Long-Distance, Gradient Based Identification of Corrosion Through Analysis of Piezo-Generated Impulse Transmission

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1. Abstract

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 structure over a time domain and a perturbed signal due to damaged locations. 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.

2. Key words

Damage identification, inverse dynamic analysis, elastic wave propagation

3. Methodology for the inverse dynamic problem

The damage detection systems based on an array of piezoelectric transducers sending and receiving strain waves have been intensively discussed by researchers recently [1], [2]. The signal-processing problem is the crucial point in this concept and a neural network based method is one of the most often suggested approaches to develop a numerically efficient solver for this 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, cf. [3]) approach for dynamic problems, a dynamic influence matrix D concept will be introduced. Pre-computing of the time dependent matrix D allows decomposition of the dynamic structural response into components caused by external excitation in undamaged 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 for 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.

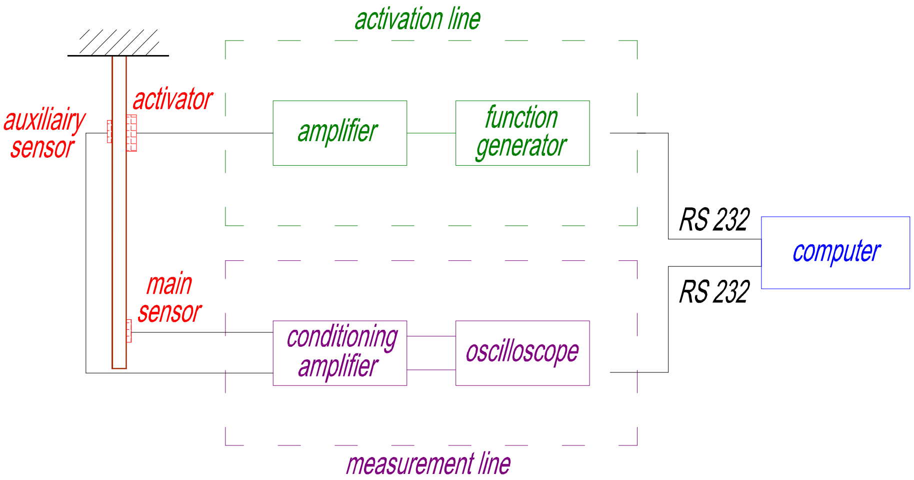

Fig. 1 Scheme of the experimental set-up for detecting damage in an aluminium beam specimen

4. Short characteristic of the 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 (cf. [4]), time-domain-based methodology of data processing for damage identification (VDM-based *PiezoDiagnostics Software*) fits well to the following technique of measurements (*PiezoDiagnostics Hardware*):

i) wave generator produces a low frequency impulse of flexural wave with long-distance propagation,
ii) few well located, distant sensors collect measurements of frontal section of the transferred wave,
iii) 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) allowing precise damage identification, including multi-damage cases.

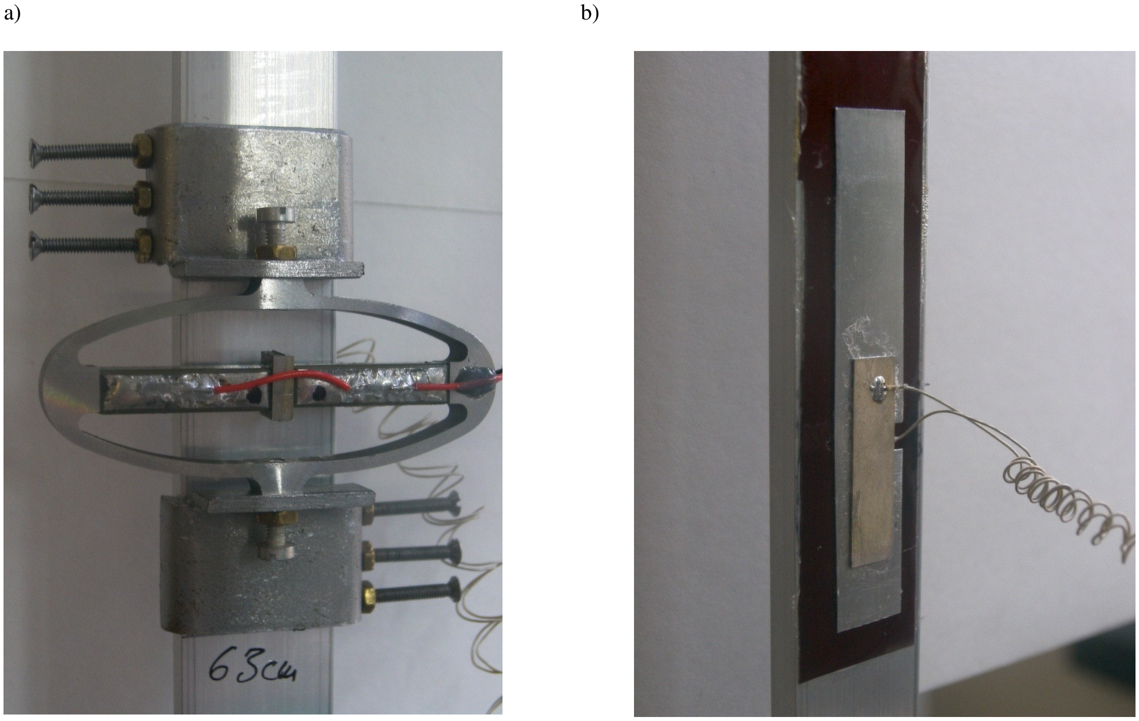
a)
b)

Fig. 2 Photos of the actuator (cf. [5]) (a) and the sensor (b)

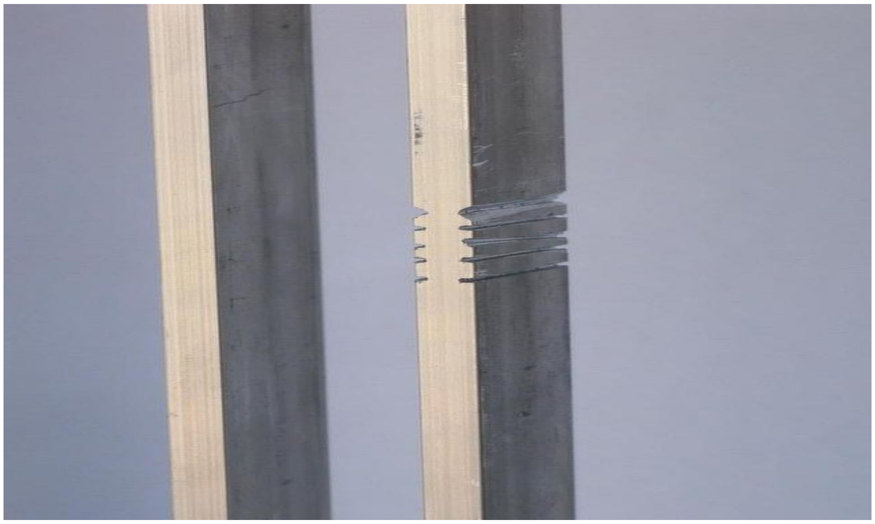

Fig. 3 Original specimen and damaged specimen (series of cuts to account for stiffness rather than mass reduction)

5. 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:

- Assume potential locations of all possible defects
- Calculate the so-called *Influence Matrix* D describing global structural dynamic response for unit Dirac-like impulse virtual distortions generated in potential defect locations
- 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)
- Perform gradient-based identification procedure searching for the intensities of virtual distortions (modelling potential damages) minimizing the objective functional.

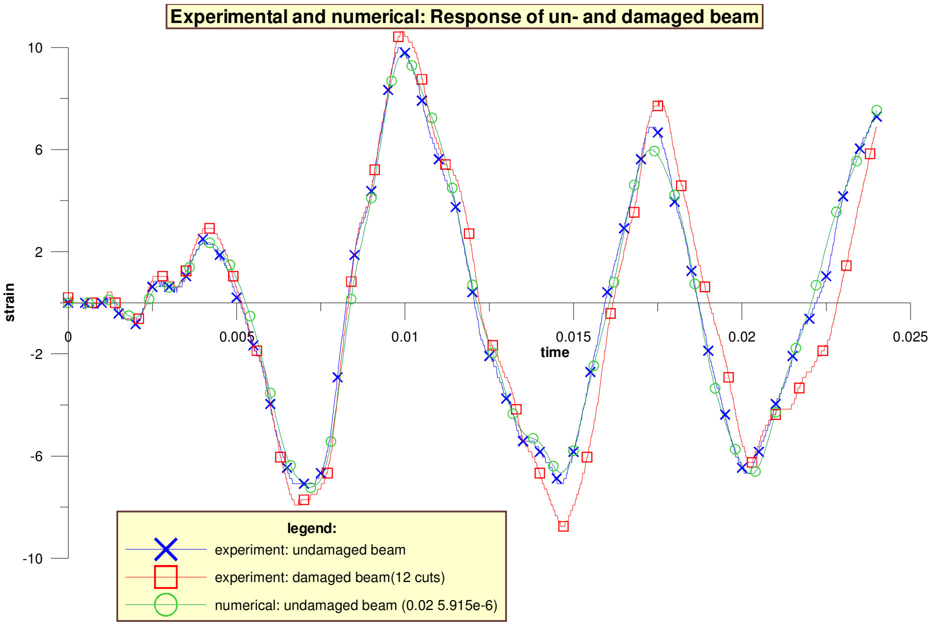

Fig. 4 Numerical simulation for undamaged beam (green line) vs. measured responses for the original (blue line) and damaged (red line) structure (1000 time steps analysis)

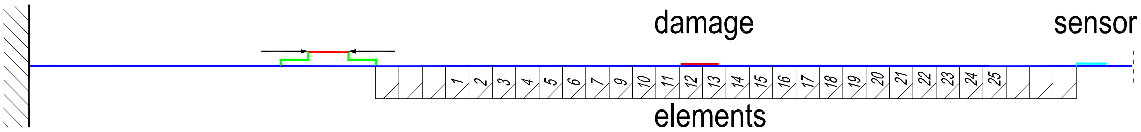

Fig. 5 FE discretization of an aluminium beam specimen subject to damage in the middle section

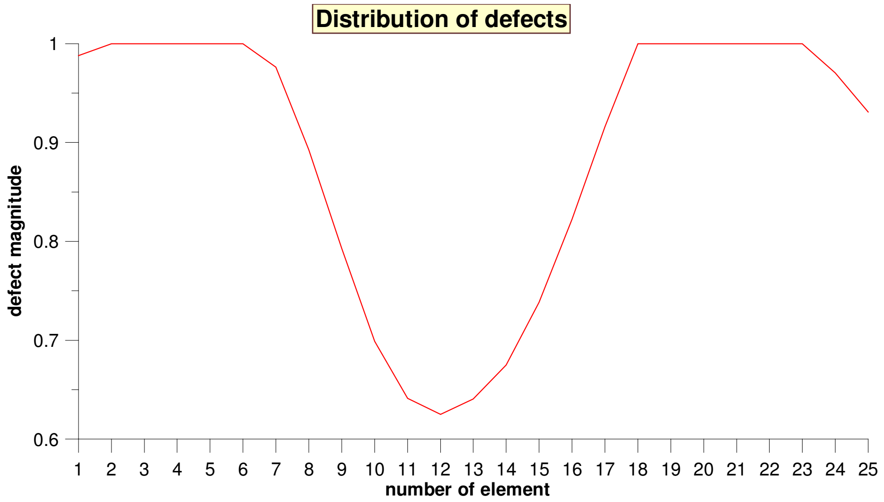

Fig. 6 Results of damage identification for the aluminium beam by VDM-based PD Software

6. Trial with a real engineering structure

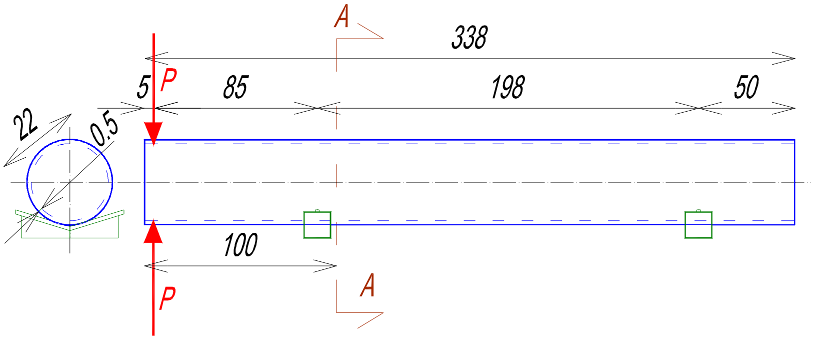

Fig. 7. The tube specimen for lab measurements of elastic wave propagation.

Fig. 8. The APA 230L activator (cf. [5]) *inside the tube.*

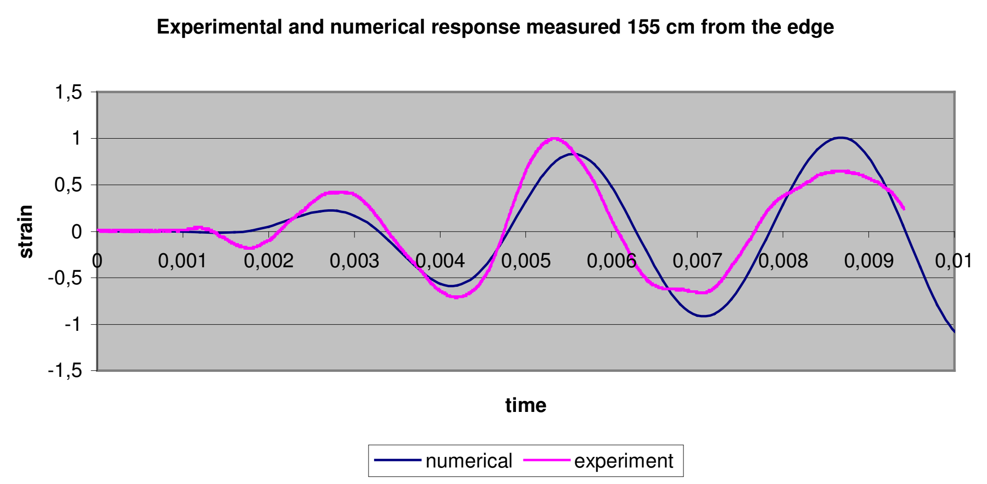

Fig. 9. Experimental vs. numerical response for the tube specimen.

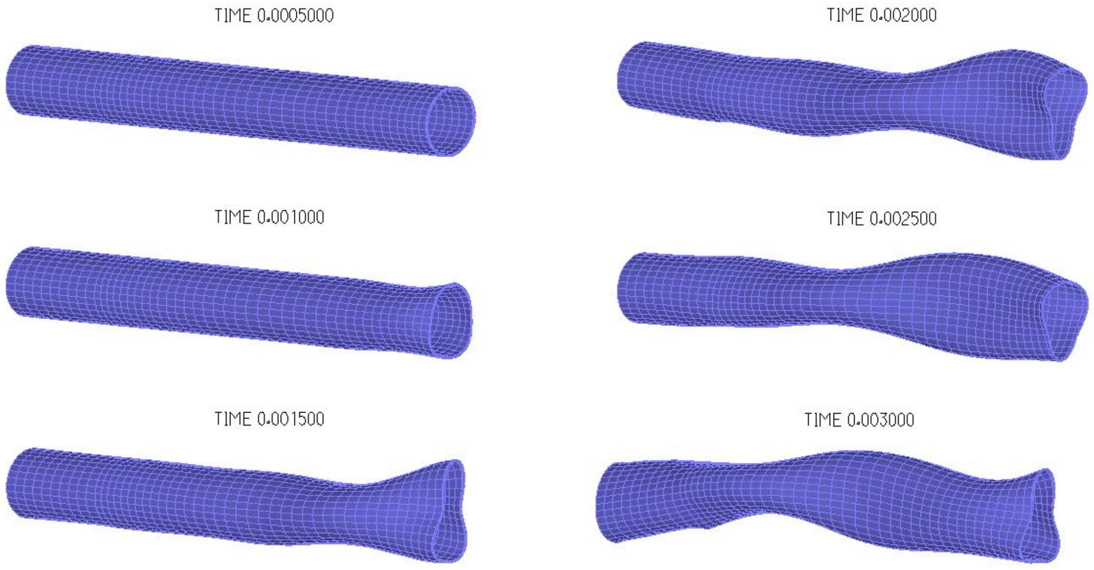

Fig. 10. Deformation of the tube (in selected time steps) due to propagation of the bending-like elastic wave, induced by a sine pulse.

7. Conclusions

The identification result obtained for the beam model is "fuzzy" – it is spread over 8 elements with the maximum in the middle elements, which corresponds to the actual defect localization (see Fig. 6). For the excitation signal of the assumed frequency *the objective function is very flat in vicinity of the obtained solution*. Further improvement of this result will be searched thorough the following steps:

- application of wave excitation correlated with a higher eigenmode (e.g. the fifth one) or, generally speaking, application of some excitation signals of higher frequencies;
- approach based on analysis of transient functions obtained for several different frequencies ("sweep of frequencies") – e.g., application of at least two wave excitations (for example correlated with the 4th and the 5th mode);
- improvement of the optimisation procedure;
- more sensors (in this simple experiment the application of two sensors may be tried),
- more dense discretisation (dimension of finite element is close to the dimension of searched defect).

Especially the second proposition seems to be very promising and can be easily applied.

The primary test with a tube specimen shows that a good start for matching the numerical model to experimental data has been made. Further research will be carried out and a compromise will be hopefully achieved between the accuracy of FE modelling and reliable numerical response enabling successful performance of the inverse dynamic analysis.

8. Acknowledgement

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9. References

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