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Parameter estimation for finite element analyses of stationary oscillations of a vibro-impacting system

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Abstract

Impacts in forced dynamic systems lead to non-smooth vibrations, showing a scenario of bifurcations. Mechanical and numerical modelling is known for rigid body systems with distinct points of contact. In contrast, continuous systems can have a line of possible contact. As an example a vibrating beam with a delaminated layer will be considered. The objective is to establish a finite element formulation for stationary nonlinear oscillation arising from the evolution of impacts along the contact line between the delaminated layer and the remaining beam. The objectives are focussed on the choice of the unknown values of a set of parameters that mainly describe energy dissipation. A calibration of these parameters can be achieved by experimental results and by investigation of a minimal mechanical model.

Keywords: Impacts; Dynamic contact problem; Nonlinear oscillations

1. Introduction

Among mathematical and mechanical modelling as well as experimental investigations, numerical simulation has been developed as an integral part of research in engineering sciences. The results of such simulations depend on the choice of several parameters and the sensitivity of both the model and the algorithm to these values. The parameters have to be calibrated by an experimental reference.

Sandwich materials are being increasingly used in engineering applications. The presence of damages, in particular delaminations between adjacent plies, may degrade the mechanical properties of a structure. Therefore, the ability of non-destructive testing and monitoring of the structural integrity becomes an important issue [1,2]. There are many approaches for non-destructive evaluation of structures from very different fields of science, e.g. acoustic or ultrasonic methods [1] and vibration-based methods [2]. In the following, the vibration-based approach is considered.

Damage identification based upon changes in the vibrational characteristics is one of the few methods that monitor changes in the structure on a global basis. Currently available vibration-based methods are mostly linear methods, since these methods consider properties of linear dynamic systems [2]. Experimental investigations show that oscillations of delaminated structures are dominated by nonlinear phenomena caused by unilateral constraints and impacts. The deliberate utilisation of these phenomena for the identification of delaminations is the crucial point of the present work. Furthermore, an improvement of the efficiency of vibrational methods can be achieved by combining experimental methods and numerical simulation. Such model-dependent vibration-based methods for damage identification need suitable mechanical as well as numerical models to capture the nonlinear phenomena within a stationary oscillation.

Previously published investigations which consider nonlinear phenomena arising from delamination damages are mostly aimed at capturing the vibrational characteristic during short-time processes, such as the transient response by impact loads [3]. Then, contact events are described by

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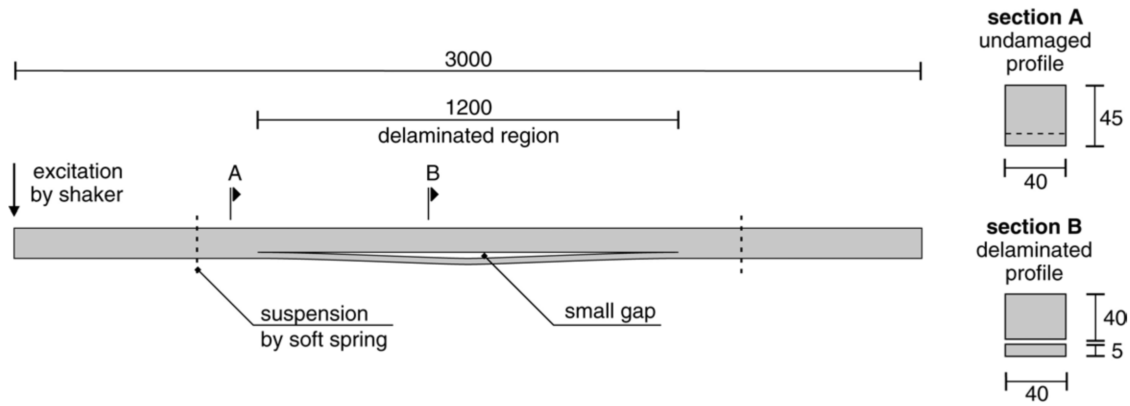

Fig. 1. Delaminated beam (measuring in mm).

very simplified models, since there is a limited influence on the system behaviour within the short-time process. In contrast, the present work focuses on the modelling of dissipative, impact-like contact events within stationary oscillations of a delaminated structure. In particular, the suitable capturing of the energy dissipation during contact is one essential premise for the accuracy of the numerical simulation, as can be seen later on.

The penalty method is a common procedure in the FE formulation of bodies in contact (see e.g. [4,5]). This method involves introducing a contact stiffness and subsequently choosing a penalty parameter. This procedure can also be applied to oscillating systems where impacts occur during motion [6]. The observed energy loss due to impact can be accounted for by introducing a contact damper which implies the choice of a second penalty parameter. However, the two parameters cannot be chosen independently. Moreover, within the numerical integration of the equations of motion sufficiently small time steps have to be taken for accurate description of all events in the time interval during contact. This third parameter also depends on the two other parameters, as has been shown in [7].

In the following the simulation of stationary nonlinear oscillations arising from the evolution of impacts along a contact line is studied using finite element methods. The aim of this paper is to illustrate the fundamental difficulties and the procedure for the estimation of several numerical parameters to capture the correct numerical result. The considerations clarify that the set of appropriate parameters can be taken only from a small window. Leaving this range of parameters the computed type of motion is far away from the experimental reality. Summarising these facts, only an experimental reference can qualify a certain result of computation to be correct. The work below has been limited to the consideration of one typical type of oscillation discovered on delaminated structures. Here, the procedure of a systematical identification of numerical parameters is outlined. The consideration is focussed on the most important parameters for the present task which describe energy dissipation.

2. Experimental investigations

A sandwich beam with a distinct surface delamination is considered as an example. In the stationary state of a forced motion, the gap between both separated parts of the beam opens and closes. This oscillation is dominated by the amount of energy dissipation due to the impact-like contact phases. It is well known that externally excited vibro-impacting systems have no unique solutions. Depending on the system properties as well as the amplitude and frequency of a harmonic excitation, a bifurcation scenario up to chaotic motion may occur. Thus, the calibration of the three numerical parameters mentioned above is possible only if information is given about the type of oscillation to be analysed. The investigation in the following focuses on the simplest type of motion, with identical input and output frequency, without bifurcation and only one contact phase during one period of excitation.

Experimental results allow the calibration of all parameters needed for the numerical analysis. The experimental setup and the geometrical quantities are given in Fig. 1.

The beam is made of aluminium with YOUNG’s modulus $E = 7.0 \times 10^{10}$ N/m^2 and density $\varrho = 2700$ kg/m^3. It is suspended by soft springs at the nodes of the lowest natural mode without contact. The given delamination is symmetric along the longitudinal axis of the beam with a maximum gap width of about $g_{\max} = 1$ mm at the centre. Vibrations are induced by an uncontrolled shaker at one end of the beam. In the present case, this excitation exhibits the characteristic of a prescribed harmonic displacement. Low excitation amplitudes lead to linear oscillations without contact between the two delaminated parts. The corresponding lowest resonance frequency is 26.24 Hz. Internal damping in this case is very low. Experiments show a damping coefficient of 0.4%. Taking the resonance frequency of the linear system and increasing the amplitude of excitation to the value 1.5 mm causes periodic impacts which can be heard as continuous clapping. Displacements and velocities of the two contacting points in the middle of the delaminated