Validation of Damage Identification Using Non-Linear Data-Driven Modelling

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INTRODUCTION

As pointed out in the previous part, it is an important goal to design and construct safe, ecological and reliable structures, which are still cost effective. In order to guarantee these requirements, especially in industries where the component reliability is crucial, regular inspection intervals must be defined. As traditional inspection techniques can be very expensive in terms of both man hours and structure down-time, the development of suitable automatic and reliable monitoring methods, which can be used on demand, would be very valuable. This requires techniques which can monitor the given structure either continuously or in fixed intervals and can provide suitable early warning before a propagating damage reaches the limits of criticality. Here is the place where structural health monitoring systems enter into play. To perform these tasks, a monitoring system should decide autonomously whether the host structure is damaged or not. On that account the article "Damage Identification using Non-linear Data-Driven Modelling – Methodology" of this book describes the methodology of a novel data driven approach based on scale-frequency analysis, multiway hierarchical nonlinear principal component analysis (h-NLPCA), squared prediction error statistic (SPE) and self-organizing maps (SOM) for the detection and classification of damage in structures. In this article the application of this approach is described in detail for two case studies, a metallic pipeline and an aircraft composite skin panel.

This article, which contains the experimental results of the proposed method, is organized as follows: First, a very short summary of the proposed methodology is given in the section "Theoretical Background". Afterwards the application of this method is shown in detail within an experimental evaluation for two samples made from different materials. Their analysis is followed by the discussion of the results. Finally, concluding remarks are given in the last section.

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THEORETICAL BACKGROUND

The innovative data driven approach used in for the experimental evaluation in this article uses scale-frequency analysis, multiway hierarchical nonlinear principal component analysis (h-NLPCA), squared prediction error statistic (SPE) and self-organizing maps (SOM) to achieve the identification of damages in structures. It is based on the use of signals collected from a distributed piezoelectric transducer network which is permanently attached to the structure. Within this transducer network each transducer can work either as a sensor or actuator. The inspection of the structure is performed in several actuation steps. Within each step, one transducer is used as actuator while the rest acts in turn as sensors to collect the structural dynamic responses included in the ultrasonic waves propagated throughout the structure. To process the data, in a first step, the discrete wavelet transform (DWT) is used for feature selection and extraction from the structural dynamic responses at different frequency scales. Neural Networks are then used to build a probabilistic model from these features for each actuation step with the data from the healthy structure by means of sensor data fusion. Next, the features extracted from the dynamic responses in different structural states (damaged or not) are projected into the probabilistic models of each actuation step in order to obtain the non-linear principal components, and then the SPE metrics are calculated. Finally, these metrics together with the projections onto the non-linear principal components (scores) are used as input feature vectors to a SOM. A sketch of the single steps of the methodology is given in Figure 1. Results show that with the proposed approach all the damages were detectable and classifiable, and the selected features proved capable of separating all damage conditions from the undamaged state. For an extensive description including also a large number of references, which describe the theoretical background of the single components used in this method, the reader is referred to the chapter "Damage Identification using Non-linear Data-Driven Modelling – Methodology" within this book.

EXPERIMENTAL VALIDATION

The proposed methodology was tested in two complex structures, a pipeline including flange connections and a carbon fibre reinforced stiffened plate, similar to aircraft composite skin panel. The next subsections present the experimental setup and the results obtained by each structure.

Pipeline Case Study and Results

An experiment was performed in order to evaluate the practical performance of the proposed methodology in pipework. Figure 2(a) depicts the experimental setup used for testing. Four piezoelectric transducers PIC-151 from PI Ceramics are attached to the surface of the structure with equidistant angular spacing on both sides at a distance of approximately 35 mm from the flanges. The piezoelectric transducers have a diameter of 10 mm and a thickness of 2.5 mm.

The monitored pipe has a length of approximately 850 mm. It was made of stainless steel with an outer radius of 20 mm and 2.15 mm wall thickness. Damage was introduced into the structure in several steps. It was executed as a cut with an angular grinder. The depth and its vertical extension are enlarged in four steps, starting with a cut of 0.75 mm depth. This cut is increased in depth in a second step until the wall is almost penetrated, followed by an increase in vertical direction. Finally the pipe wall is penetrated, increasing the depth in the middle of the former notch. The different states can be found in Figure 2(b) to (e).

It is well-known that each of the possible excited modes will produce different deformation fields along the wall thickness, i.e. the particle displacements and velocities as well as the stress and strain fields will all vary for each mode. Therefore, it is desired to select a mode with greater penetration power across the wall thickness in the pipeline. Previous works have shown that the second order longitudinal mode L(0,2) is very attractive to use for long-range testing since it is practically non-dispersive and it is also the fastest mode (Alleyne, Lowe, & Cawley, 1998). Additionally, this mode has most of its energy flow proportionally located across the wall thickness. For this reason, special attention was paid in order to excite this mode. In order to assure the selection of the mode, dispersive characteristics and energy distribution analysis is carried out.

To guarantee these requirements, the excitation voltage signal was a 12 V Hanning windowed cosine train signal with five cycles and carrier frequency of 180 kHz. The input signal to the actuators was generated using the arbitrary signal generation capability of a combined signal generator and oscilloscope instrument manufactured by TiePie Engineering. The time histories

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