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Analysis of Piezoelectric Diaphragms in Impedance-Based Damage Detection in Large Structures

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Summary

- Introduction;
- The Electromechanical Impedance Technique and Piezoelectric Sensors;
- Experimental Setup;
- Results and Discussion;
- Conclusions;
- Acknowledgments.

Introduction

- Structural Health Monitoring (SHM);
- Use of low-cost piezoelectric transducers;
- Non-Destructive Techniques applied to the monitoring of structures;
- Simple application in the diagnosis of failures.

Introduction

- The objective is to verify the viability of the low cost piezoelectric transducer 7BB20-6 of Murata Manufacturing (Murata®) for the detection of damages in large structures;

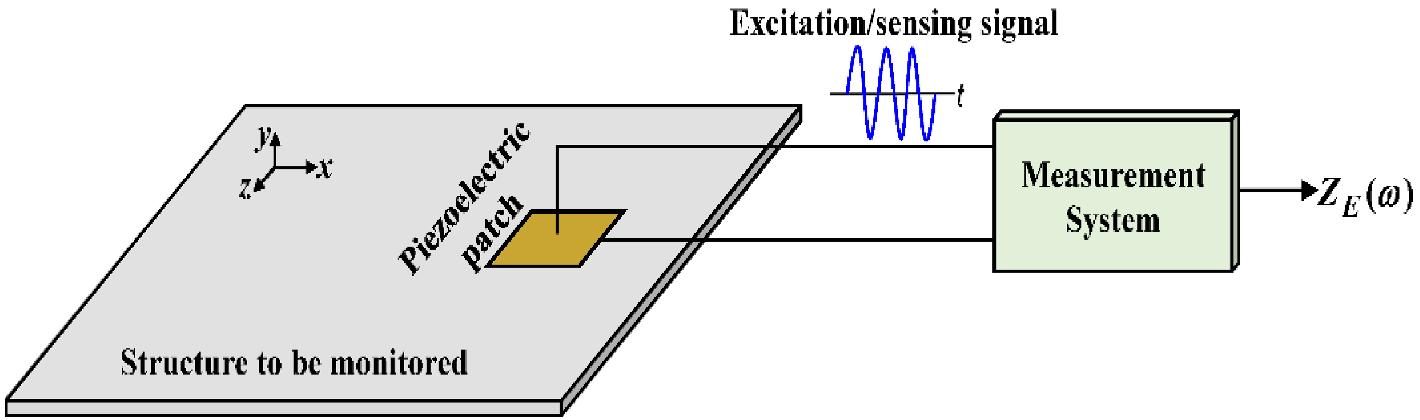
- Based on the electromechanical impedance technique.

The Electromechanical Impedance Technique and Piezoelectric Sensors

- The electromechanical impedance technique is based on the piezoelectric effect;
- An electromechanical coupling is established between the structure and the transducer installed in the structure.

The Electromechanical Impedance Technique and Piezoelectric Sensors

- In this method, a piezoelectric diaphragm functions both as an actuator (reverse piezoelectric effect) and as a sensor (direct effect).



The Electromechanical Impedance Technique and Piezoelectric Sensors

- Establishes the relationship between the mechanical impedance of the structure ($Z_S(\omega)$) and the electrical impedance of the transducer ($Z_E(\omega)$).

$$Z_E(\omega) = \frac{1}{j\omega\tau}\left(\varepsilon_{33}^{T} - \frac{Z_S(\omega)}{Z_S(\omega) + Z_P(\omega)} d_{3x}^{2} \hat{Y}_{xx}^{E}\right)^{-1}$$

The Electromechanical Impedance Technique and Piezoelectric Sensors

- The identification, classification and quantification of the degree of damage is performed through statistical indices comparing two signatures of electrical impedance;

- The whole structure (baseline) and the possible damage condition.

The Electromechanical Impedance Technique and Piezoelectric Sensors

❖ The most used indexes in the literature is the RMSD (root mean square deviation), which is based on the Euclidean norm.

$$RMSD = \sum_{n}^{N} \sqrt{\frac{\left(Z_{n,d} - Z_{n,h}\right)^2}{{Z_{n,h}}^2}}$$

The Electromechanical Impedance Technique and Piezoelectric Sensors

- The relationship between the size of the structure and the transducer may interfere with the sensitivity to damage;

- Thus, it is feasible to study the sensitivity of the piezoelectric transducer for the diagnosis of failures in large structures.

Experimental Setup

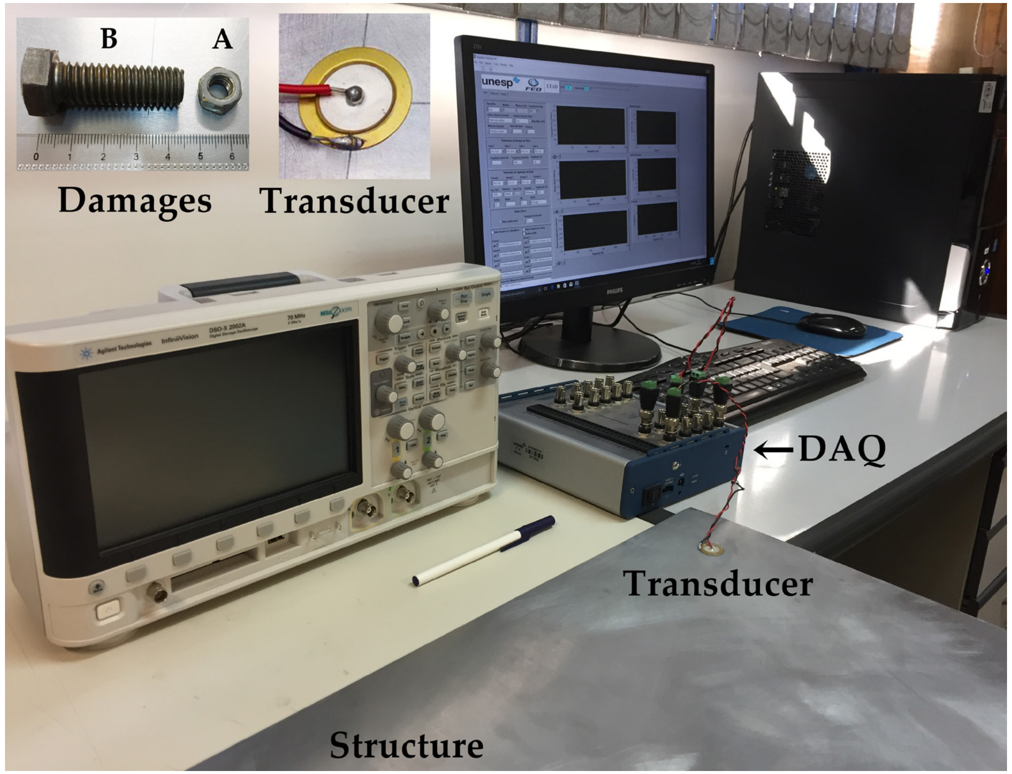
- ❖ An aluminum plate with dimensions of 2000 mm x 1000 mm x 2 mm;
- ❖ A transducer with an active piezoelectric element with a diameter of 14 mm and installed by means of a cyanoacrylate based glue;
- ❖ The damage was simulated by the addition of two metallic masses of 0.005 kg (Damage A) and 0.04 kg (Damage B).

Experimental Setup

- The two masses were coupled at 0.5 m from the sensor;
- Subsequently, the same damages were inserted at 1.5 m from the sensor in order to analyze the sensitivity of the sensor at a distance from the damage;
- The impedance measurement system used was an NI-USB-6366 multifunctional data acquisition device (DAQ) by National Instruments.

Experimental Setup

- A personal computer with LabVIEW software to electrical impedance measurement;
- A chirp signal of 1 V amplitude to excite the transducers;
- The signals were sampled at a rate of 2MS/s;
- And the impedance signatures were obtained in a frequency range between 0 and 500 kHz with step of 2 Hz.

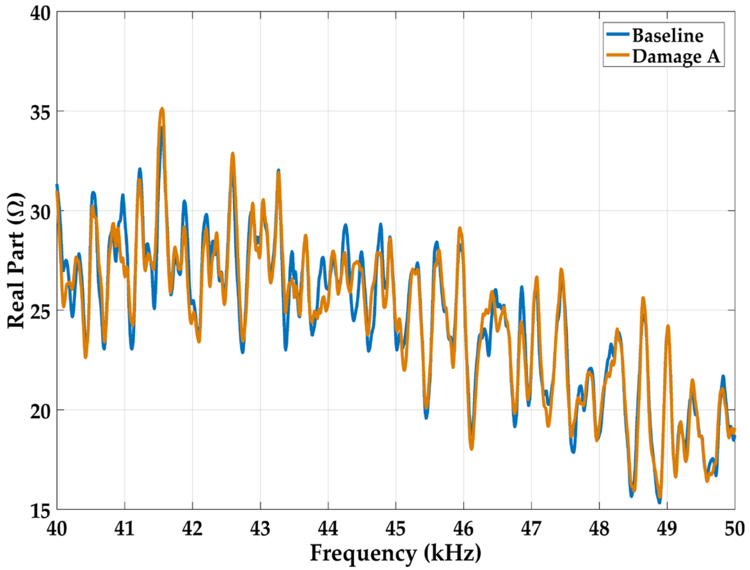


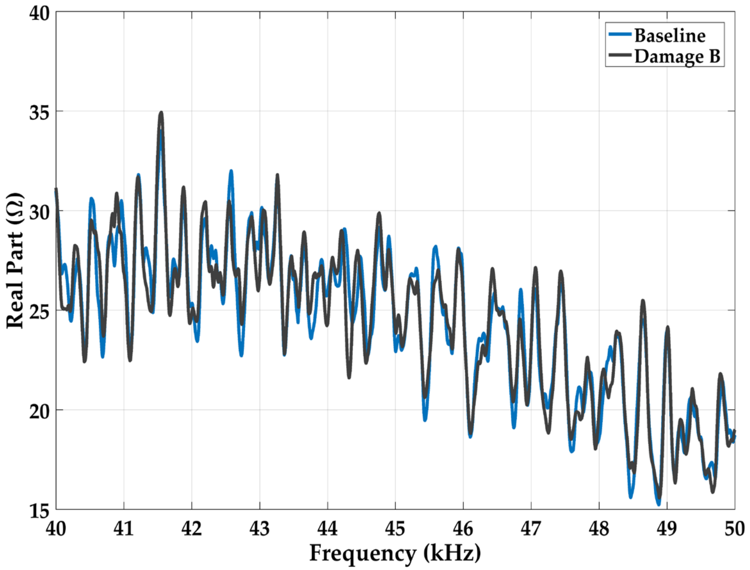
Results and Discussion

- The damages altered the electrical impedance signature in relation to the baseline;
- The actual part of the impedance curves for the 40 to 50 kHz frequency range for "A" and "B“.

Results and Discussion

❖ Impedance curves for damage A (a) and B (b) at 0.5 m from the transducer.

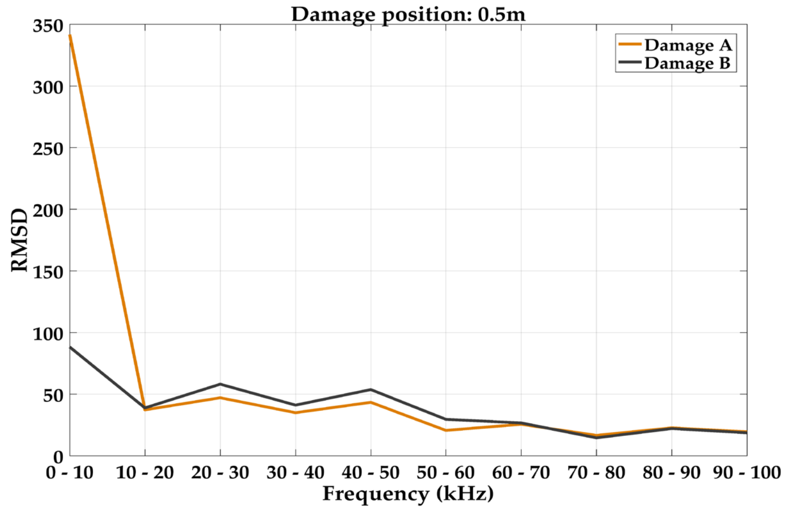




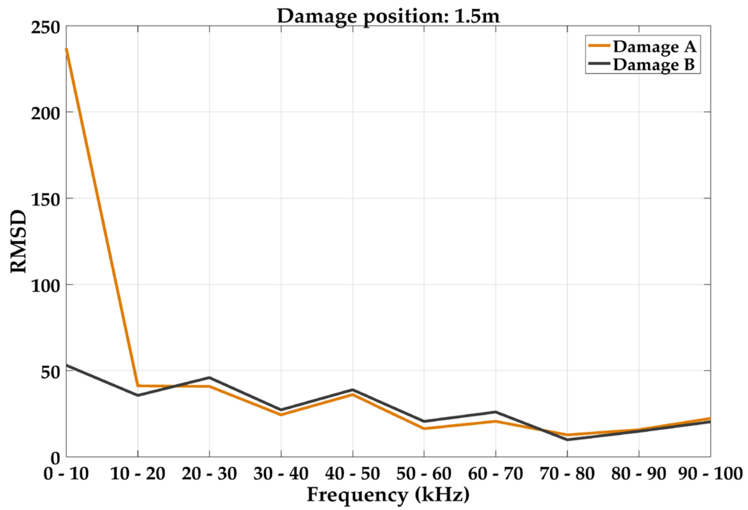
Results and Discussion

- The selection of the frequency range occurred in the band by which the index presented the most expressive values (10kH);
- RMSD index for the 0.5 m (a) and 1.5 m (b) positions relative to the transducer.

a)



b)

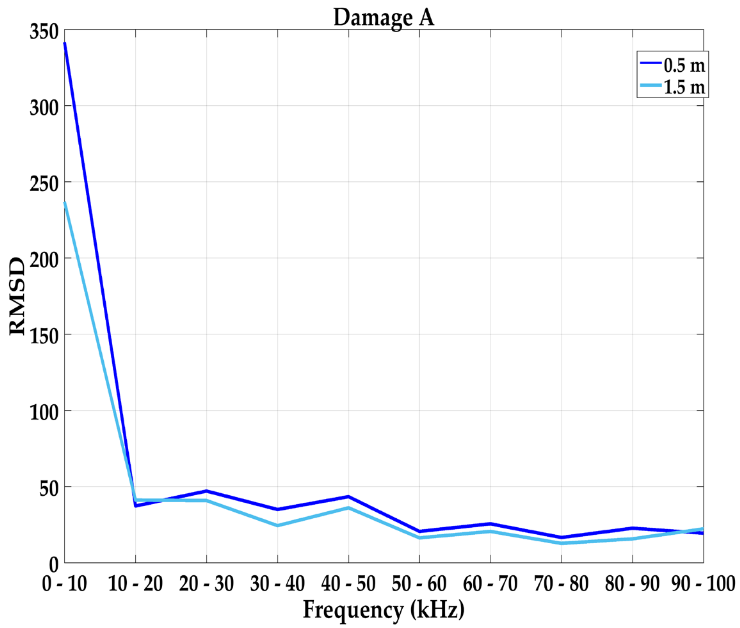


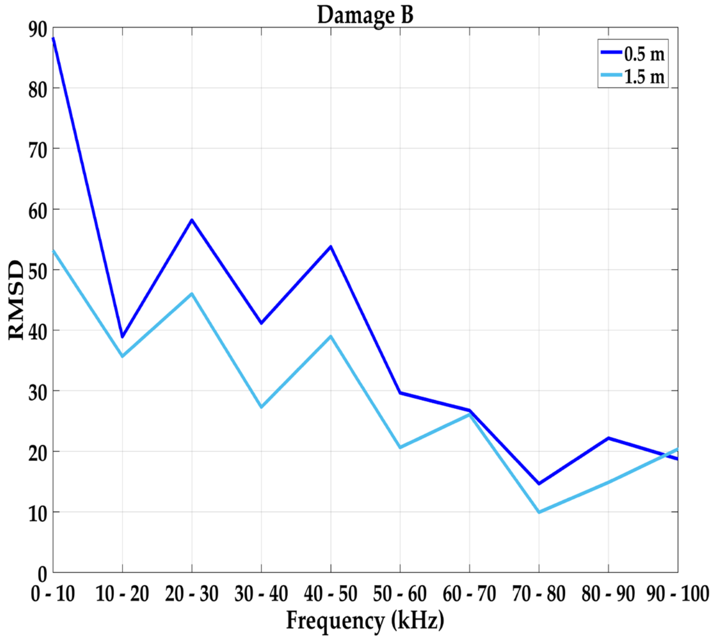
Results and Discussion

- For both positions, the RMSD presented a similar behavior, that is, for the bands of up to 20 kHz the minor damage (A) presented higher indices than the indices generated by the impedance curves of the major damage (B);
- From 20 kHz to 100 kHz the RMSD index increased with the increase of the degree of structural damage, allowing the classification of the damage;
- Therefore, for this range, it can be affirmed that this method can be applied in order to monitor the evolution of the size of the damage in large structures;
- For bands above 100 kHz the method was not effective in the classification of the damage, that is, the index did not increase with the size of the breakdown.

Results and Discussion

❖ Analysis of the sensitivity of the method at a distance from the damage to the sensor for damage at 0.5 m and 1.5 m of the transducer.





Results and Discussion

- The RMSD decreased with the distance for both damages to the band of up to 100 kHz;

- For frequencies above 100 kHz it was not possible to establish the decay relationship of the index with the distance of the transducer.

Conclusions

- This work presented a feasibility study of a low cost piezoelectric transducer in the diagnosis of failures in large structures based on the electromechanical impedance technique;
- Based on the obtained results, it was verified that its values are proportional both to the distance of the damage to the sensor, and to the size of the damage.

Conclusions

- The RMSD index proved to be effective in characterizing both the size and the distance of the damage to the sensor;

- The piezoelectric transducers type 7BB20-6 can be a low-cost alternative for the correct monitoring and diagnosis of failures in large structures.

Acknowledgments

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Acknowledgments

Thank you!

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