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Multiple damage detection in piezoelectric ceramic sensor using scanning point contact excitation and detection method

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1. Introduction

Lead zirconate titanate $Pb[Zr_xTi_{1-x}]O3$ (PZT) is a piezoelectric material. PZT ceramics have negligible mass, have easy and fast integration, large frequency responses, low power consumption, low cost of the sensors, superior electro-mechanical coupling, and impedance matching with various substrates. These properties make PZT ceramics extremely suitable for integration into the host structure as an *in-situ* generator/sensor, and thus used extensively in structural health monitoring (SHM) or in non-destructive evaluations (NDE). SHM or NDE focuses on diagnostic, etiognosis, and prognosis for improving the reliability and operational life of mechanical and aerospace structures[1, 2)]. SHM can be broadly classified into two main categories, i.e., i) global health monitoring, and ii) local health monitoring. The near-surface flaws are critical for several applications as the operational stresses tend to concentrate along the periphery of the defects. These micro scale defects in both the bulk and surface of the PZT ceramics act as a precursor to damage that limits the strength, lifetime, and performance of the sensors. It is thus necessary to identify, locate, and quantify the defect in sensors to avoid structural failure and false alarm in SHM applications.

In last several years, a significant amount of effort is devoted for improving the point contact excitation and detection method to excite the acoustic waves in piezoelectric crystals and ceramics. The Coulomb coupling method and spectral decomposition technique has been implemented for detection of extent of surface defect in PZT sample wherein the signal processing is done using Fast Fourier Transform. Wavelet transformation has a unique ability to define any signal in both time and frequency domain simultaneously, and is fast to compute. Thus, the main paper aims to implement the Discrete Wavelet transformation technique on signal[3)], for damage localization in piezo-ceramic sensor, also using coulomb coupling method.

2. Experimental setup

Our group has previously provided a comprehensive overview of the excitation and detection probes fabrication, as well as the experimental setup[4-9)] .

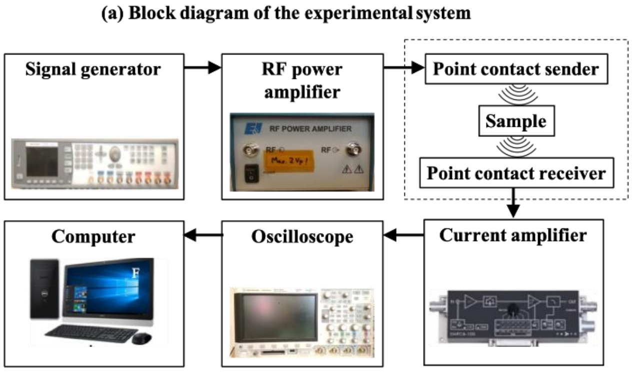

Fig. 1: Experimental setup for point contact excitation and detection method

PZT sample was placed on the top of receiving electrode in the middle of the scan area. The data collection stared with a healthy state scan with a scan area of 10 ×10 mm^2, performed on the surface of the PZT ceramic sample. The sample was then introduced with a circular hole of diameter 500 µm using a high-speed drill. The depth of the holes was fixed to 2.8 mm, approximately for all the damages. After, the 1st damage insertion, a line scan was performed and data was collected from 12 different positions. Step size was 82 µm in X direction. Later on, the size of the damage was increased sequentially by employing 600 µm, 800 µm, and 900 µm drill bit. The whole process was then repeated three more times, where new holes were drilled on the previously damaged PZT sample-surface. This created the 4 damage states, and at the end of 4th state, the surface had four holes of 900µm diameter each.

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3. Results and discussion

3.1 Method 1: Haar wavelet analysis

Haar DWT was implemented for each of the 12 features, and every feature had 4000 data points. The time-series data recorded was zero padded, followed by implementation of haar algorithm which takes original signal as input and returns, approximate and detail coefficient signals. The approximate coefficient is in turn used as input for the next level, and this process is continued six times. All the detail coefficients were equated to zero to minimize the noise, thus resultant signal has 64 data points for each feature. The boxplot of 12 such features give us the complete understanding of a particular damage size of a damage state.

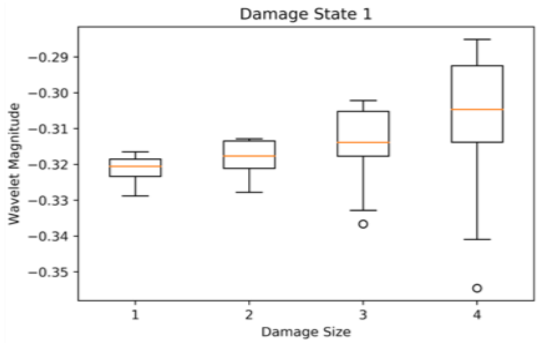

Fig. 2: represents the boxplot of all the damage sizes (500, 600, 800 and 900 μm) in damage state 1.

A clear distinction is visible between each category, thus proving the Haar DWT method is efficient for damage detection even for differentiating between two damages, with only 100μm difference in them.

3.2 Method 2: Power spectral analysis

The input [x(t)] is the time-series signal received from different features. Power spectral density works upon the concept of damage degradation. It is computed by multiplying Fast Fourier transform by its complex conjugate and PSD of the signal describes the power stored in the signal as a function of frequency, per unit frequency.

$$ps = |FFT(x(t))|^2$$

Upon analyzing the plot of different features' data, it is observed that ps remains constant for the central frequency but there are some variations for the frequencies close to zero. The variation of this magnitude is used to extract the pattern in the given data with the help of box-plots. With the increasing damages in the sample, the signal will get interrupted to a greater extent, have loss of information and thus ps is expected to have less magnitude when compared to the previous state of the sample.

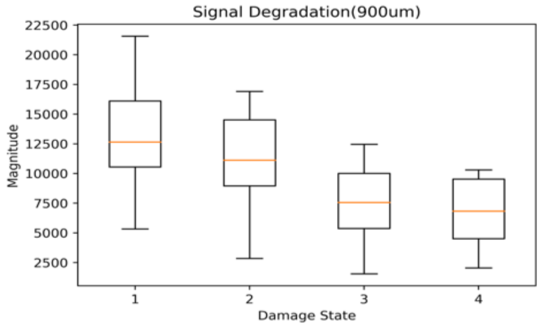

Fig. 3: Represents the boxplot of damage size (900 μm) for all the four damage states.

The box-plots are in-line with the expected result and also a clear distinction is visible between each category, thus proving that PSD method is efficient for damage detection.

4. Conclusion

This paper targets a common but challenging problem of damage detection, classification and localization for small differences in the damage size. Thus, DWT is used for noise reduction and is proven to be able to differentiate between two damages(hole), with only 100μm difference in them. In attempts to make further additions to the research work, PSD analysis was performed. Based on the above observations, both these methods are efficient for damage detection.

Acknowledgment

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References

1) C.R. Farrar and K. Worden: New Trends in Vibration Based Structural Health Monitoring. (2010)1.
2) S. Bhalla and C.K. Soh: J. Aerosp. Eng. **17** (2004)154.
3) K.J. Moore, M. Kurt, M. Eriten, D.M. McFarland, L.A. Bergman and A.F. Vakakis: Mechanical Systems and Signal Processing. **99** (2018)14.
4) A. Habib, E. Twerdowski, M. von Buttlar, M. Pluta, M. Schmachtl, R. Wannemacher and W. Grill: Proc. of SPIE, 2006, 61771A.
5) V. Agarwal, A. Shelke, B. Ahluwalia, F. Melandsø, T. Kundu and A. Habib: Ultrasonics. **108** (2020)106113.
6) A. Habib, A. Shelke, M. Pluta, T. Kundu, U. Pietsch and W. Grill: Jpn. J. Appl. Phys. **51** (2012)07GB05.
7) A. Habib, U. Amjad, M. Pluta, U. Pietsch and W. Grill: Proc. SPIE, 2010, 76501T.
8) A. Habib, A. Shelke, M. Pluta, U. Pietsch, T. Kundu and W. Grill: AIP Conference Proceedings, 2011.
9) A. Habib, E. Twerdowski, M. von Buttlar, R. Wannemacher and W. Grill: Health Monitoring of Structural and Biological Systems 2007, 653214.