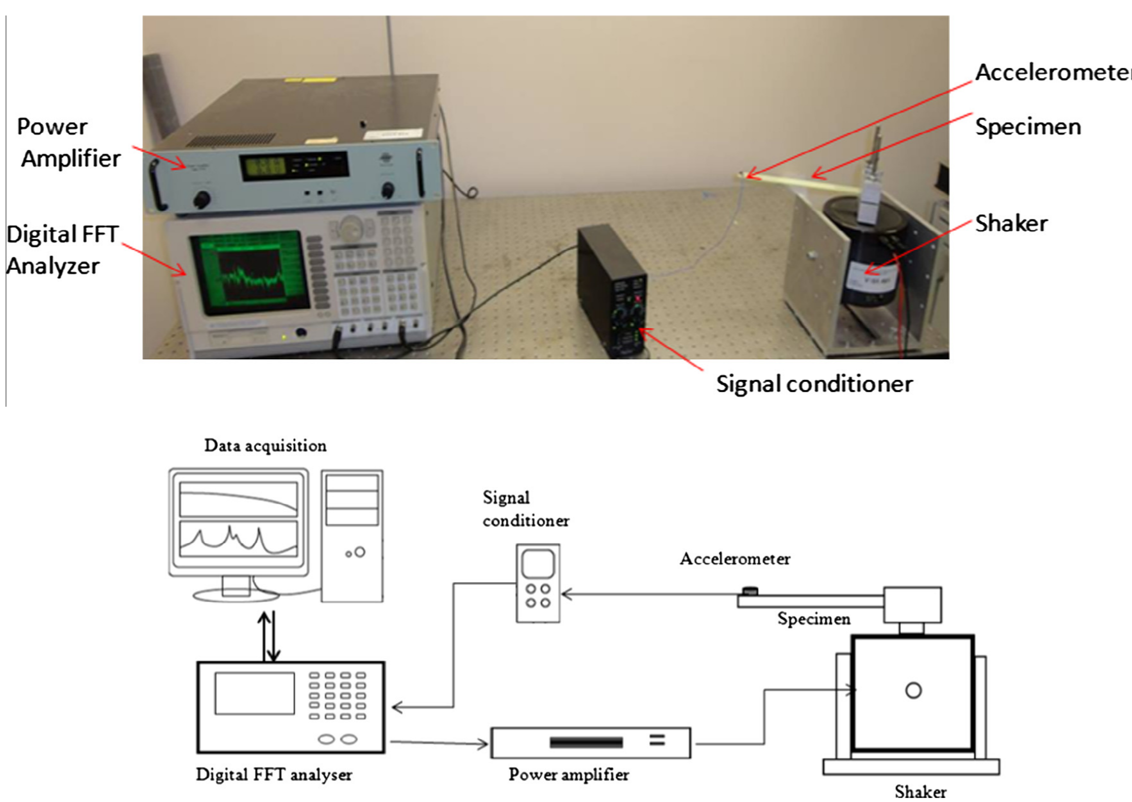

Fig. 2. Experimental set up for the resonance test.

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