Signal Acquisition from Piezoelectric Transducers for Impedance-Based Damage Detection

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Outline

- Structural Health Monitoring (SHM)
- Electromechanical Impedance (EMI) Method
- Damage Detection
- Measurement Systems
- Piezoelectric Transducers
- Experimental Setup
- Results
- Conclusions

Structural Health Monitoring (SHM)

- Monitor the presence of structural damage;
- Applications: airplanes, pipelines, dams, bridges, among others.

Structural Health Monitoring (SHM)

Damages

- Cracks;
- Corrosions;
- Fatigue;
- Delaminations.

Structural Health Monitoring (SHM)

BENEFITS

- IMPROVED SAFETY
- REDUCTION OF MAINTENANCE COSTS
- INCREASED LIFETIME

Structural Health Monitoring (SHM)

There are several non-invasive techniques, known as Non-Destructive Testing (NDT), suitable for SHM systems applications:

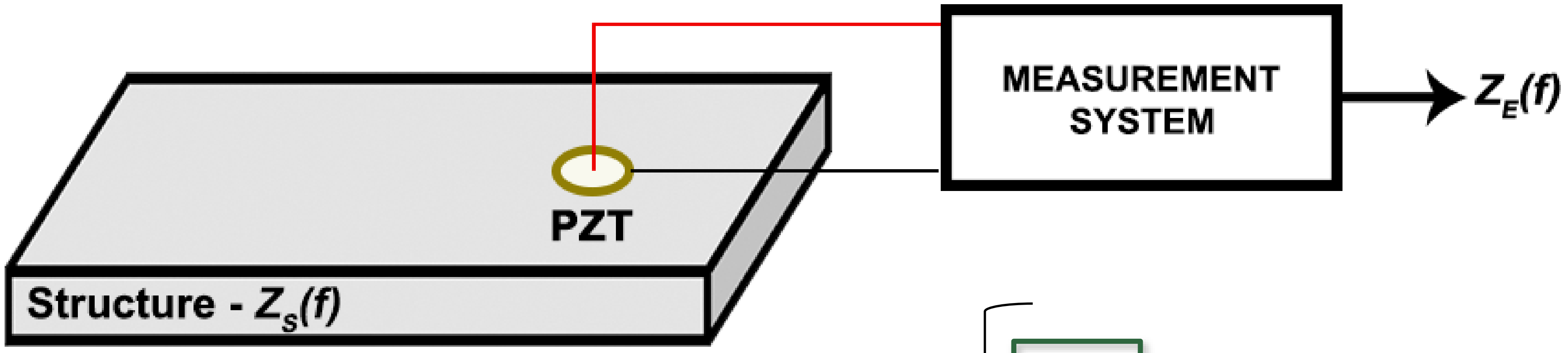
- Acoustic Emission;
- Comparative Vacuum;
- Eddy current;
- Lamb waves;
- **Electromechanical Impedance (EMI).**

Electromechanical Impedance (EMI) Method

The Electromechanical Impedance (EMI) method stands out from the other techniques for its simple methodology and the use of small and low-cost piezoelectric transducers.

Electromechanical Impedance (EMI) Method

Principle



$$\boxed{Z_E(f)} = \frac{1}{j2\pi fC}\left(1 - \frac{d_{31}^2}{s_{11}^E \varepsilon_{33}^T}\frac{\boxed{Z_S(f)}}{\boxed{Z_S(f)} + Z_P(f)}\right)^{-1}$$

- $\boxed{Z_E(f)}$ - Electrical impedance of the piezoelectric transducer
- $\boxed{Z_S(f)}$ - Mechanical impedance of the monitored structure

Damage Detection

Damage Indices

- The damage indices are calculated using two electrical impedance signatures (module, real part or imaginary part) of the piezoelectric transducer: one referring to the structure without damage (*baseline*) and the other referring to the structure in a possible damaged condition;
- For this work, the index used for the characterization of damage is the correlation coefficient deviation metric (CCDM), that was calculated using the real part of the electrical impedance.

Damage Detection

Correlation Coefficient Deviation Metric (CCDM)

$$CCDM = 1 - \frac{\sum_{k=f_I}^{f_F} \boxed{\left[Z_{E,H}(k) - \bar{Z}_{E,H}\right]} \boxed{\left[Z_{E,D}(k) - \bar{Z}_{E,D}\right]}}{\sqrt{\sum_{k=f_I}^{f_F} \boxed{\left[Z_{E,H}(k) - \bar{Z}_{E,H}\right]^2}} \sqrt{\sum_{k=f_I}^{f_F} \boxed{\left[Z_{E,D}(k) - \bar{Z}_{E,D}\right]^2}}}$$

Structure Condition

- Healthy Condition
- Damaged Condition

Measurement Systems

- Since the detection and quantization of damages are performed by comparing two electrical impedance signatures, it is essential that the measurement system be of high precision to enable the correct diagnosis of the monitored structure;

- Thus, two measurement systems that use different methods of signal acquisition of the piezoelectric transducers are compared in this work in terms of precision of the measurements and sensibility to the presence of damage. The main difference between these systems is the type of excitation signal.

Measurement Systems

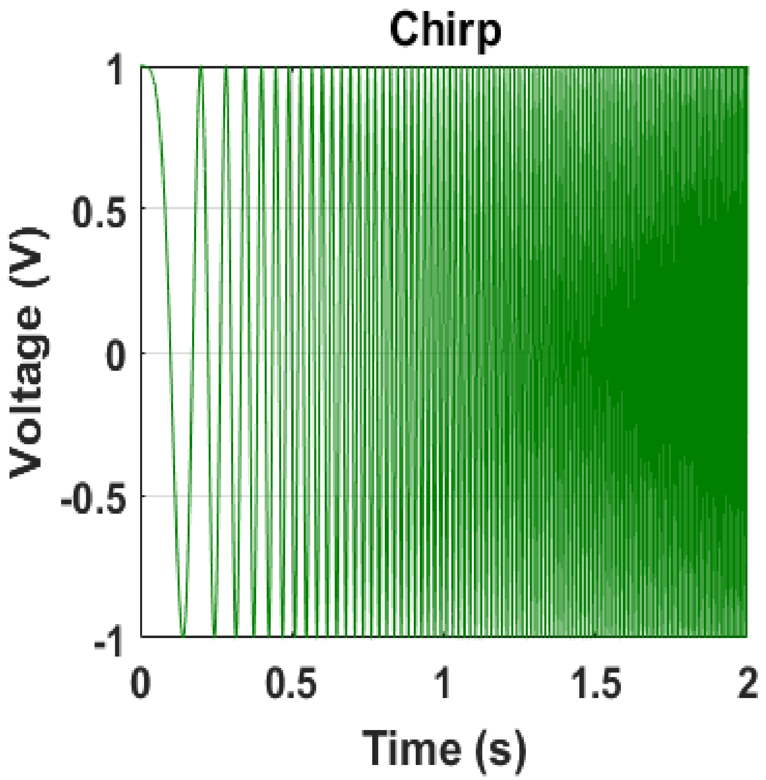
Excitation Signals

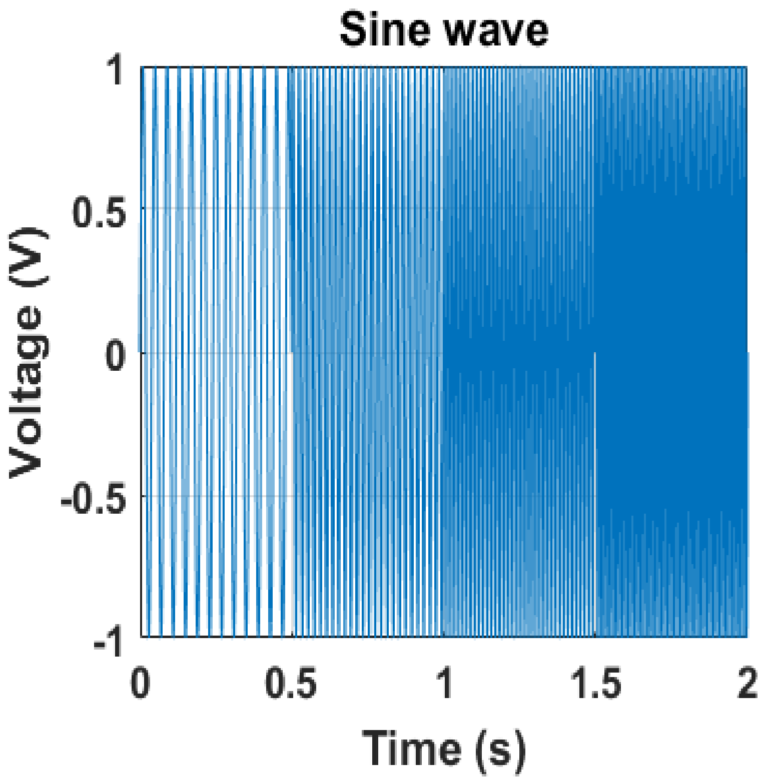
- ***Chirp dynamic signal***

A single signal containing all the frequencies desired for analysis;

- ***Sine wave signals***

Composed of various sinusoidal signals to encompass all the frequencies desired for analysis

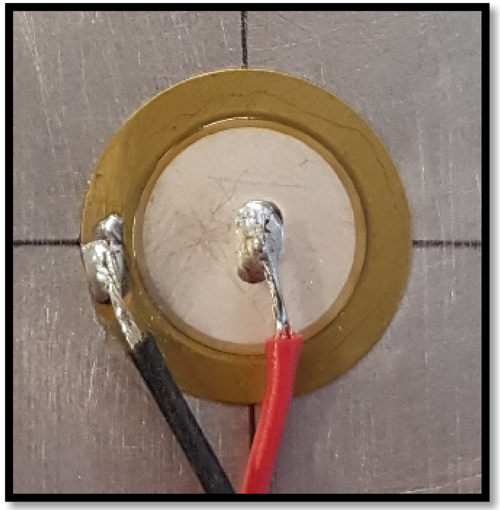




Piezoelectric Transducers

Piezoelectric Diaphragm – “Buzzer”

7BB-20-6



Manufactured by
Murata Manufacturing

Dimensions

- ***Active element***

Diameter: 14 mm;
Thickness: 0.22 mm.

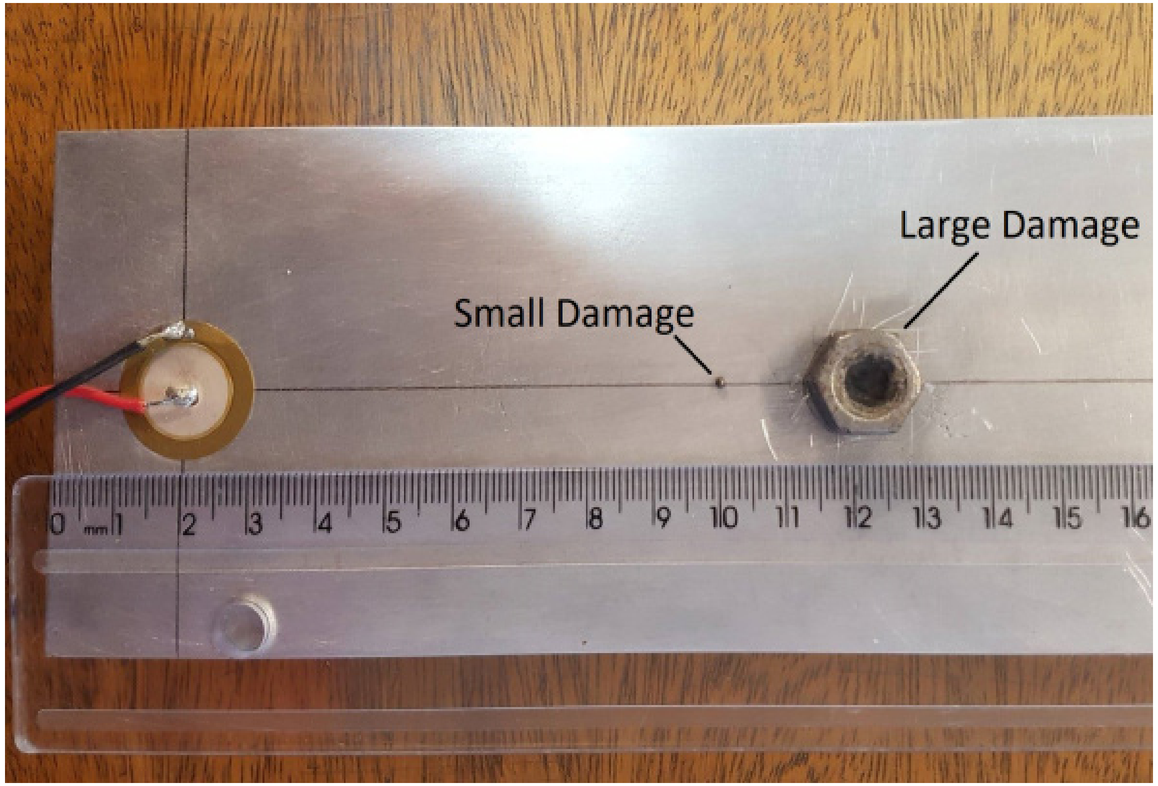
- ***Brass plate***

Diameter: 20 mm;
Thickness: 0.20 mm.

Experimental Setup

Materials

- DAQ NI-USB-6361;
- Aluminum bar of 790 mm x 75 mm x 3 mm;
- Piezoelectric diaphragm 7BB-20-6 type;
- Steel nut of 8 mm x 14 mm (Large Damage);
- Steel sphere of 1 mm in diameter (Small Damage).



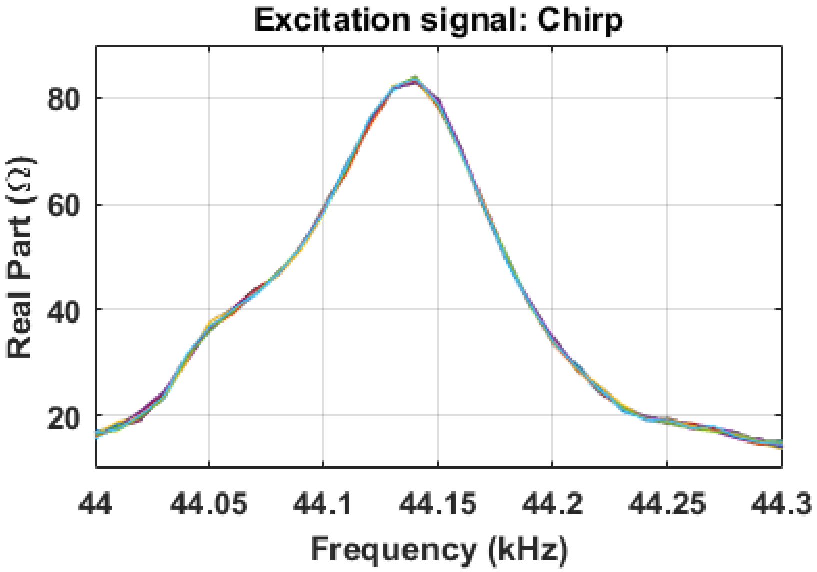
Experiments

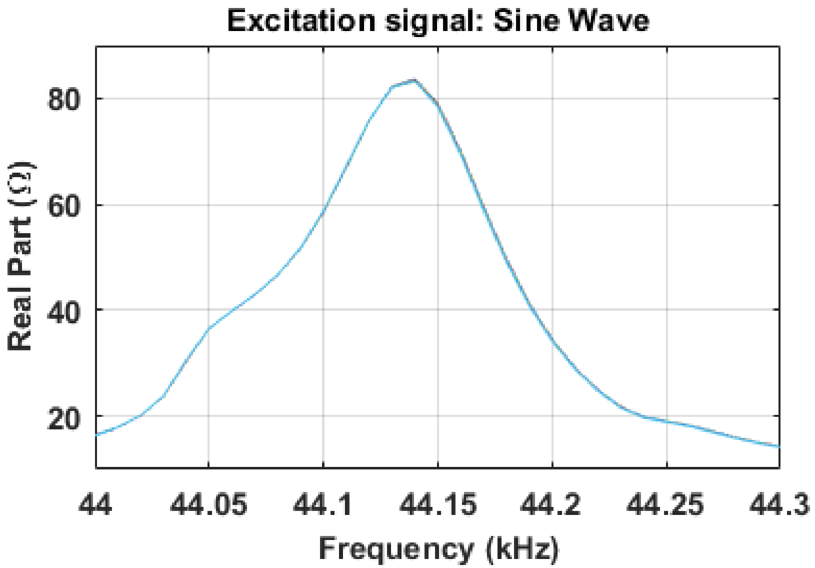
- **Experiment 1:** Evaluate repeatability and precision of the measurements of each system;
- **Experiment 2:** Evaluate the sensitivity of each system to detect different damages.

Results

Experiment 1

Twenty measurements with each measuring system around a resonant peak of the monitored bar, between 44 kHz and 44.3 kHz.

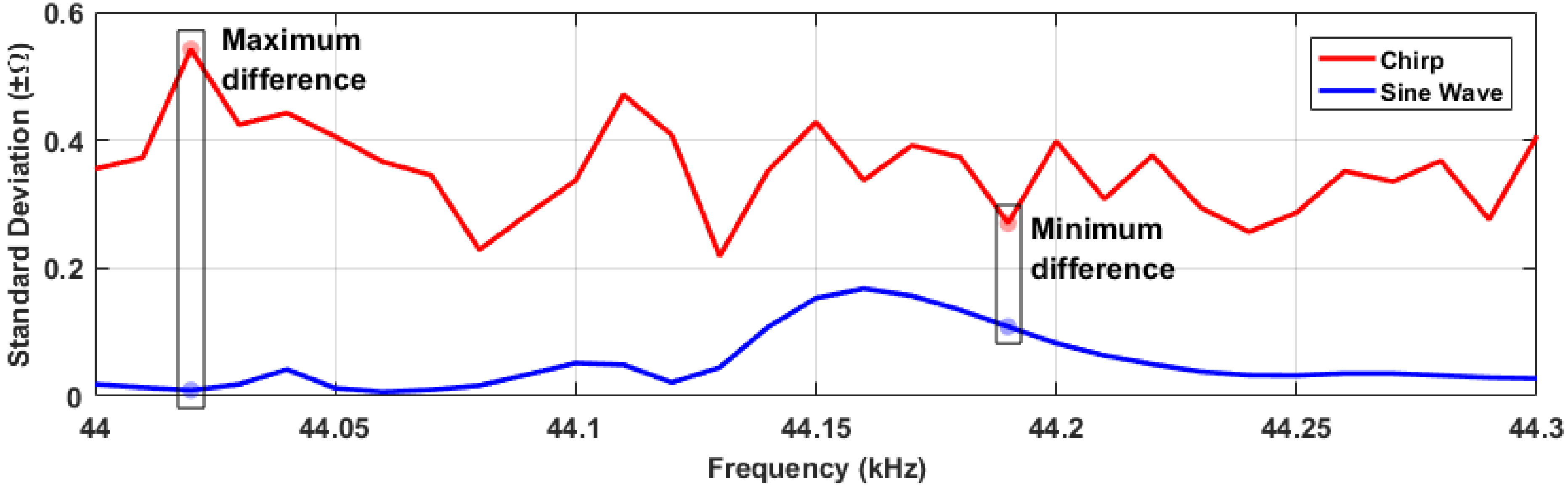




Results

Experiment 1

Standard deviation, point-to-point, of the twenty measurements taken with the two measurement systems.



Results

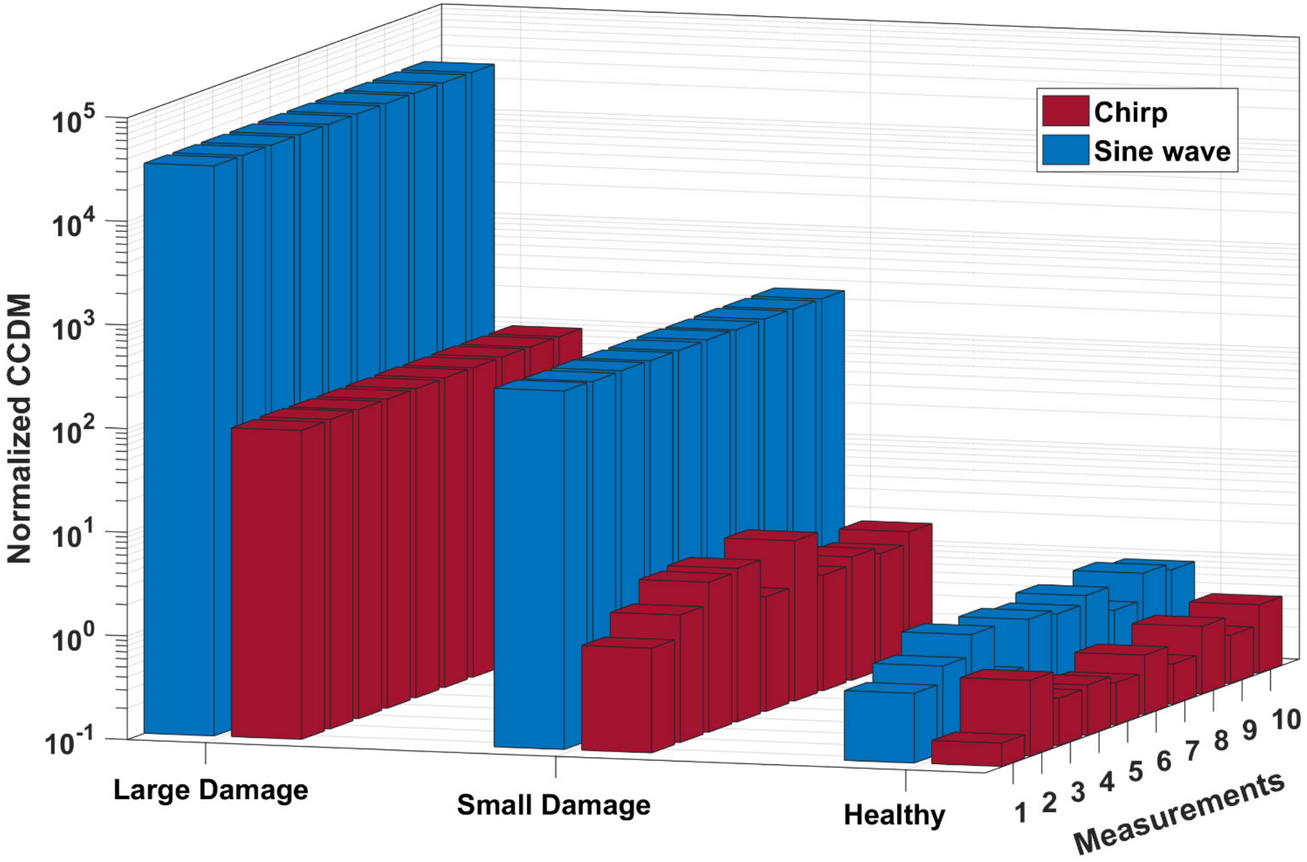
Experiment 1

- The method with sine wave excitation signals presented better precision than the chirp type excitation signal method for all points analyzed;
- The largest difference between the standard deviations of the systems occurred at the frequency of 44020 Hz, with the deviation of the system with chirp signal being 58.34 times greater than the deviation of the system with sine wave signals;
- The smallest difference between the standard deviations was in the frequency of 44190 Hz, being the deviation of the system with chirp signal 2.49 times greater than that of the sine wave system

Results

Experiment 2

Normalized CCDM indices calculated for a sub-band of 10 kHz, between 40 kHz and 50 kHz, with the bar undamaged and with the two different damages for the two measurement systems.



Results

Experiment 2

- The precision of the two methods can be further compared by analyzing the indices obtained for the healthy structure. Since the data were normalized, the indices were expected to be unit value.
- Regardless the damage size, the method with sine wave signals is more sensitive to damage than the system with chirp signal;

Conclusions

- Both acquisition methods are able to detect damage and, therefore, are suitable for impedance-based SHM applications;

- The method using sine waves showed higher precision and sensitivity to the presence of damage in the monitored structure;

- These results should be considered in the development of SHM systems, since a more precise and sensitive method can detect incipient structural damage and avoid false-positive diagnoses.

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Thank you!

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