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An Initial Study of Commercial Piezoelectric Diaphragms for Damage Detection Based on the Electromechanical Impedance Principle

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Outline

- Structural Health Monitoring (SHM)
- Electromechanical Impedance (EMI) Method
- Damage Detection
- Piezoelectric transducers
- Experimental Setup
- Results and Discussion
- Conclusions

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Structural Health Monitoring (SHM)

SHM systems monitor the integrity of critical structures such as bridges, dams, aircraft fuselages, pipelines, wind turbines, ships, oilrigs, large machines, among others.





Structural Health Monitoring (SHM)

The main objective is to detect damage, such as cracks, corrosion, fatigue, and wears, preferably during the normal operation of the structure, thereby preventing the interruption during the testing process.

Benefits

SHM

- Reduction of Maintenance costs
- Improved safety
- Increased lifetime

Electromechanical Impedance (EMI) Method

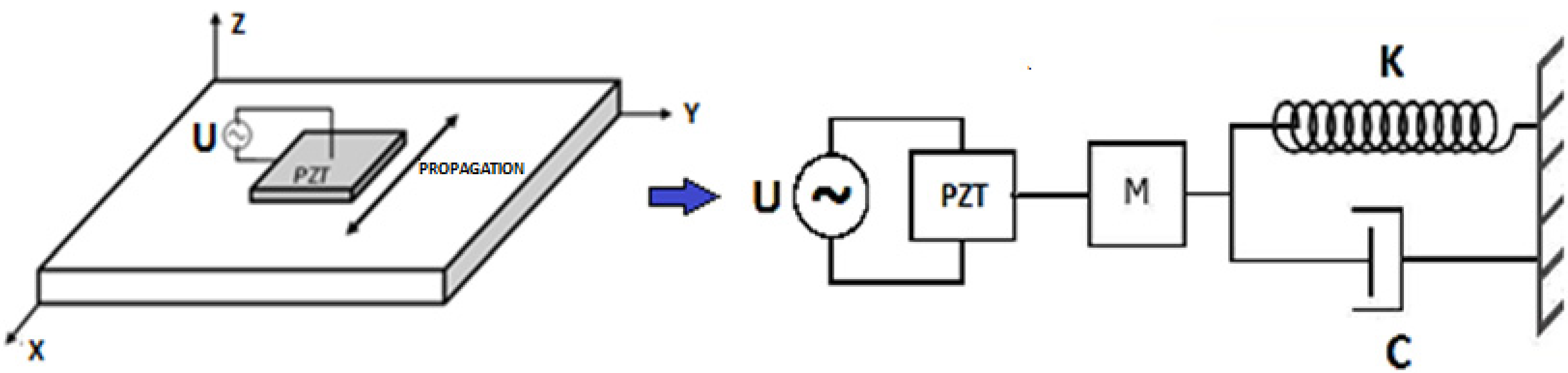
Methods

- Acoustic Emission
- Electromechanical impedance
- Comparative vacuum
- Eddy current
- Lamb waves

Electromechanical Impedance (EMI) Method

The EMI method is known for its simplicity and its use of low-cost and lightweight piezoelectric transducers, allowing for multiple transducers to be installed in the structure, enabling a vast area to be monitored without significantly changing the characteristics of the host structure

Electromechanical Impedance (EMI) Method



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

According to equation, any variation in the mechanical impedance “$Z_S(\omega)$” of the structure caused by damage involves a corresponding variation in the electrical impedance “$Z_E(\omega)$” of the transducer

Damage Detection

- The detection and quantification of structural damage can be directly performed through damage indices using the real the part of the electrical impedance signatures obtained from a piezoelectric transducer installed in the host structure. In this study we used the CCDM – Correlation coefficient deviation metric.

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

Signatures averaged under damaged conditions

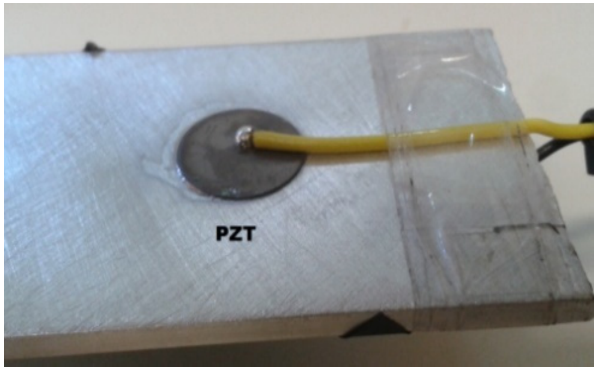
Signatures for damaged structure

Signatures averaged under intact conditions

Signature for healthy structure

Piezoelectric Transducers

Conventional PZT Ceramic



Type: 5A

Dimensions:

Active element 12.7 x 0.191 mm

Piezoelectric Diaphragm (Buzzer)

Type: 7BB-20-6

Dimensions:

Active element: 14.0 x 0.22 mm

Brass plate: 20.0 x 0.20 mm

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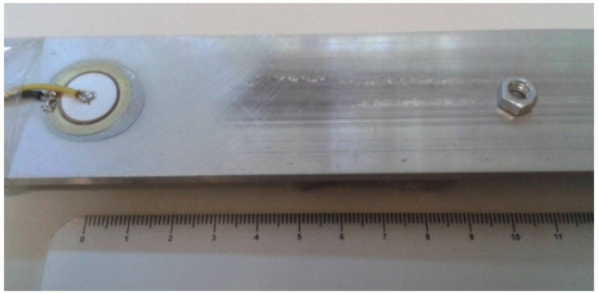
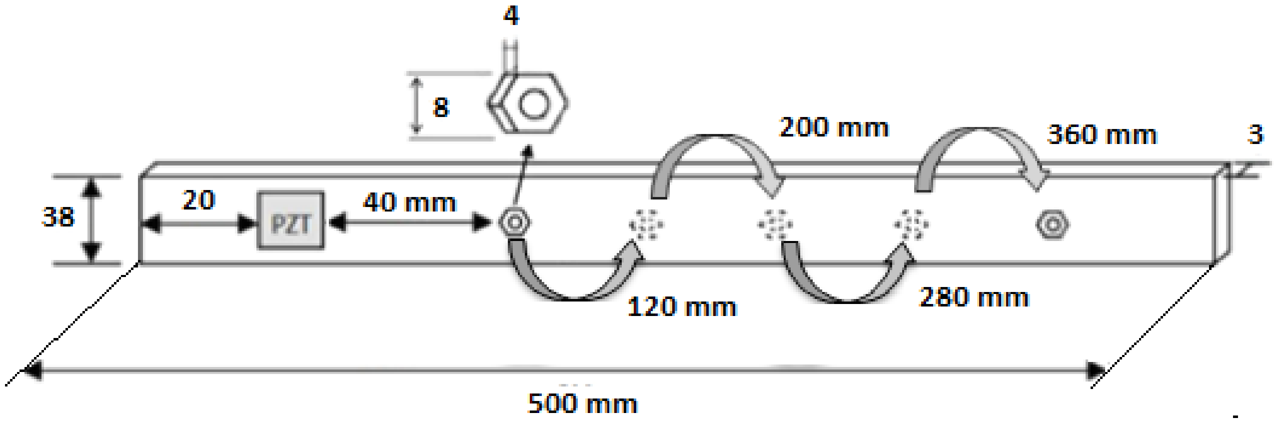
Experimental Setup - Structures



Aluminum beams: 500 x 38 x 3mm

Damage was simulated by adding a metal mass (nut) onto the beams at a distance ranging from 40 mm to 360 mm in steps of 80 mm from each transducer

Transducers placed using cyanoacrylate glue



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Experimental Setup – Measurement System

Data acquisition device (DAQ NI-USB-6361)

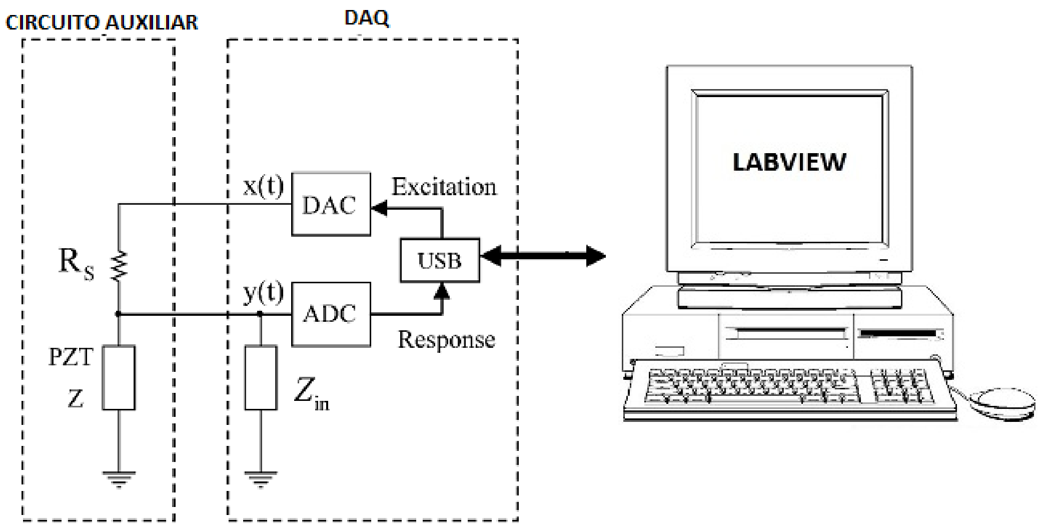
LabVIEW software

Excitation signal – a chirp signal with amplitude of 1 V

Frequency range of 0-500 kHz

Frequency steps of 2 Hz.

Sampling rate of 2 MS/s



Results and Discussion

Frequency Range

Identification e selection of the appropriate frequency range for damage detection is a critical process

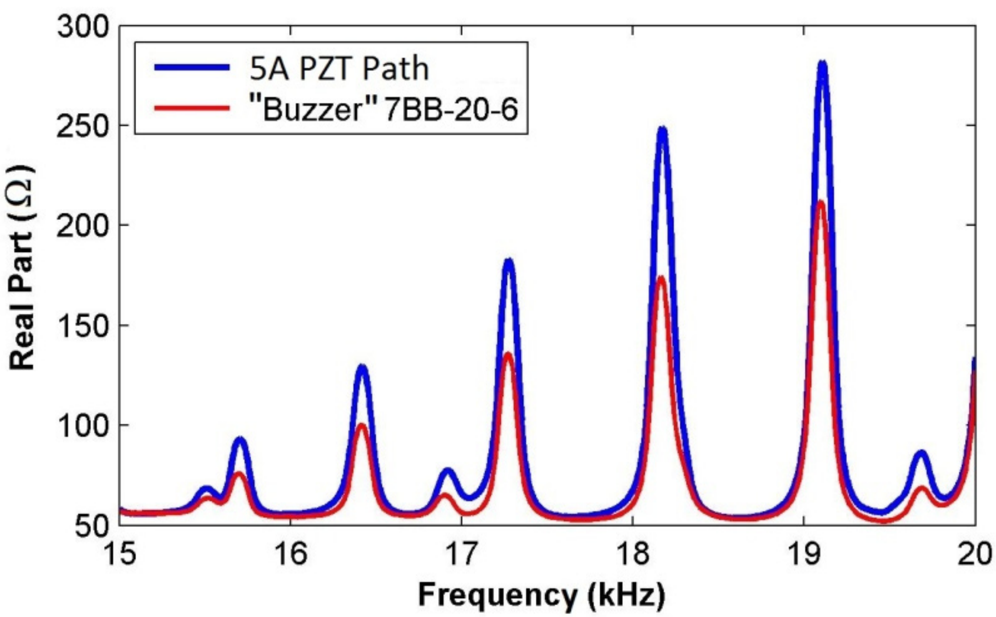
In this study, the proper frequency range was chosen experimentally by trial and error

Thus, the frequency range of 45-55 kHz was determined as the most sensitive to damage, providing high CCDM indices

Results and Discussion

Impedance Signatures

Comparison between the real part of the impedance signatures obtained from the conventional ceramic and the piezoelectric diaphragm



Results and Discussion

Impedance Signatures

The impedance signatures obtained from the two transducers show similar trends and resonance peaks, indicating the similarity of the characteristics and behavior of the two transducers

In general, the conventional ceramic provides more prominent resonance peaks with high amplitude. In addition, there are small differences in the shape of the signatures, probably due to the effect of the brass plate

Results and Discussion

Damage Indices

A more effective way to compare the two transducers for sensitivity to detect damage is the use of **damage indices**

In this study, we used the **CCDM index**, which is based on the **correlation coefficient**

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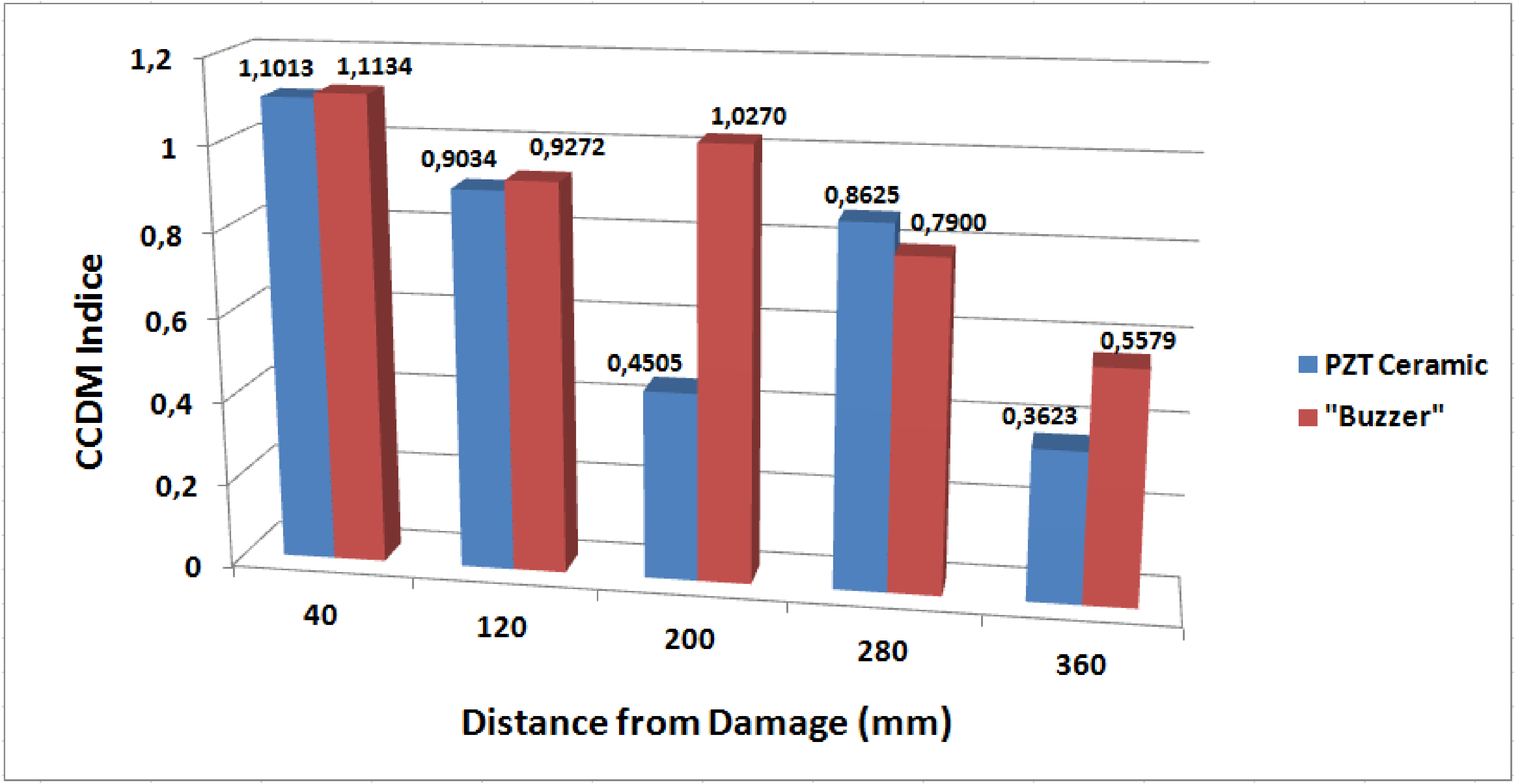
Results and Discussion

CCDM Indices



Results and Discussion

CCDM Indices

The two transducers provide indices with similar trends for different distances of damage, except for distances of 200 mm and 360 mm, where the diaphragm had provided significant higher indices

The experimental results indicate that the piezoelectric diaphragms are feasible for use in damage detection based on the EMI method, providing similar results to those of a conventional PZT ceramic with similar dimensions

Conclusions

This study analyzed the applicability of the piezoelectric diaphragms for damage detection based on the principle of electromechanical impedance

The results indicate that the diaphragm presents impedance signatures and damage indices similar to those of a conventional ceramic with similar dimensions

This work is an initial study. Other important characteristics, such as temperature effects, frequency range and reproducibility of the results, require further research

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Thank You!!

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