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Extending modal testing technology for model validation of engineering structures with sparse nonlinearities: A first case study

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ABSTRACT

Modal testing is widely used today as a means of validating theoretical (Finite Element) models for the dynamic analysis of engineering structures, prior to these models being used for optimisation of product design. Current model validation methodology is confined to linear models and is primarily concerned with (i) correcting inaccurate model parameters and (ii) ensuring that sufficient elements are included for these cases, using measured data. Basic experience is that this works quite well, largely because the weaknesses in the models are relatively sparse and, as a result, are usually identifiable and correctable. The current state-of-the-art in linear model validation has contributed to an awareness that residual errors in FE models are increasingly the consequence of some unrepresented nonlinearity in the structure. In these cases, additional, higher order *parameters* are required to improve the model so that it can represent the nonlinear behaviour. This is opposed to the current practice of simply refining the mesh. Again, these nonlinear features are generally localised, and are often associated with joints. We seek to provide a procedure for extending existing modal testing to enable these nonlinear elements to be addressed using current nonlinear identification methods directed at detection, characterisation, location and then quantification – in order to enhance the elements in an FE model as necessary to describe nonlinear dynamic behaviour. Emphasis is placed on the outcome of these extended methods to relate specifically to the physical behaviour of the relevant components of the structure, rather than to the nonlinear response characteristics that are the result of their presence.

1. Introduction

1.1. Background

In recent years, there has been a growing interest in the significant prospect of extending the updating of structural dynamics models for the design of critical structures so as to make them valid for the higher levels of excitation and response that are encountered under service conditions, as opposed to those usually used in laboratory tests. This development frequently involves the inclusion of nonlinear behaviour and the transition from linear to nonlinear characterisation

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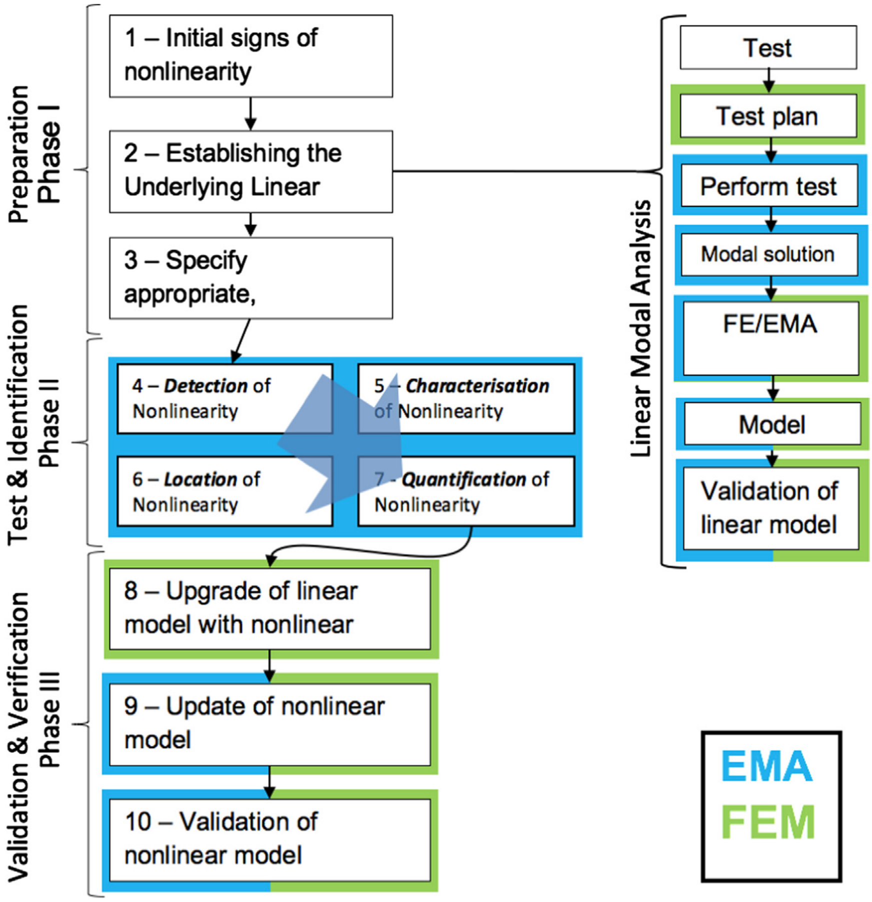

Fig. 1. Schematic representation of the proposed Modal Test+ procedure.

of complex engineering structures is a daunting prospect. However, it is considered probable that many practical cases will have the possibility of significant improvement to the relevant models for a relatively modest extension of linear model validation procedures. Essentially, the nonlinear features in many structures and machines tend to be localised, and even sparse, and so by focussing on the most significant of the nonlinear regions of the structure, it is likely that a notable improvement over the underlying linear representation can be gained without a fundamental re-think of the whole model.

A methodology for such an extension to the modal testing that is undertaken for traditional linear model validation has recently been proposed and described in. One constraint on this new procedure is that it should require the minimum of additional test equipment, practice and analysis software beyond that routinely available in today's high-technology industries. Ref. [1] includes mention of a range of algorithms that are currently available or under development to fill the gaps necessary for nonlinear identification, but does not extend to recommendation or critical comparison of any of these. The purpose of the current paper is to describe a specific worked example test case to explore the more advanced and more promising of these new techniques.

1.2. *A new approach*

The procedure outlined in Ref. [1] comprises a series of 10 steps grouped in 3 Phases, as can be seen in Fig. 1: Phase I *Preparation* – preparation for a nonlinear model validation process, including derivation of a validated Underlying Linear Model (ULM); Phase II *Test and Identification* – of the primary nonlinear features in the test structure, also referred to as Modal Test+; and Phase III *Verification and Validation* extending (i.e. upgrading) the model to include the necessary additional parameters, and then validating these by updating the coefficients for the additional model features. Full details can be found in Ref. [1] and will not be repeated here.

One of the main features of the proposed methodology is the formalisation of how the nonlinear characteristics are to be included in the model. This cannot be achieved by increasing the number of elements in the model mesh but, rather, by increasing the complexity and order of each relevant element, and the number of parameters that are required to describe the nonlinear characteristic appropriately. Only when the model has an adequate set of parameters it can be subjected to an updating procedure whose role is to determine the most appropriate numerical coefficients for this model.

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