PIEZODIAGNOSTICS – A NEW SHM METHOD AND ITS POTENTIAL ENGINEERING APPLICATIONS

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Summary This paper presents a novel approach to damage identification based on the phenomenon of elastic waves propagation. The theoretical background is the dynamic Virtual Distortion Method, which is capable of modelling both a reference excitation signal propagated in the intact structure over a time domain and a perturbed signal due to some damage in the structure. The damage is modelled as stiffness loss. A dynamic inverse analysis is carried out in the time domain in order to identify multi-damage cases in terms of their locations and intensities. The main focus is taken on addressing numerical aspects of the presented approach as well as its potential engineering applications. The related methodology is presented including a brief description of experimental verification. Numerical example with successful identification is demonstrated. Advantages of the approach as well as its challenging points are discussed.

INVERSE DYNAMIC PROBLEM

The purpose of this paper is to propose an alternative approach to the inverse dynamic analysis problem. Generalising the so-called VDM (Virtual Distortion Method) approach for dynamic problems, a *dynamic influence matrix D* concept will be introduced. Pre-computing of the time-dependent matrix *D* allows for decomposition of the dynamic structural response into components caused by external excitation in the intact structure (the linear part) and components describing perturbations caused by the internal defects (the non-linear part). As a consequence, analytical formulas for calculation of these perturbations and the corresponding gradients can be derived. The physical meaning of the so-called *virtual distortions* used in this paper are externally induced strains (non-compatible in general, e.g. caused by piezoelectric transducers, similarly to the effect of non-homogeneous heating). The compatible strains and self-equilibrated stresses are structural responses to these distortions.
Assuming possible locations of all potential defects in advance, an optimisation technique with analytically calculated gradients could be applied to solve the problem of the most probable defect location. The considered damage can affect the local stiffness as well as the mass distribution modification. It is possible to identify the position as well as intensity of several, simultaneously generated defects.

DAMAGE IDENTIFICATION SYSTEM

The proposed methodology will be applied to corrosion detection (reduction of material thickness), and identification of its location in steel pipelines, using long-distance transmissions of impulses. The mechanical model can be reduced in this case to the isotropic one, with virtual distortions modelled through thermal-like, deviator-less tensor fields. This problem, similar to thermal shock propagation, can be solved numerically cheaper than the general problem of elastic impulse propagation.
The proposed, time-domain-based methodology of data processing for damage identification (VDM-based *PiezoDiagnostics Software*) fits well to the following technique of measurements (*PiezoDiagnostics Hardware*):

1) wave generator produces a low frequency impulse of flexural wave with long-distance propagation,
2) few well located, distant sensors collect measurements of frontal section of the transferred wave,
3) if the received structural response differs significantly from the reference response (for undamaged structure), the collected measurements are transmitted to a computer centre for further data processing (damage identification).

The main advantage of the proposed approach is large number of measurements (done in consecutive time steps) enabling precise damage identification, including multi-damage cases.

NUMERICAL AND OPTIMISATION ASPECTS

The objective function to be minimised (*PD Software*) describes the distance between the measured response of the damaged structure (red line with squares in Fig. 1) and the computer-simulated response influenced by the composition of all possible defects modelled by *virtual distortions* (green line with circles in Fig. 1). These virtual distortions are parameters to be identified in the efficient, gradient-based optimisation procedure, where gradients are determined analytically. Software vs. experimental verification demonstrated on the above figure has been elaborated making use of small cantilever beam excited with a sinus-shaped impact generated with piezo-actuator, which will be discussed in details in the final presentation.
The VDM-based approach to damage identification consists of the following steps:

1) Assume potential locations of all possible defects
2) Calculate the so-called *influence matrix D* describing global structural dynamic response for unit Dirac-like impulse virtual distortions generated in potential defect locations

3) Formulate the objective functional describing *mean square-distance* between the *measured* structural response to externally generated flexural wave and the numerically composed response (superposition of un-damaged structural response and linear combination of influences from all potential damages)
4) Perform gradient-based identification procedure searching for the intensities of virtual distortions (modelling potential damages) minimizing the objective functional.

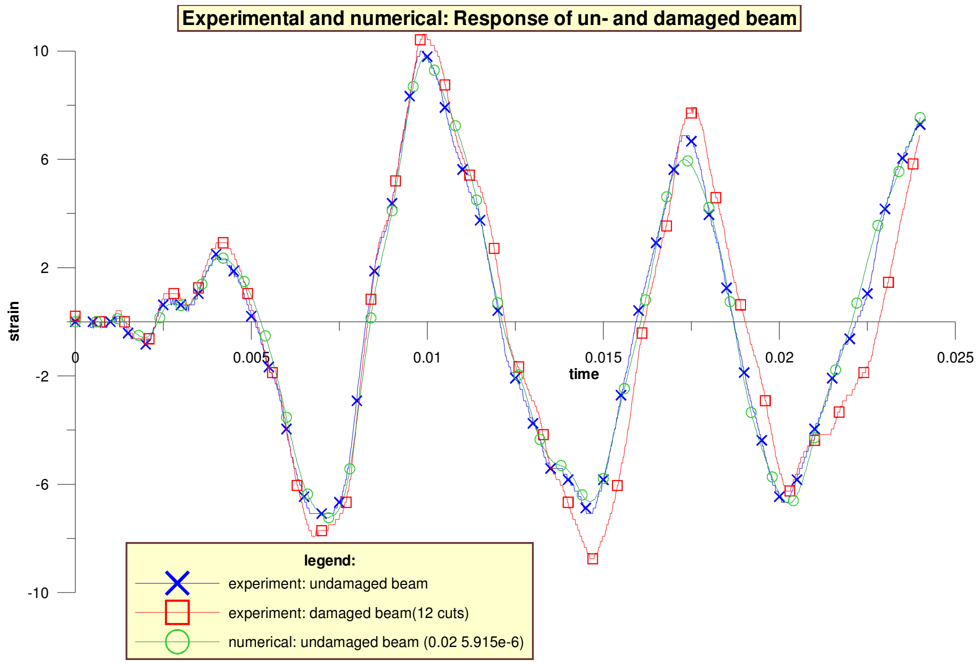

Fig. 1 Numerical simulation for undamaged beam (green line - circles) vs. measured responses for the original (blue line - Xs) and damaged (red line - squares) structure (1000 time steps analysis)

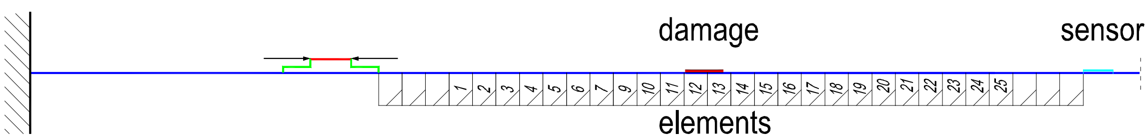

Fig. 2 FE discretization of an aluminium beam specimen subject to damage in the middle section

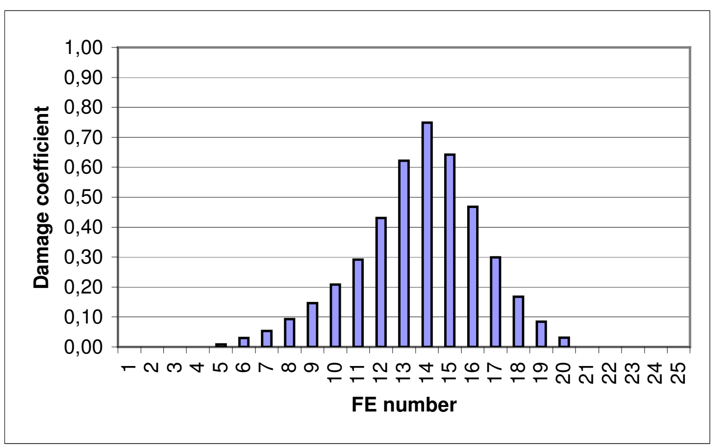

Fig. 3 Results of damage identification for the aluminium beam by the VDM-based PiezoDiagnostics Software

Acknowledgement

Research results presented in this paper have been obtained on the basis of the 5FP Research Project: G1RD-2001-00659 (2002-2005): *Smart Structural Diagnostics using Piezo-Generated Elastic Waves - PIEZODIAGNOSTICS*, supported by the European Commission. Partners: CEGELEC, TWI, WSATKINS, CEDRAT, CIMNE, CDRiA, IFTR, ECL, ALSTOM.