Experimental Analysis of Piezoelectric Transducers for Impedance-Based Structural Health Monitoring

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Outline

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

Structural Health Monitoring (SHM)

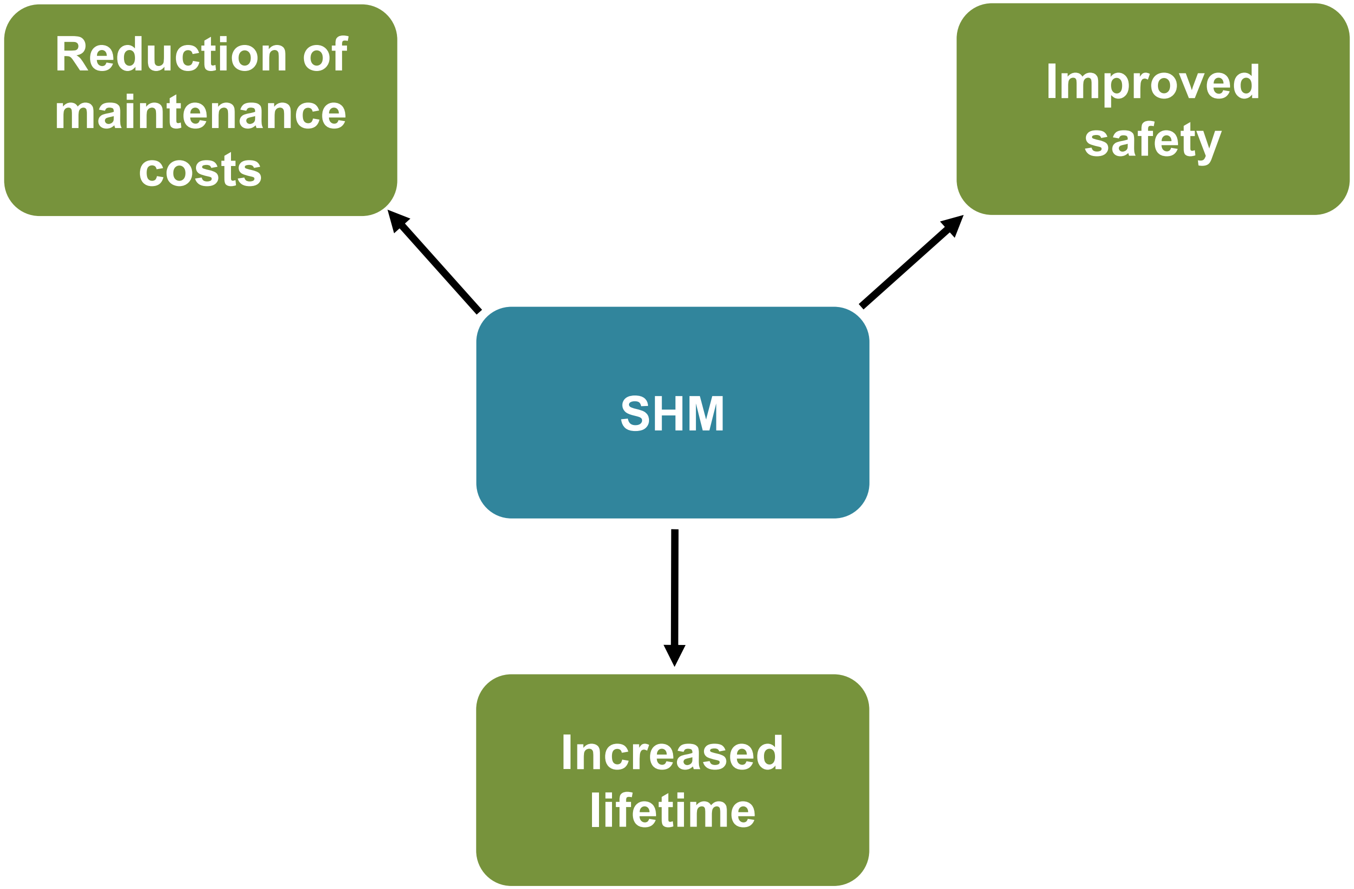
Objective: monitoring and detection of structural damage

Application: various types of structures

Wikipedia/Wikimedia

Structural Health Monitoring (SHM)

Benefits



Electromechanical Impedance (EMI) Method

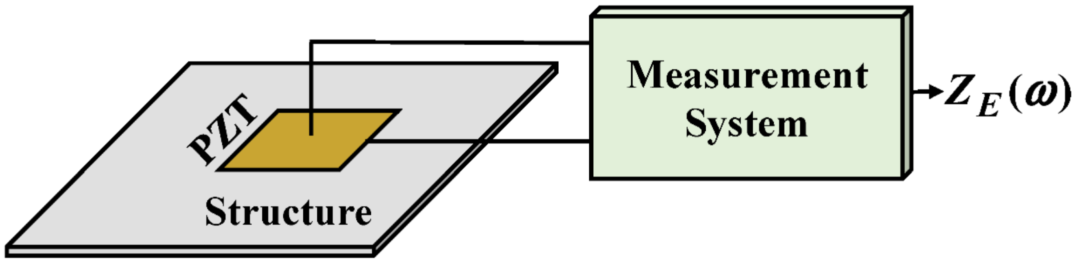
Damage detection

- Acoustic Emission
- Comparative vacuum
- Eddy current
- Lamb waves
- Electromechanical impedance (EMI)

The electromechanical impedance (EMI) method stands out from the other methods by its simplicity and by using low-cost, lightweight and small piezoelectric transducers

Electromechanical Impedance (EMI) Method

Principle



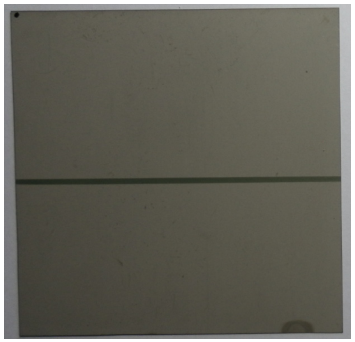
$$Z_E(\omega) = \frac{1}{j\omega C_0} \| jZ_T \left(\frac{s_{11}}{d_{31}\ell}\right)^2 \left[\frac{1}{2}\tan\left(\frac{k\ell}{2}\right) - \frac{1}{\sin(k\ell)} + \frac{Z_S}{j2Z_T}\right]$$

Electrical impedance
Transducer
$Z_E(\omega)$

↔

Mechanical impedance
Structure
Z_S

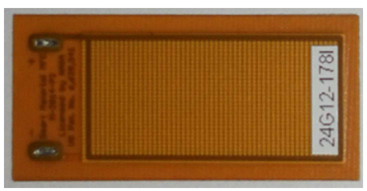
Piezoelectric Transducers



PZT (lead zirconate titanate) piezoceramic

Type: 5H

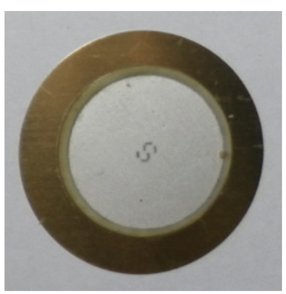
Size: 15 x 15 x 0.267 mm



MFC (macro-fiber composite)

Type: M2814-P2

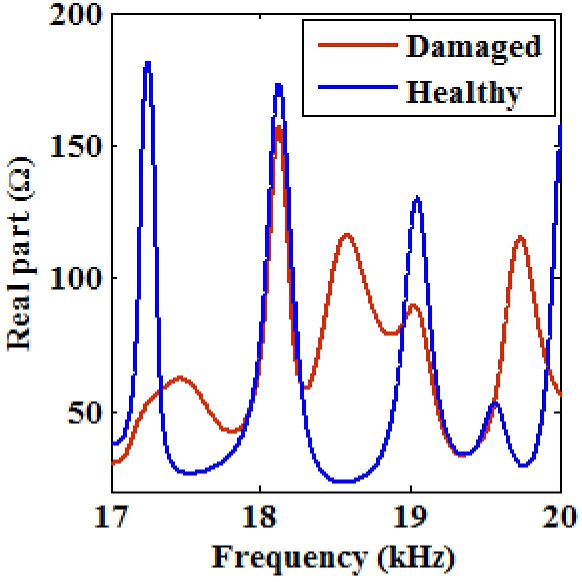
Size: 37 x 18 mm



Piezoelectric diaphragm – “Buzzer”

Size: 27 mm (external diameter)

Damage Detection – Damage Indices



- Comparison of two electrical impedance signatures: healthy condition and damaged condition
- We used the real part of the electrical impedance

RMSD
Root mean square deviation

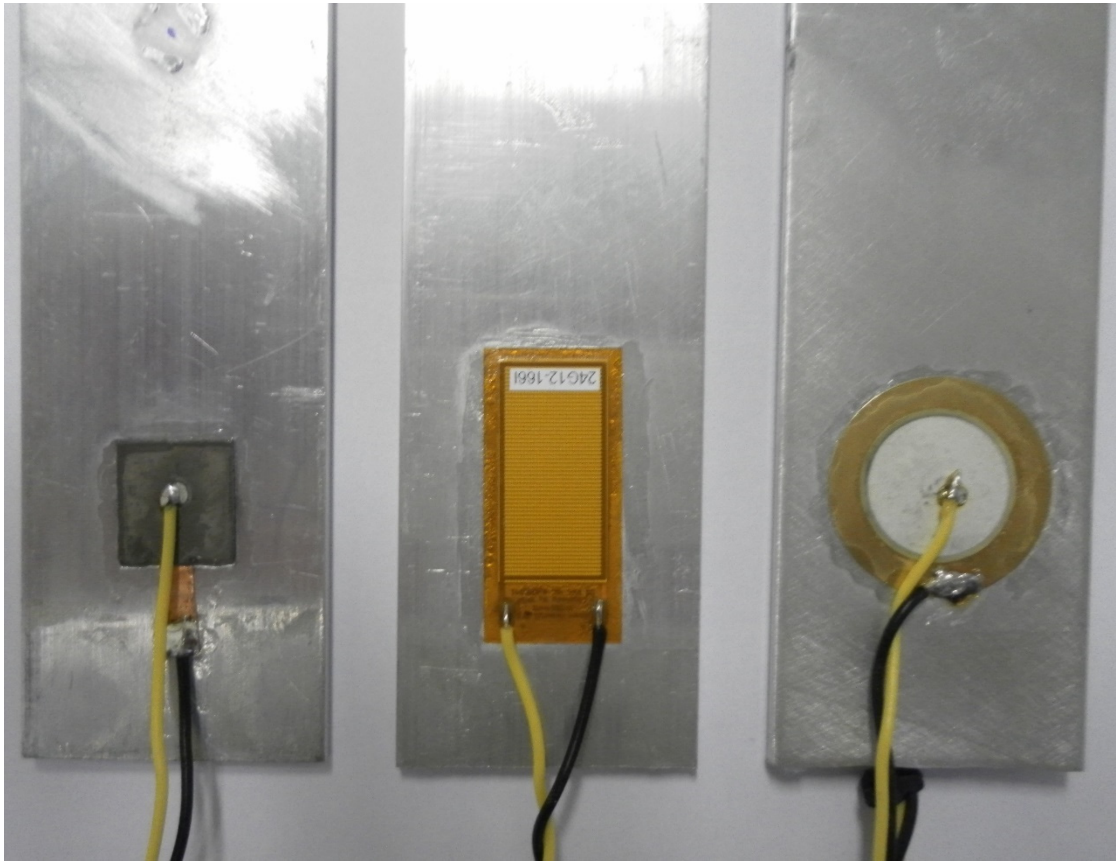
$$RMSD = \sum_{k=\omega_I}^{\omega_F} \sqrt{\frac{\left[Z_{E,D}(k) - Z_{E,H}(k) \right]^2}{Z^2{}_{E,H}(k)}}$$

CCDM
Correlation coefficient deviation metric

$$CCDM = 1 - \frac{\sum_{k=\omega_I}^{\omega_F} \left[Z_{E,H}(k) - \overline{Z}_{E,H} \right] \left[Z_{E,D}(k) - \overline{Z}_{E,D} \right]}{\sqrt{\sum_{k=\omega_I}^{\omega_F} \left[Z_{E,H}(k) - \overline{Z}_{E,H} \right]^2} \sqrt{\sum_{k=\omega_I}^{\omega_F} \left[Z_{E,D}(k) - \overline{Z}_{E,D} \right]^2}}$$

Experimental Setup

Structures



Aluminum beams

500 x 38 x 3 mm

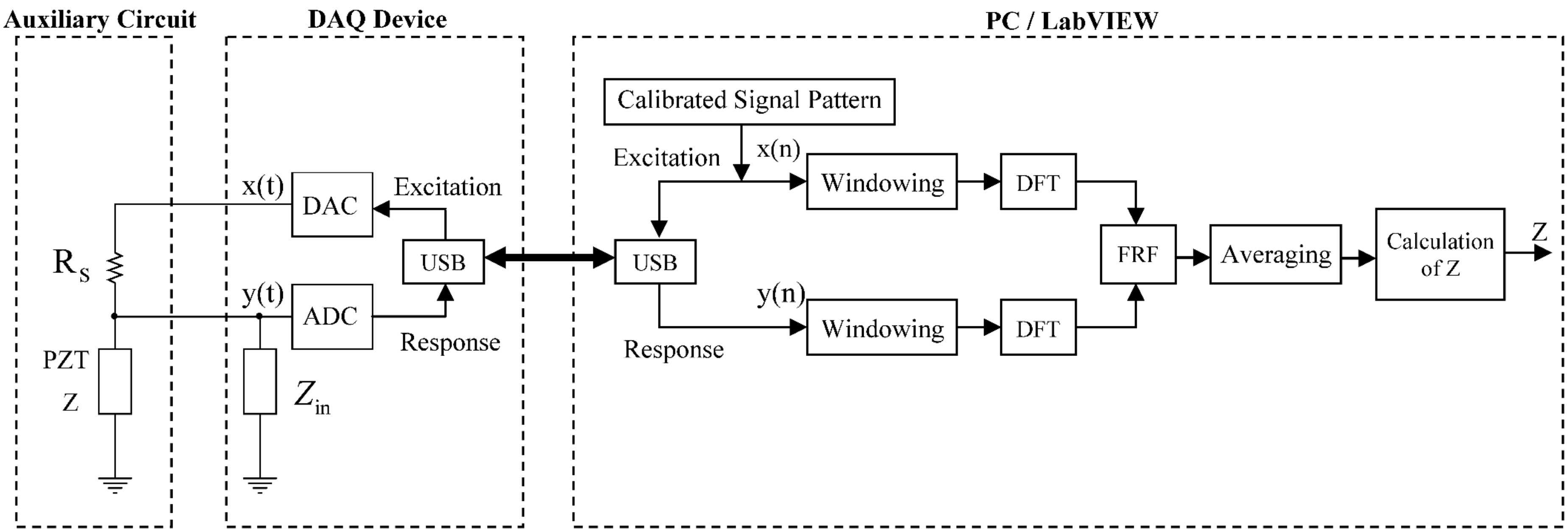
The transducers were placed on the beams using cyanoacrylate glue

Damage was simulated by placing a small steel nut

11 x 0.5 mm, 1 g

Experimental Setup

Measurement System



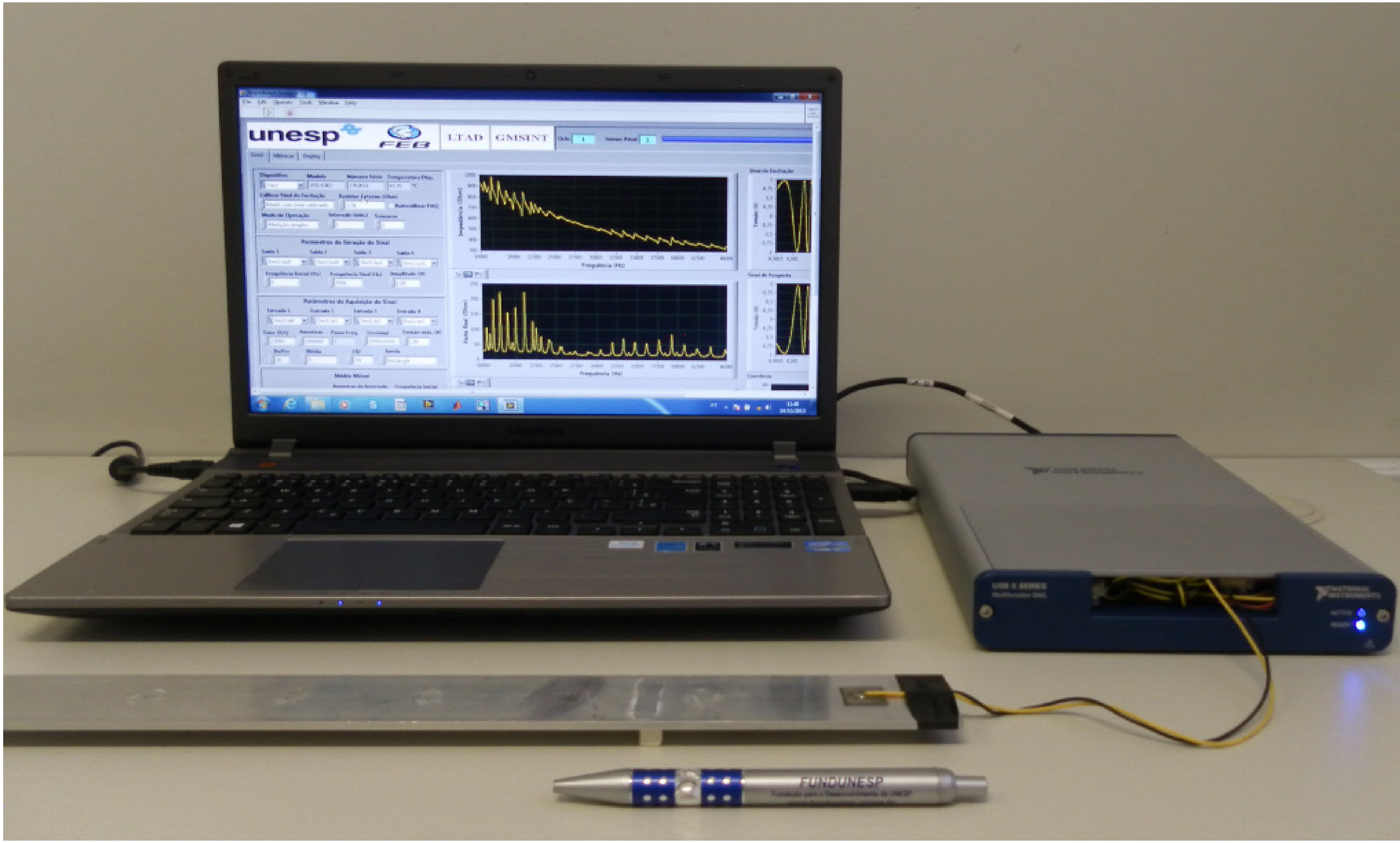
NI USB-6361

ni.com

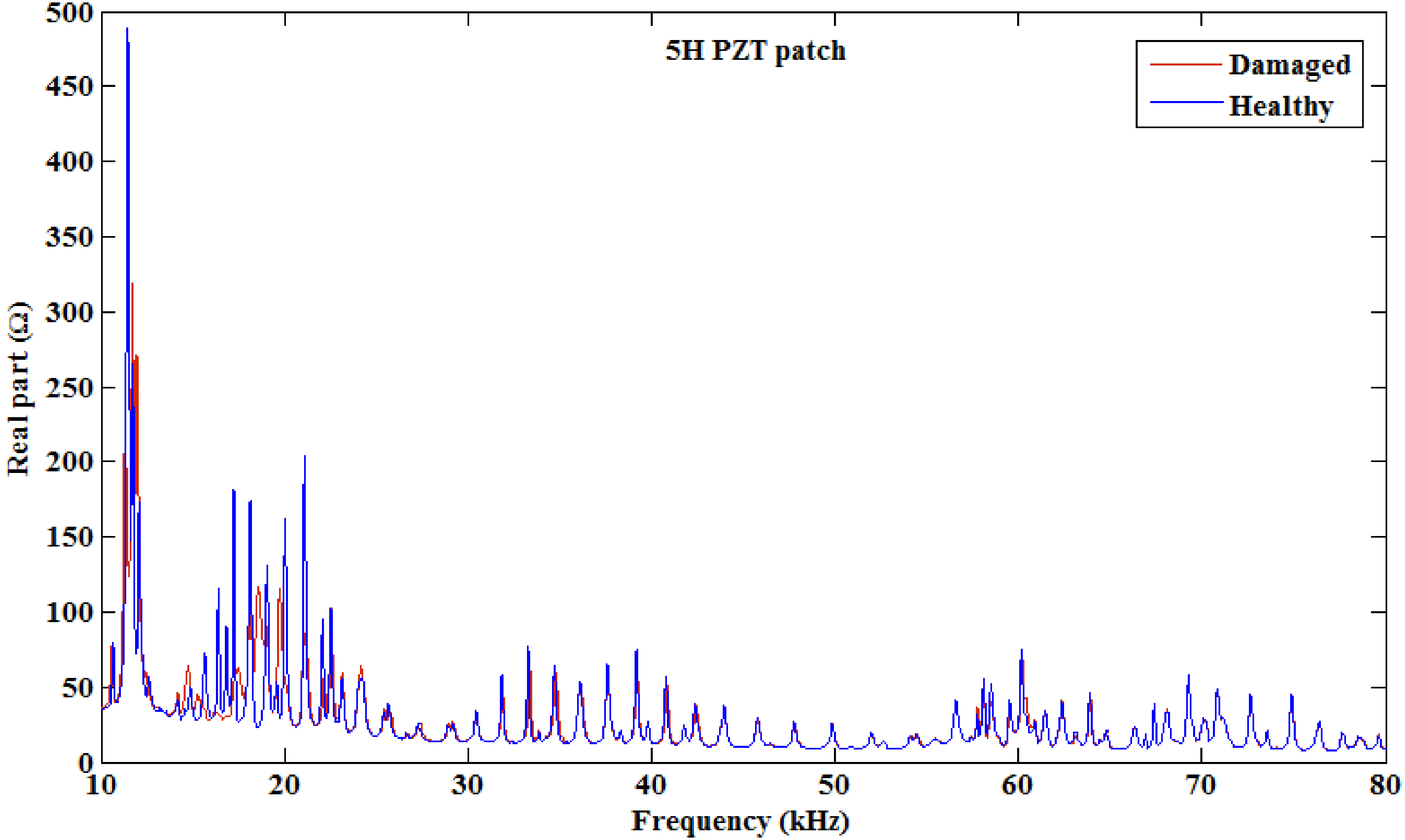
Configuration

- **Sampling rate: 2 MS/s**
- **Excitation voltage: 1 V**
- **Frequency range: 0 – 500 kHz**
- **Frequency step: 2 Hz**

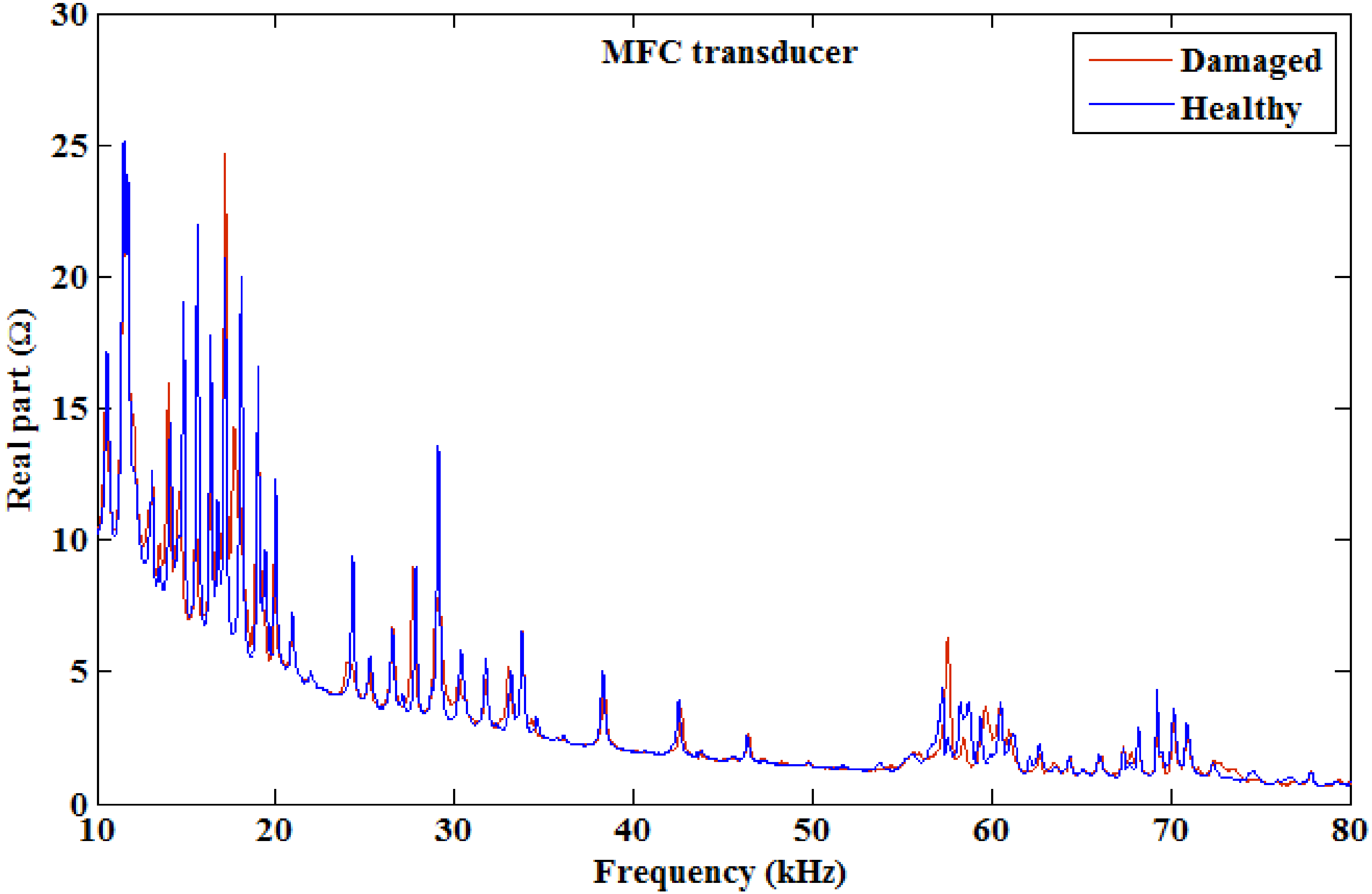
Experimental Setup



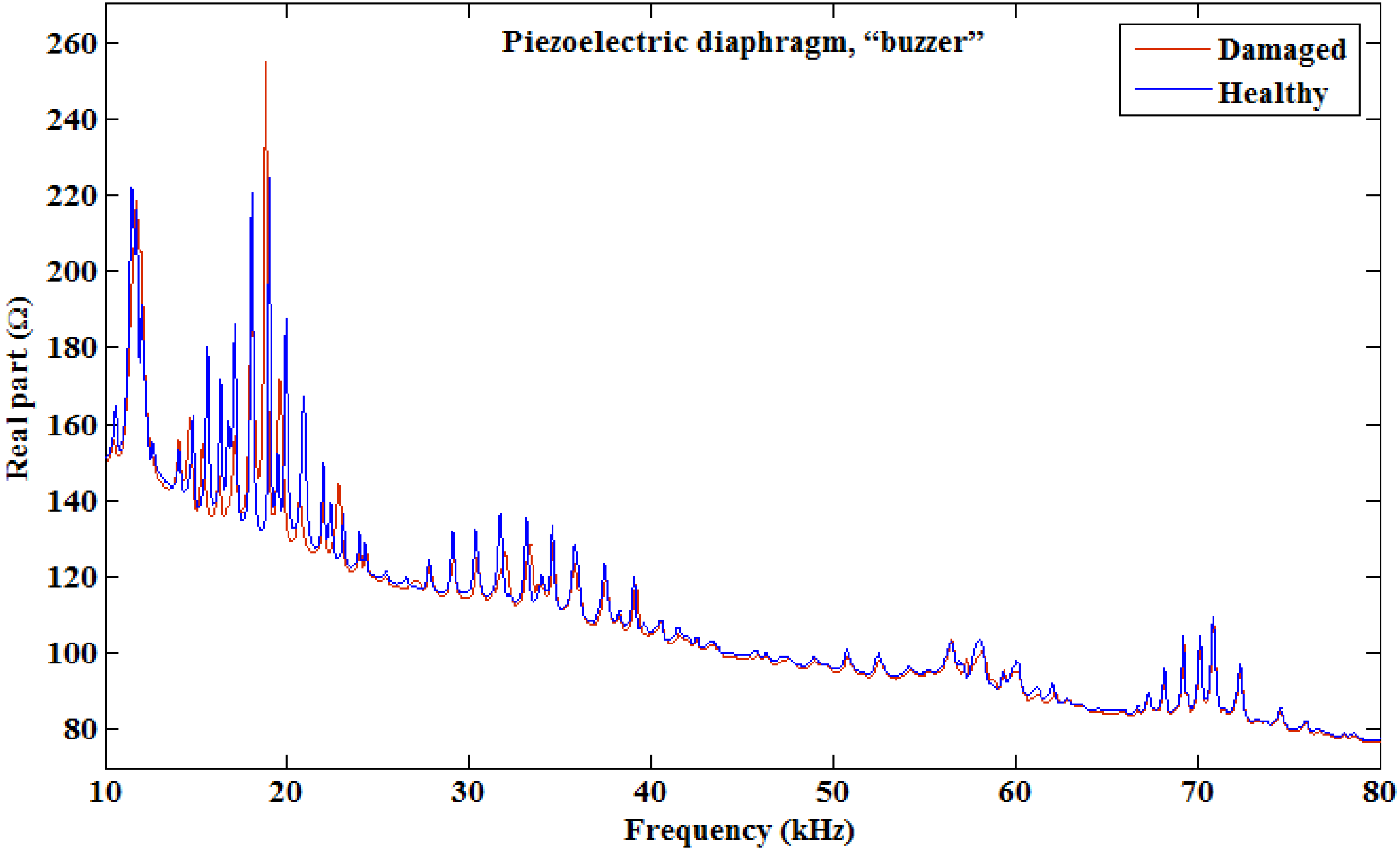
Results – Impedance Signatures – 5H PZT patch



Results – Impedance Signatures – MFC transducer



Results – Impedance Signatures – Buzzer

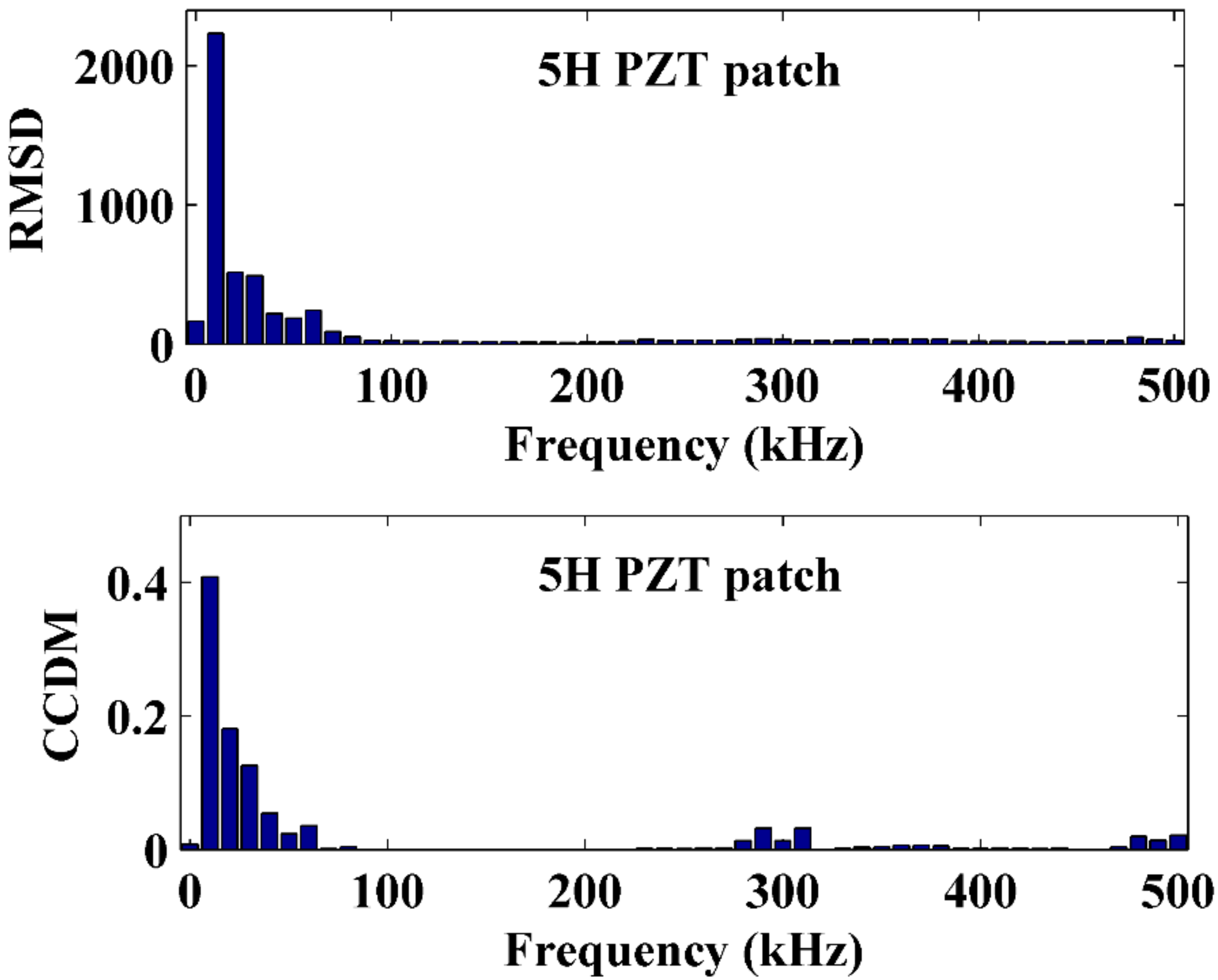


Results – Impedance Signatures

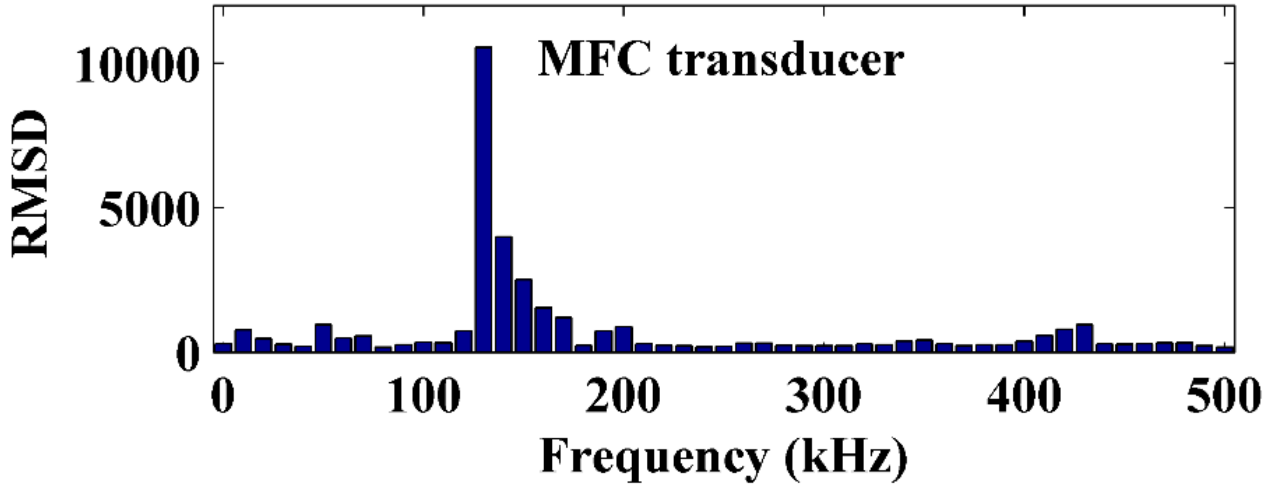
According to the electrical impedance signatures:

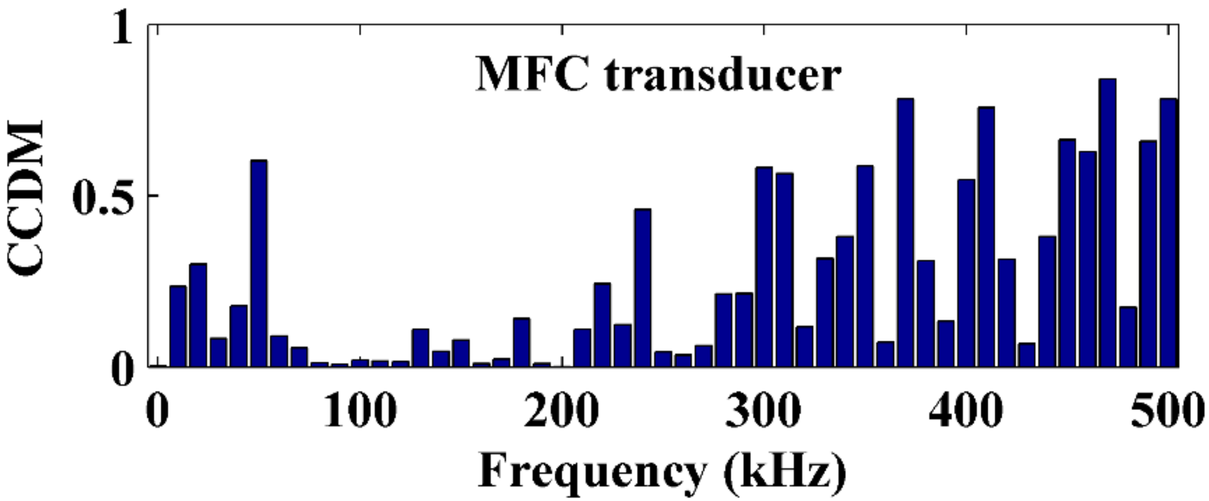
- There are resonance peaks in the signatures related to the natural frequencies of the structures;
- Structural damage (nut) causes variations in frequency and amplitude in these peaks, which can be quantified by indices of damage;
- The peaks are more significant at low frequencies and tend to decrease as the frequency increases;
- The PZT patch has provided impedance signatures with higher amplitude;
- Impedance signatures with lower amplitude were obtained using the MFC transducer;
- The piezoelectric diaphragm provided impedance signatures with intermediate amplitude between the other two transducers.

Results – Damage Indices – 5H PZT Patch

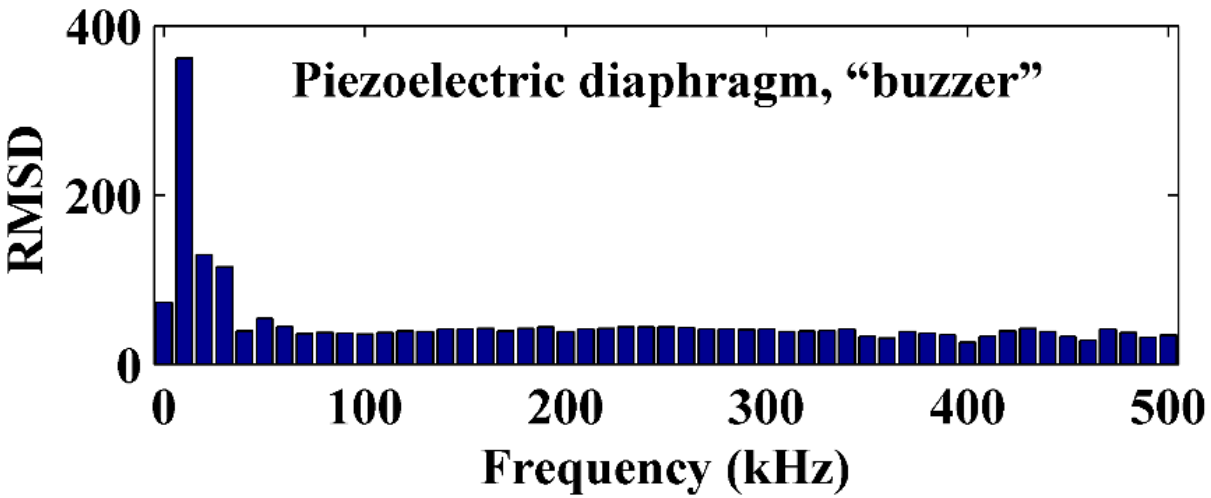


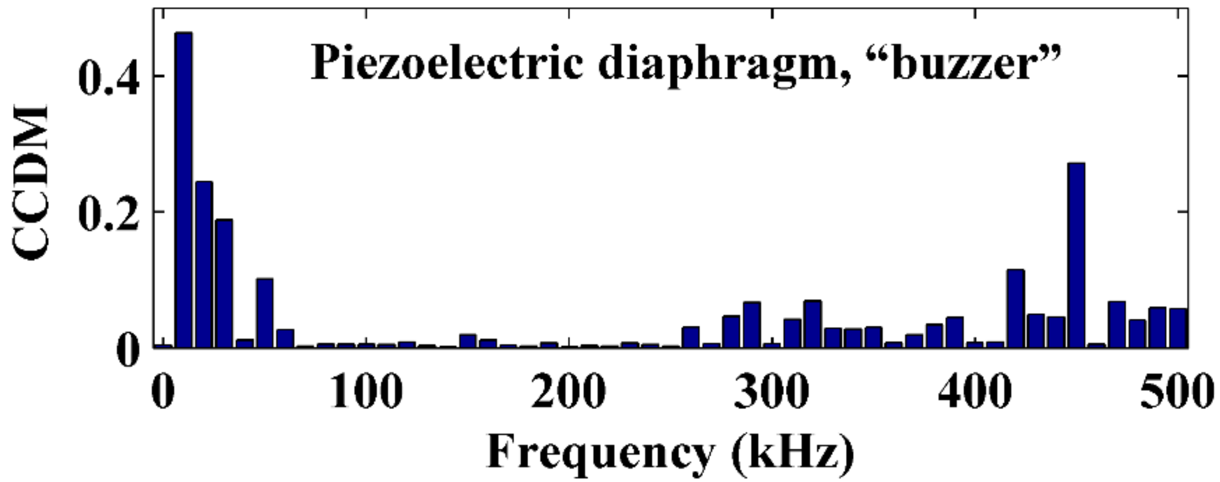
Results – Damage Indices – MFC transducer





Results – Damage Indices – Buzzer





Results – Damage Indices

According to the damage indices:

- The **PZT patch** and the **diaphragm** provided the highest indices for low frequencies around approximately 10-70 kHz;
- The **MFC transducer** provided higher indices at high frequencies;
- The **piezoelectric diaphragm** showed a reasonable sensitivity to detect damage, although the indices were lower compared to other transducers. However, this device has the advantage of having a very low cost.

Conclusions

- The experimental results indicate that the transducers have different sensitivities to detect damage;
- The sensitivity varies significantly with the frequency range;
- it is important to note that this study does not consider an important feature of the transducers for the EMI method, which is to provide repeatable and consistent impedance signatures.

Acknowledgments

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Questions?

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