Non-smooth Resonant Vibrations of Delaminated Beam-type Structures

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Introduction

Oscillation properties of delaminated structures are governed by strongly nonlinear phenomena, which are associated with two major mechanisms, namely the presence of a unilateral constraint across the interface of the debonded zone and dissipative impact-like contacts in this region. Therefore, damage mechanisms will produce local sources of nonlinearity in a predominantly linear structure, that are detectable on a global basis [1]. Investigations of the arising nonlinear response, as will be addressed, are promising for reliable localisation of the involved delamination. As a general conclusion, it was found that a consideration of the damage-related nonlinearity is much more sensitive to structural alterations than any other method based on the investigation of linear system properties (e.g. modal characteristics [2]).

Delaminated Beam

The model problem for non-destructive damage analysis is a straight laminate beam with a distinct debonded zone. Harmonic resonant vibrations are induced at one end of the beam. In the stationary state of motion, the gap between both separated parts of the beam opens and closes. In the following, a delaminated beam as depicted in figure 1 is investigated by different mechanical models of increased complexity to obtain insight into the nonlinear oscillation behaviour of damaged structures. The outlined experimental investigations will provide both a possibility of judging the quality of the numerical models and the basis for the following damage identification procedure.

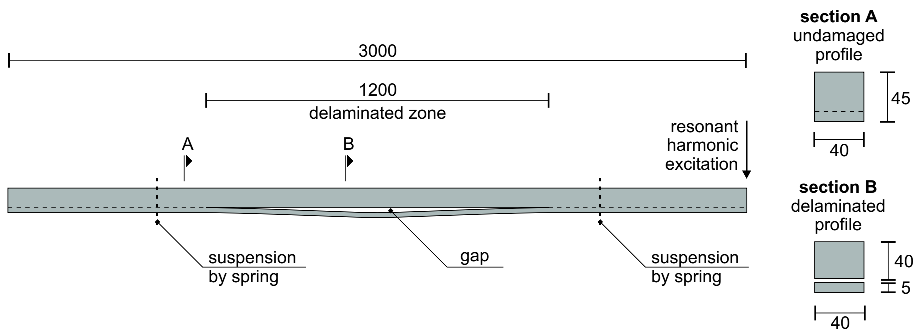

Figure 1: Delaminated beam with symmetric damage scenario.

Minimal Mechanical Models

The present major task, with a view to the damage identification, is the isolation of the predominant damage-related oscillation phenomena - the fingerprint of the flaw - and to prove the robustness of these phenomena. Therefore, the investigation starts with two non-smooth rigid body models that allow the capturing of the most conspicuous effects. The dynamic contact-impact problem has as the simplest approximation two neighbouring linear oscillators (see figure 2 [a]). It is well known that externally excited vibro-impacting systems have no unique solutions [3]. Depending on the system properties as well as the amplitude and frequency of a harmonic excitation, a cascade of bifurcations up to chaotic motions may occur. The essential point in this scenario is its dependency on the amount of energy dissipation at each impact-like contact. Introducing a high contact dissipation according to the experiment, only one-periodic (non-bifurcated) oscillations exist [4]. On the basis of this knowledge, the distortion factor [1] can be employed to quantify the degree of response nonlinearity at each oscillator. As a result, it was found that the responses of both subsystems bear noticeable nonlinearity.

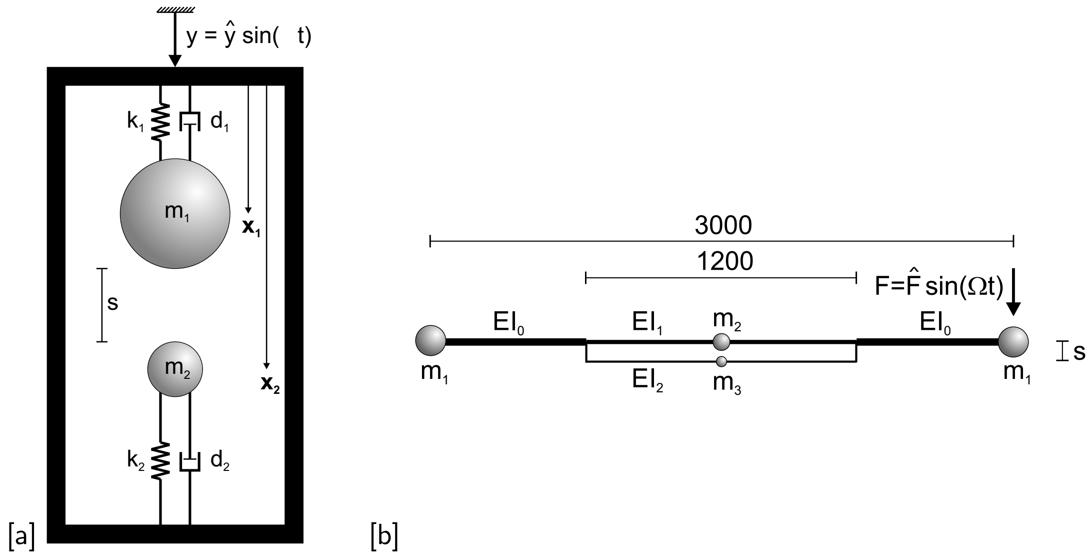

Figure 2: Minimal models: [a] 2 DOF model, [b] 4 DOF model.

A more detailed approach provides a 4 DOF beam model with lumped masses (see figure 2 [b]). For this purpose, two intact regions are added in regard to the afore considered system. The extended model additionally reveals the penetrative character of the local source of nonlinearity to all responses, even in the undamaged region. Finding the fingerprint of the damage on nearly arbitrary test points provides the key for the development of global methods (on a system level) for damage assessment.

Finite Element Model

Finally, a Finite Element model (fig. 3) is proposed that affords both a reliable prediction of all predominant oscillation phenomena as well as a qualitatively and quantitatively correct simulation of the system's response. For this purpose, the one-dimensional continuum problem (fig. 1) is discretised by EULER-BERNOULLI beam elements. Supplying the time harmonic excitation on the system with sufficiently large amplitude, coupling of the linear subsystems (remaining beam and delaminated layer) in the debonded region occurs due to impact-like contact events along the delamination. Two fundamental challenges appear: the appropriate time integration in regard to the non-smooth nature of the problem and the reliable capture of the periodically appearing dynamic contacts within the stationary state of motion. The conception of the node-to-node contact description via impact law in combination with a penalty stiffness is adopted to tackle the special type of contact. The impact law mainly involves the distinct contact dissipation while the latter helps to capture states of permanent contact. This technique turns out to be very advantageous in regard to the robustness of the simulation results.

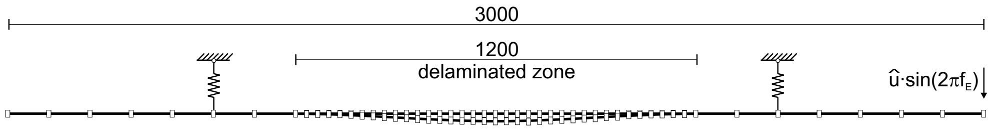

Figure 3: Finite Element model.

Inverse Analysis for Vibration-based Damage Identification

A nonlinear model-based approach for inverse damage identification can be established by parametric updating of the Finite Element model. Therefore, an error function is needed to control the iterative adaption of the damage scenario involved in the numerical model. Due to the distinct damage-related sensitivity of the nonlinear structural response, an appropriate error function shows great promise for overcoming the ill-posedness of the inverse problem without any mathematical augmentation (i.e. regularisation). Due to the nonlinear nature of the parameterised mapping the minimisation problem to be solved is, in general, non-convex and may imply in the majority of cases that several minima occur. Thus, a special optimisation technique with global character is required to overcome this difficulty and to achieve success in inverse damage identification.

References

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