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Damage detection in plates using the electromechanical impedance technique based on decoupled measurements of piezoelectric transducers

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A B S T R A C T

Electromechanical impedance (EMI) technique plays an important role in the monitoring of structures with piezoelectric transducers (PT). According to the EMI technique, diagnosis and prognosis can be carried out to detect structural modifications in an operative state. However, to develop an efficient methodology for damage detection; damage metrics and patterns should be defined using indices to quantify changes in the signals. In this study, a new approach is proposed considering the electrical impedance (EI) of PT as an array of coupled electrical impedances. It means that when a PT is bonded to a structure, the EI is governed by an electrical circuit that is assumed to be parallel and composed by electrical contributions of both, the structure and the PT. In our perspective, each free PT presents unique mechanical characteristics and those differences may influence the measured electrical signals, therefore the electrical contributions generated by each piezo-transducer are taken into account. To evaluate the electrical decoupling, two methodologies of damage detection are proposed to identify and locate an induced damage. In these methodologies, the damage metrics are based on ellipses of Gaussian confidence. Four experimental tests were performed to evaluate the methodologies, applying two damage intensities. The results show that the partial process of identification of a damage type is a feasible and applicable procedure, moreover the proposed method was able to evidence the damage location..

1. Introduction

Piezoelectric transducers (PT) are bonded to the structures to monitor and assess its condition by means of the electric signals provided by electromechanical coupling. Therefore PT can be used to evaluate, identify, classify and estimate the structural conditions and, as a consequence, different applications of PT have been described especially in the fields of Non-

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Destructive Evaluation (NDE), Structural Health Monitoring (SHM), and Control, among others [1–3]. Generally, integrated monitoring systems, if implemented in situ, could decrease the operative costs of maintenance and increase the reliability and safety of the structures such as it is mentioned in [4,17]. The methodologies implemented with PT play an important role in the service of structures, specifically, in the diagnosis and prognosis [5,6].

Damage detection methodologies are based on sensors and actuators technologies that can apply active and passive methods. Passive methods use a set of sensors to monitor different physical quantities as acceleration, velocity, stresses, and strains among others. The sensors should not modify mechanical properties of the structure, it means that these should not be invasive. On the other hand, active methods may proceed by means of kinematic variables (displacements and strains) that may change the structural state with the aim to obtain information and modify structural dynamics. Some active methods that use PTs are electromechanical impedance (EMI) technique, pulse-echo, pitch-catch, phased-array methods, Lamb-waves, and multi-mode detection, among others [7,8,16,32].

In the last few years, the EMI technique has become an essential part in development of the field of damage detection since many applications have shown that the technique presents a great capacity for capturing structural changes [3,31,37,38,40]. It is well known that the mechanical and geometrical parameters of a PT are coupled electromechanically with the host structure [10–12,27]. The coupling is established by the following functioning principle: the PT is harmonically deformed in a desired frequency spectrum, when a harmonic electric field is applied in the PT in a polarization direction. In this way, it excites the host structure by means of vibrations. At the same time, the PT receives structural response converting mechanical energy in electrical energy, specifically in current form; this is due to the electromechanical (EM) effect. Initially, the coupling phenomenon was explained by [9]. From its beginning, the EMI technique has shown a great potential in the field of monitoring, as evidenced in the studies carried out by [3,10,13–15].

For the monitoring of the health of a structure with the EMI technique, it is necessary to quantify variations in the electrical signatures obtained from the monitoring process. These variations are quantified with respect to a baseline by means of indices that reflect the structural modifications. For that purpose, different damage metrics have been developed to define thresholds and observe changes in the indices. The damage indices establish a categorization of the structural modifications which in some cases may determine the damage intensity and type [4,5,17,31,37]. Commonly, the indices in the EMI technique are built on statistical principles, from which we can highlight some quantitative assessments that establish a scalar damage metric. Different statistical indices have been implemented for quantifying the differences between baselines and monitored signals, particularly these are based on the root mean square deviation (RMSD), root mean square (RMS), mean absolute percentage deviation (MAPD), and correlation coefficient deviation (CCD), among others [9,16,17,25,39]. The identified changes point out that the initial structure was modified because it exceeds the established damage threshold. Basically, the majority of these indices are computed from the electrical admittance (inverse of the electrical impedance) because it has shown to be more effective in the identification process [18–20,25,33,39]. It means that the electromechanical admittance is preferred to quantify variations, specifically using its real part; which is called conductance. The application of the imaginary part (susceptance) has been neglected for its low sensitivity to structural modifications [14,19–21]. Despite its disadvantages, it is important to mention that only a few studies explored the sensitivity of the susceptance [13,33]. Additionally, we would like to highlight that some indices based on the admittance are considered to be better than others depending on its applications; this aspect was discussed by [14] and [31]. The above affirmation indicates that every information processing presents an influence on the sensitivity of each constructed index.

Currently, new damage metrics have been explored in different applications; for instance [33], implemented an index based on Gaussian confidence ellipses which proved to be sensitive in both components of the admittance. Recently [13], showed that the susceptance (imaginary part) can also be used to identify damage. They performed an experimental analysis to identify damage in plates with an index based on Gaussian confidence ellipses. The procedure presented feasibility in the process of damage identification. Additionally [31], proposed a methodology to identify and locate a damage type by means of an index established from united mechanical impedances (UMI). The technique was applied to monitor a steel beam with corrosion damage. The sensitivity of UMI was investigated through the comparison with conventional indices obtained from EM admittance. The study considers that admittance has an active and a passive part, which can be decomposed to increase the sensitivity of the damage in the measured signatures, such as it was analyzed by [15] in a previous study. Moreover, a new index was designed by [39] to identify damage in concrete slabs. The performed study predicted variations in the proposed index when the damage intensity was increased on the reinforced concrete slabs. The index presented a regular variation with respect to the distance of the induced damages. It means that the damage location could be determined with this new metric.

This study presents a new approach that considers the EI signals emitted by PT as coupled electrical signals. It means that when a PT is bonded to a structure, the electrical impedances act governed by a parallel circuit. In our perspective, each free PT presents unique mechanical characteristics and it implies that these have small geometric differences which may influence the set of measured electrical signals. In fact, it is known that when a PT is free, the electrical impedance contains its mechanical information in an intrinsic way as it was demonstrated by [25]. Therefore, the EI is decoupled from the acquired signals when it is bonded to a structure without damage. The main objective of the decoupling is to capture only the electrical contributions done by the structure inside EI. To show the advantages of this procedure, two methodologies of damage identification are derived from the EI measurements in the present work. Resistance (R) and reactance (X) are used for the identification and location of the damage induced during the experiments. For this purpose, four plates were

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