A wavelet transform approach for acoustic emission localisation and an examination of PZT sensor self-diagnostics

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Abstract. Damage in mechanical components can be normally very effectively detected using common non-destructive testing methods such as Acoustic Emission (AE) measurements. Presently, in the research area of AE testing, there is a growing interest in the development of reliable and cost-effective sensor systems. The main objectives of this paper are to explore the performance of a localisation approach, based on a time-scale analysis and to examine how the same approach can be applied additionally to sensor self-diagnostics for the purpose of detecting debonding of bare piezo electric elements (PZTs). The proposed analysis can provide a more thorough understanding of the dispersive modes of the AE signals, compared to classic time-domain or frequency-domain techniques. The AE signals are analysed using the Continuous Wavelet Transform (CWT) and sensor self-diagnostics are achieved by tracking the changes of the electrical admittance of the PZT component: different types of debonding change the PZT's admittance response, accordingly. Furthermore, lack of knowledge in regard to the exact placement of sensors is also taken into account.

Introduction

AE sensors most commonly consist of a PZT component, a backing plate and a matching layer. This transducer geometry helps to enhance the signal measurements, although the use of bare PZT elements could potentially offer a more affordable and flexible alternative, in order to perform AE testing. In this case, the reliable use of bare PZT sensors for structural health monitoring (SHM), condition monitoring (CM) and non-destructive testing (NDT), requires a more advanced signal processing strategy for the analysis of the AE signals acquired, as well as an in-depth understanding of the sensor performance in various scenarios. The examination of the suitability and performance of the sensor system chosen is a significant part of an SHM/CM strategy that mainly consists of four steps, as described in [1], the operational evaluation, the data acquisition, the feature extraction and the feature discrimination.
The first part of this work addresses the data acquisition step, mainly, from this perspective. A holistic approach to SHM/CM, that takes in to account sensor issues, in this case, is desired for the development of a reliable strategy. Debonding effects may have a negative impact on the captured AE signals, depending on the level of the sensor defect and, as a result, can modify the stress and strain transfer mechanisms [2,3] exploited in the acquisition of the signals [4]. Another factor that inhibits the reliability of an SHM strategy is the potential lack of knowledge of the placement of specific sensors. This situation can arise if during the sensor installation stage appropriate documentation was not produced to describe sufficiently the sensor system, but also due to potential changes in the dimensions of the structure/mechanical component instrumented, that can occur for example with temperature changes [5].
The next two steps of an SHM/CM strategy (feature extraction and feature discrimination) focus on the analysis of the acquired data, and in our case we deal in particular with AE measurements. The challenge in the data analysis part of our strategy has to do with the nature of the AE signals that propagate in thin structures like plates. Common triangulation techniques assume a constant propagation speed and in the case of finite-bounded media, such as plates, infinite dispersive modes are mainly generated at different frequencies [6]. This is the reason why a more advanced signal processing approach as the CWT, is examined in order to achieve a more informative representation of the AE signals analysed and to improve the damage detection procedure.

Methodology

The benchmarking approach used for the PZT sensors is presented in Fig. 1a. This technique was validated through the standard triangulation method commonly used on a 5.5mm thin Aluminium plate as depicted in Fig. 1b.

An 80x80 mm square grid was defined with 9 nodes, where an artificial AE burst was generated using pencil lead breaks, each node was excited 100 times in order to study thoroughly the measurements errors. For the benchmarking experiment a one sensor triggering mechanism was implemented to give an initial time estimate as shown in the Fig. 1c.

The performance of the PZT sensors was examined on the context of the localisation error obtained from specific grid nodes. In order to reduce the frequency variation, a tolerance band was set at around 10% at 150kHz. The velocity of the propagation of the AE signal, for the zero-order symmetric mode was calculated analytically from the dispersion curves for the aluminium plate, examined. The CWT transform was used to determine the frequency content of the signal as shown in Fig. 2. This approach leads to a more detailed analysis providing information of the mode arrival. Initially the time of arrival will be determined using the Akaike Information Criterion [7] and lately iteratively corrected.

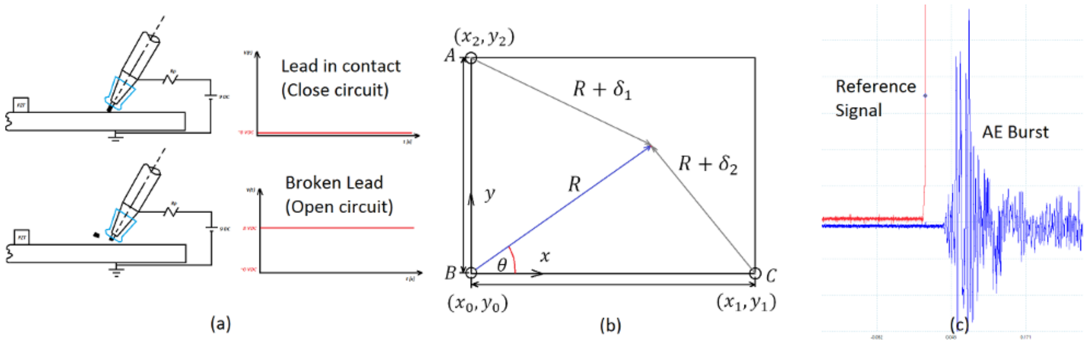

Fig 1: (a) Triggering mechanism, (b) Triangulation of an AE source and (c) Reference signal

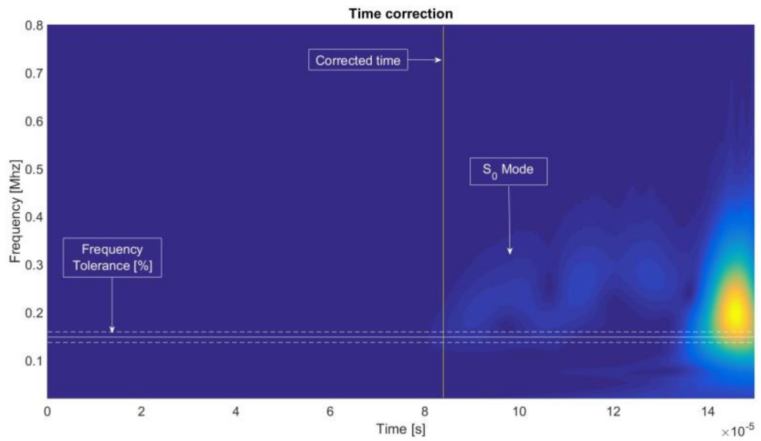

Fig 2: CWT of an AE burst

Debonding progression is examined by means of electrical impedance measurements, this parameter indicates whether any onset of debonding has occurred. Several debonding scenarios will be artificially introduced by changing the bonding area between the sensors and the structure, in order to examine sensor self-diagnostics problems.

Conclusion

Applying the CWT method can improve the estimation of AE source, since it provides a more detailed signal representation than classic time or frequency-domain methods, that enhances the understanding of the propagating modes in plates. The potential use of bare PZT sensors, is also examined here, and it is shown that they can prove a good alternative for AE detection and localisation, being at the same time a cost/effective solution for this problem. Debonding effects that might have an impact in the accuracy for AE localisation, in this case, are also investigated for the purpose of sensor self-diagnostics.

References

[1] K. Worden, C. R. Farrar, “Structural Health Monitoring: a machine learning perspective”, Wiley, 2012.
[2] G. Park, C.R. Farrar, A.C. Rutherford and A.N. Robertson: *Piezoelectric Active Sensor Self-Diagnostics using Electrical Admittance Measurements*, ASME Journal of Vibration and Acoustics, Vol. 128 (2006), p. 469-476.
[3] X.D. Wang, S.A. Meguid: *On the Electroelastic Behaviours of a Thin Piezoelectric Actuator Attached to an Infinite Host Structures*, International Journal of Solids and Structures, Vol. 37 (2000), p. 3231-3251.
[4] G. Park, H. Sohn, C. R. Farrar and D.J. Inman: *Overview of piezoelectric impedance-based health monitoring and path forward*, Proc. Shock Vib. Digest, Vol. 35 (2003), p. 451-463.
[5] J.C. Chen, R.E. Hudson and Y. Kunk: *Maximum-likelihood source localization and unknown sensor location estimation for wideband signals in the near-field*, IEEE Transactions on Signal Processing, Vol. 50 (2002), p. 1843-1854.
[6] J. Rose: *Ultrasonic Guided Waves in Solid Media*, Cambridge University Press, (2014).
[7] N.A. Maeda: *A method for reading and checking phase times in auto-processing system of seismic wave data*, Expert Syst. Appl., (1985).