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Experimental Identification of a Surface Delamination of a Laminated Sandwich Beam

The oscillation properties of a laminate structure yields information about its structural integrity. Unilateral constraints and impacts dominate the oscillation properties of delaminated structures. These phenomena give rise to a nonlinear system response, whereas the degree of the nonlinearity augments with increasing intensity of excitation. The distribution of the nonlinearity on various test points allows the localisation of a delamination, exemplarily shown here on a laminated beam with a surface delamination.

1. Introduction

The mechanical properties of sandwich materials may degrade severely in the presence of delaminations between adjacent plies. Therefore, the ability of the non-destructive monitoring of the structural integrity of structures consisting of these materials is becoming increasingly important.

Most of the current vibrational detection methods are based on linear assumptions, which do not suitably capture the oscillation properties of the structure. Investigations show that oscillations of delaminated structures are dominated by non-linear phenomena caused by unilateral constraints and impacts [1], which have not yet been sufficiently considered.

As an example, let us consider a delaminated sandwich beam with rectangular cross-section 40mm/45mm. It consists of two laminaes of aluminium with a symmetrical delamination along a length of 1200mm (Fig. 1) and a small gap in the delaminated zone. Vibrations are induced by an uncontrolled shaker at one end of the beam.

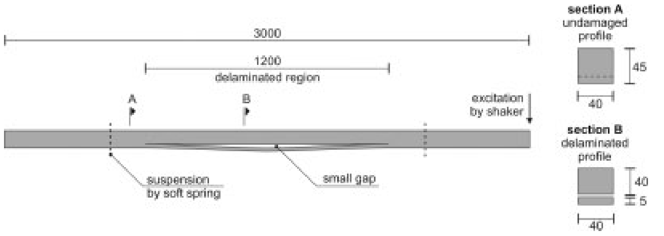

Fig. 1: Delaminated beam

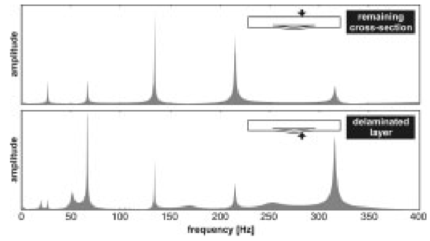

Fig. 2: FRF's of the delaminated beam

2. Survey of the experimental procedure and achieved results

The considered method is based on an experimental identification. The actual investigations have been restricted to plane beam oscillations and delaminations in the vicinity of the structure surface. The system response a_i gained at different test points by movable accelerometers and the induced shaker force F are measured for the characterisation of the structural condition.

Depending on the amplitude of excitation the behaviour of the system can be subdivided into two basic types. In the case of a low level excitation, an approximately linear system is obtained. When increasing the intensity of excitation the system's behaviour tends to distinct nonlinearity firstly caused by an opening/closing motion of the gap in the transition region of the delamination and later on by impacts between the separated layers.

The first step of investigation comprises a low level excitation of the system, where the frequency response functions (FRF) are independent of the excitation amplitude. An experimental modal analysis is carried out and yields the basic information about the oscillations (e.g. the resonances as well as the number and position of possible impacts). The most conspicuous phenomenon with regard to the damage is the occurence of additional local resonances of the delaminated part of the beam. Figure 2 compares the FRFs on arbitrarily chosen opposite test points in the delaminated region. We selected the first global resonance at a frequency of 26.24Hz as an example for the following considerations. As can be seen in Figure 3 the corresponding mode shape shows one region of possible impacts near the middle of the delaminated zone.

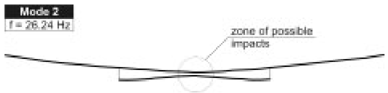

Fig. 3: First global mode of the delaminated beam (f=26.24Hz)

This section considers the nonlinear system, which arises by the excitation at higher magnitudes. In this case, the measurement is based on a harmonic mono frequency excitation at the above-mentioned first global resonance at 26.24Hz. Considered are the auto-spectra functions (Fig. 4) of two opposite points at the middle of the beam with increasing level of the excitation amplitude. The system response measured at the middle of the delaminated layer shows, depending on the excitation amplitude, numerous peaks besides the basic oscillation. These peaks represent the harmonics of the basic oscillation and characterise the nonlinearity of the response. As evident from Figure 4, the nonlinearity increases with the intensity of excitation and can be subdivided into three sections. A low excitation amplitude leads to an approximately linear system, where no harmonics occur. Intermediate excitation amplitudes yield a weak nonlinear system, which shows high order harmonics. If impacts occur, a strong nonlinear system with the most distinct harmonics is obtained. At the remaining cross-section the nonlinearity of the system response almost vanishes. Generalising this fact, in the case of a surface delamination the system response of the delaminated layer is primarily influenced by the occuring nonlinear phenomena.

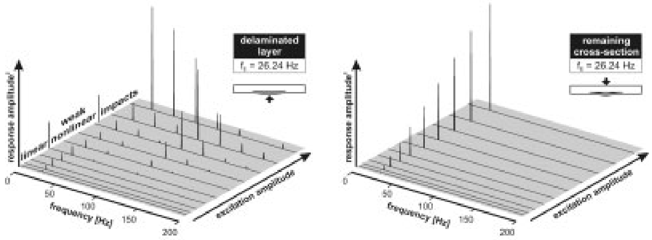

Fig. 4: Autospectra functions at different levels of excitation

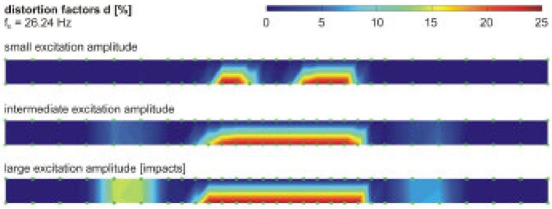

Fig. 5: Distribution of the distortion factors

A qualitative characterisation of the degree of the nonlinearity of the system response allows the introduction of the distortion factor d, which is given by equation (1).

$$d = \sqrt{\sum_{i=1}^{n} ({A_i}^2)/{A_1}^2} - 1 \quad \text{with} \quad \begin{array}{lll} A_i & \ldots & \text{amplitude of harmonic i} \\ A_1 & \ldots & \text{amplitude of basic oscillation} \end{array} \tag{1}$$

Using the method described above, the distribution of the nonlinearity of the response over the treated structure can be determined. The results given in Figure 5 show the enlargement of regions with high distortion factors d when increasing the intensity of excitation. In the case of small excitation amplitudes, only the response in the transition region of the delamination exhibits nonlinearity. Applying large excitation amplitudes, the oscillations are dominated by impacts and a large zone of strong nonlinear responses can be obtained. This region marked by high distortion factors d identifies the delamination. Additionally, outside the delamination regions of higher distortion factors d exist. This fact allows the detection of a delamination with test points outside the delaminated zone without having to know the vicinity of the damage a priori.

3. Conclusions and Outlook

Oscillations of delaminated structures are dominated by nonlinear phenomena. Linear methods restrict the available information about the delamination. Nonlinear system response must therefore be considered. As has been shown, the delamination of a beam structure can be identified by the degree of the nonlinearity of its response. Given the fact that damage is typically a local phenomenon, the fundamental challenge in the future work is the restriction of the number of test points. Therefore, the experimental procedure must be improved through the combination of experimental methods and mechanical models [1], [2].

4. References

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2 Vielsack, P.: A vibro-impacting model for the detection of delamination. Journal of Sound and Vibration. **253**(2) (2002), 347–358.

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