Investigation of Alternative Electromechanical Impedance Method for Condition Monitoring

Ryan A. Kettle, Ekramul Haque Ehite, & Steven R. Anton

Department of Mechanical Engineering, Tennessee Tech. University, Cookeville, TN 38505

Objective

The objective of this work is to develop an alternative measurement technique to implement the electromechanical impedance method (EMI) for the conditioning monitoring of structures. The developed measurement technique will then be used with a novel multi-tonal signal for damage detection in engineering structures, with the long-term goal of applying it to highly dynamic environments for microsecond data acquisition.

Background of the Research

Condition monitoring is the in-situ non-destructive sensing and study of system features to detect changes in structures [1]. This research also builds upon the work from the field of structural health monitoring (SHM), which is a range of techniques and tools to detect the evolution of damage in a structure. SHM is necessary for timely and cost-effective maintenance of critical structures, shown in Figure 1. The SHM technique known as the electromechanical impedance (EMI) method, which utilizes piezoelectric materials (PZTs) for sensing and actuation, is used for damage detection in this research.

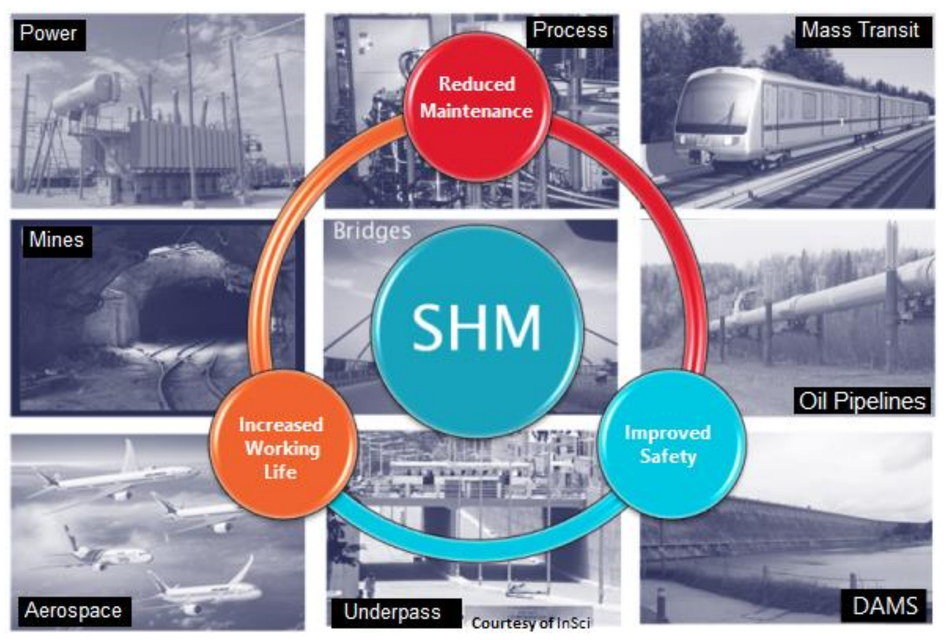

Figure 1: Applications of structural health monitoring

Methods: Electromechanical Impedance

The electromechanical impedance (EMI) method is an active sensing method, meaning it dynamically "interrogates" the structure [2]. The electromechanical properties of piezoelectric materials (PZTs) allow them to act as both a sensor and an actuator simultaneously. By bonding a PZT to a structure, the electrical impedance of the PZT becomes a function of the mechanical impedance of the host structure; therefore, changes in the mechanical structure are reflected in the electrical impedance of the PZT. This process is illustrated below in Figure 2.

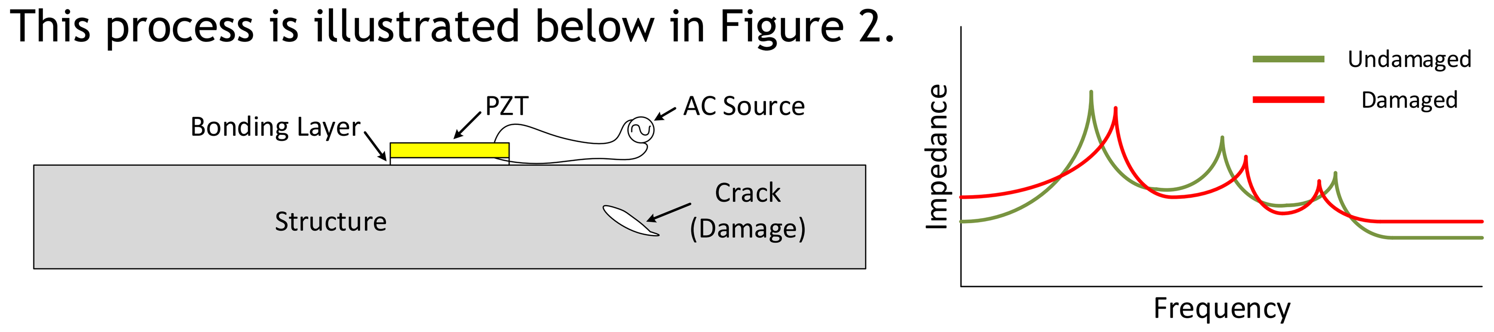

Figure 2: A schematic representation of the EMI method being used to detect damage in a structure

Methods: Deviation from Conventional EMI

Typically, electrical impedance measurements are made with commercial impedance analyzers (e.g. HP 4194A shown in Figure 3). Such impedance analyzers are large (16"x14"x24"), heavy (81.4 lbs), expensive (~$40,000), acquire a limited amount of samples (401 points), and employ a slow stepped sinewave measurement method. Conversely, this research proposes an alternative measurement technique using a standard data acquisition device (DAQ), shown in Figure 4, paired with a auxiliary measurement circuit, based on the works of Baptista [3] and Lewis [4]. DAQs allow for a wide range hardware options, have no limits on the amount of samples that can be acquired, and allow for the use of various excitation signals.

Figure 3: An HP 4194A impedance analyzer

Figure 4: An NI 9215 data acquisition device (DAQ)

The excitation signals used in this work are chirp signals, an example of which is shown in Figure 5, because they allow for broad frequency excitation in a short time period. Narrowband chirp signals can be combined to produce multi-tonal excitation signals which have the potential to decrease measurement time.

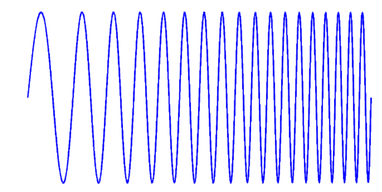

Figure 5: An example of a chirp signal

Methods: Experimental Setup

The proposed system requires a DAQ capable of simultaneous sampling, an auxiliary measurement circuit (shown in Figure 6), and an excitation source. The structure to be tested is a steel cantilever beam with a single surface bonded PZT. Damage will be simulated with mass loading at the tip of the beam. The entire experimental setup can be seen in Figure 7.

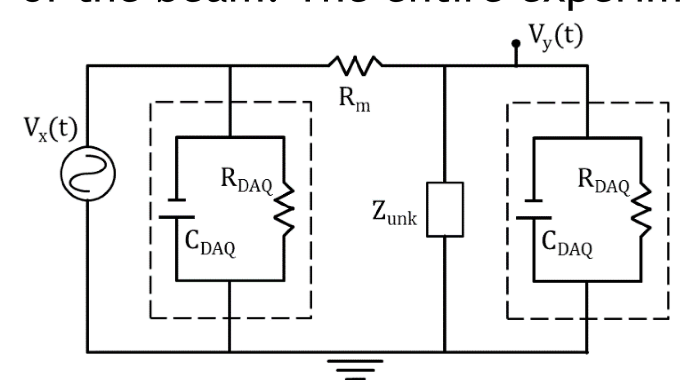

Figure 6: Auxiliary measurement circuit

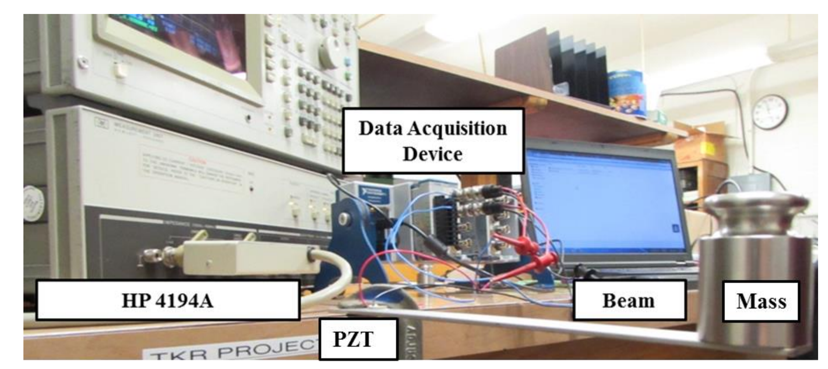

Figure 7: Experimental setup

Results: Validation of Measurement Technique

To validate the proposed measurement technique, the impedance of a 99 Ω resistor was measured and compared with it's theoretical value which is shown in Figure 8. Additionally, the impedance of a parallel RLC circuit was also measured because it has a single impedance resonance peak which is similar to those of a PZT. The RLC was measured with the proposed technique and compared with the results from the HP 4194A impedance analyzer and these results are shown in Figure 9.

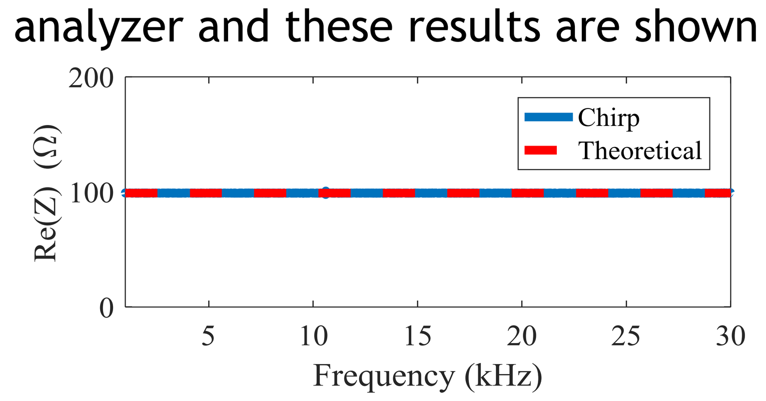

Figure 8: Impedance of a 99 Ω resistor

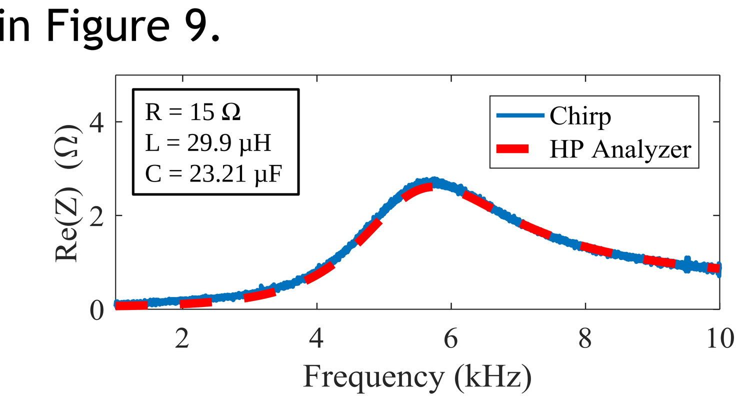

Figure 9: Impedance of a parallel RLC circuit

Results: Beam Measurements

The impedance of a steel cantilever beam (Figure 7) was measured using both the alternative technique and the HP 4194A, both in an undamaged state and with mass loading, which is shown in Figures 10 and 11. Initial testing showed that the frequency range of 24-29 kHz was the most sensitive to the mass loading condition.

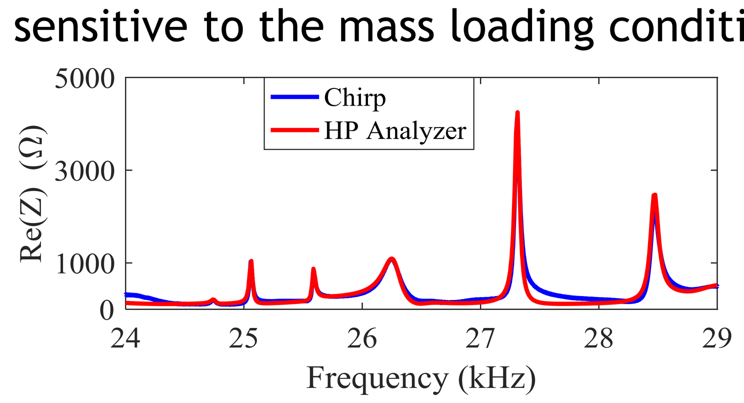

Figure 10: Impedance of the undamaged beam

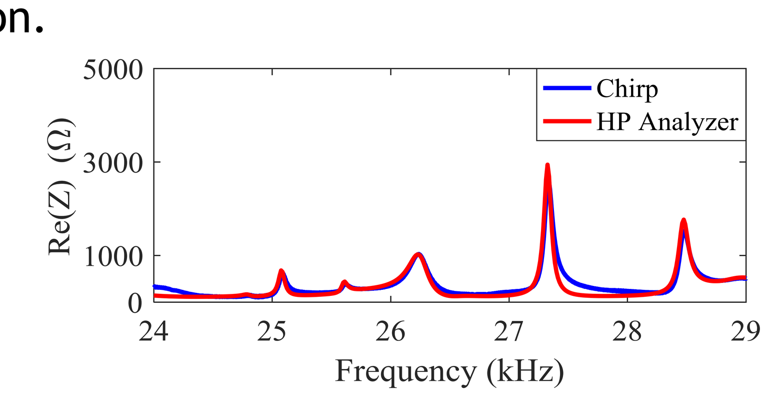

Figure 11: Impedance of the damaged beam

Results: Multi-tonal Measurements

A multi-tonal excitation was produced by adding two separate, narrow-band chirp signals, creating one combined signal. These chirp signals were targeted around the impedance peaks located at 27.3 kHz and 28.5 kHz since they showed the greatest sensitivity to mass loading. Figure 12 shows the results in the damage and undamaged case and Figure 13 compares the multi-tonal result to the other measurement methods.

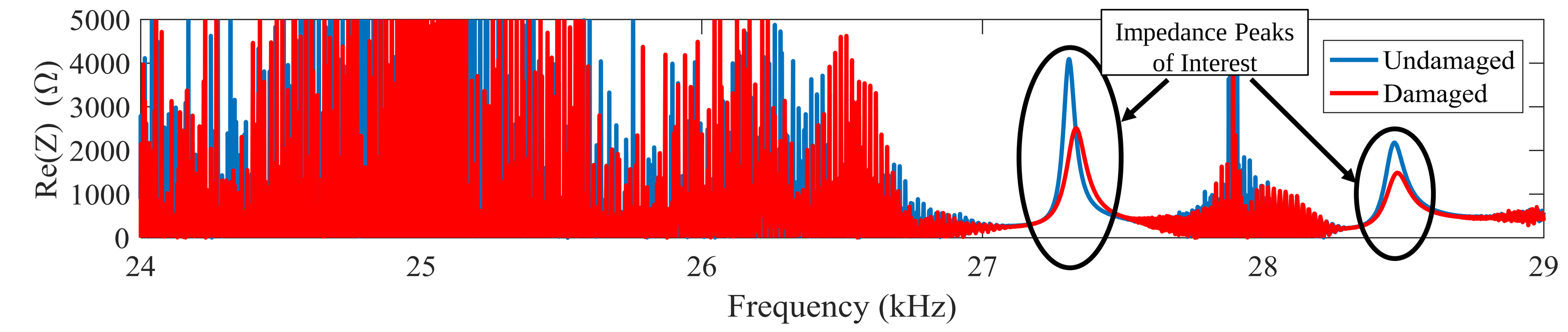

Figure 12: Multi-tonal impedance results across the entire damage sensitive frequency range

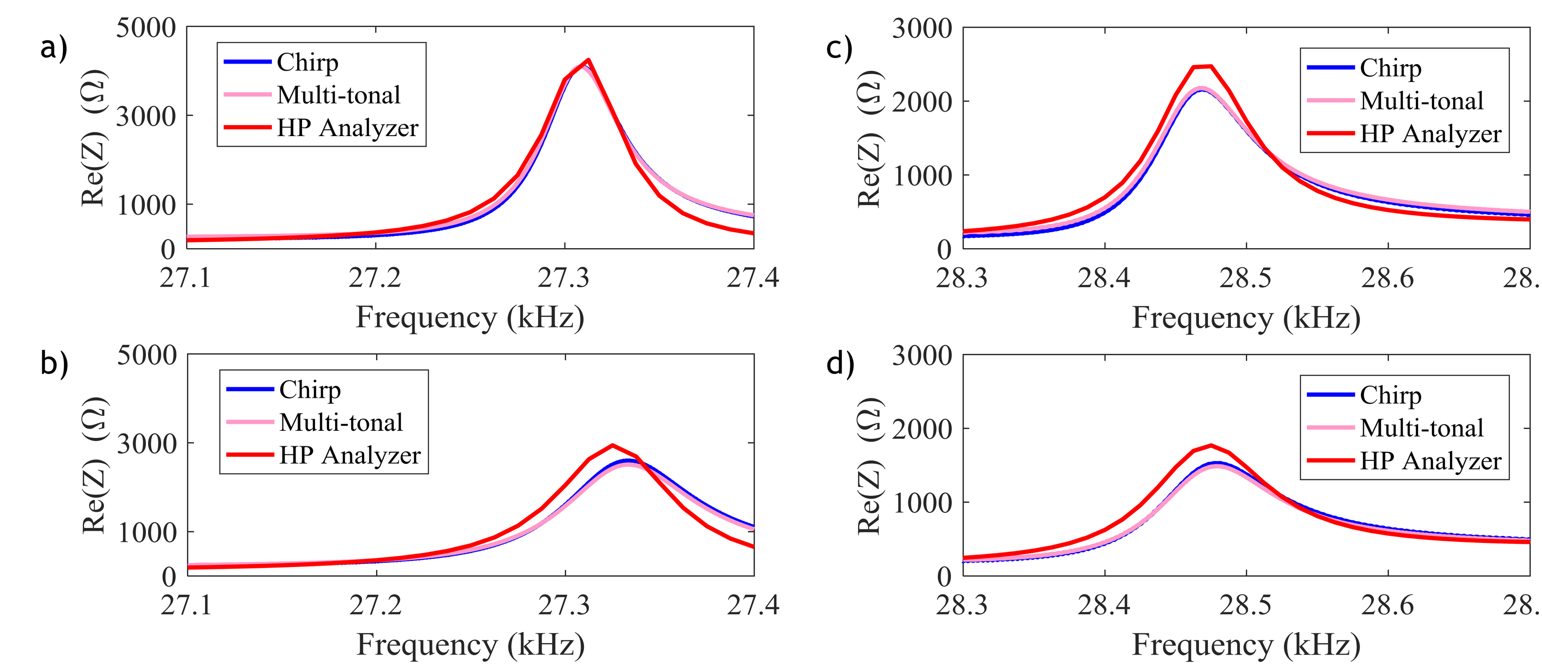

Figure 13: Impedance comparison of beam for chirp signal, multi-tonal signal, and HP 4194A at the impedance peak at 27.3 kHz in a) the undamaged case and b) the damaged case, as well as the impedance peak at 28.5 kHz in c) the undamaged case and d) the damaged case.

Discussion

The results shown in Figures 8 and 9 clearly illustrate the accuracy of the proposed method and thus validate the alternative measurement technique. Figures 10 and 11 show that the accuracy of the alternative measurement technique is comparable to the HP 4194A. It can be seen in Figure 12 that the impedance peak amplitude reductions due to mass loading occur at the targeted frequencies, 27.3 kHz and 28.5 kHz, proving that damage detection is possible with multi-tonal excitation signals. And lastly, Figure 13 shows that all three measurement methods had relatively good agreement with each other.

Conclusions & Future Work

This work presents a condition monitoring system utilizing a DAQ-based alternative impedance measurement system to implement the EMI method using a novel multi-tonal excitation signal. The proposed technique was first validated with simple circuits. Then, the impedance results for damaged and undamaged beams were found using conventional methods and the alternative technique. Finally, the use of a multi-tonal excitation signal was shown to successfully detected damage. Future work for this research includes investigating alternate means of producing fast excitation signals and conducting a timing study to quantitatively prove the time advantage of the multi-tonal approach.

References

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Acknowledgements

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