Impedance-based NDE through Instrumented Fixtures; Effects of Clamping Force on Defect-detection Capabilities

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Background

Electromechanical impedance (EMI) measurements allow for a rapid assessment of structural integrity of manufactured parts by providing insights into the parts dynamic response. This allows for Impedance signatures to be used for non-destructive evaluation (NDE) of manufactured parts based on the principle showed in Figure 1.

In practice, impedance-based NDE rely on the use of piezoelectric transducers that are bonded to the parts to be analyzed using adhesives. Hence, removal after test may affect structures dynamics and testing of multiple parts becomes cumbersome. Also,

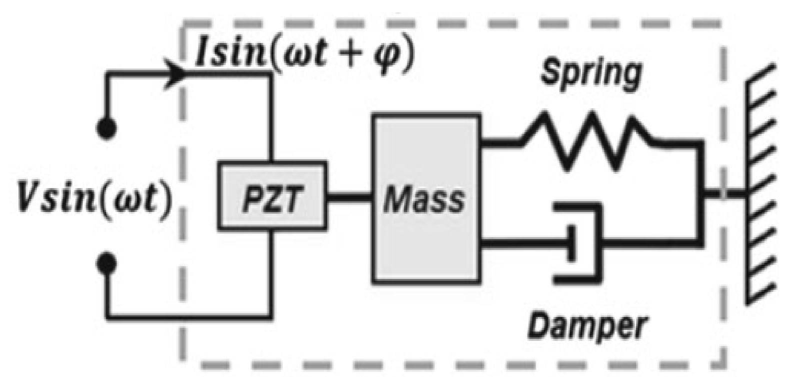

Figure 1. Principle of EMI

uncertainties in the instrumentation process, such as adhesives stiffness and curing time, affect the performance of this NDE solution.

Therefore, indirect electromechanical impedance measurements, through an instrumented fixture, is introduced to alleviate the need for individual part instrumentation. Thus, providing a favorable solution for rapid evaluation of manufactured parts.

In this study, the sensitivity of impedance signature, indirectly measured with an instrumented fixture, to clamping force is investigated.

Objectives

This research aims to:

- Evaluate the feasibility of using an instrumented fixture for indirect EMI measurements.
- Analyze sensitivity of impedance signatures to clamping force.
- Analyze effect of clamping force on defect detection capabilities.

Materials & Methods

A 3D printed fixture, shown in Figure 2a, is instrumented with a monolythic piezoelectric wafer for EMI measurements. The clamping force, exerted by the fixture on the part under test, is measured using a calibrated strain gauge. Defect-free steel blocks, Figure 2b, and blocks featuring manufacturing defects are selected as the test specimens. EMI signatures of the specimens are measured using Zurich Instruments MFIA impedance analyzer connected to LabOne computer interface. EMI signatures are measured over the frequency range of 1 kHz to 100 kHz with 10 Hz resolution. Figure 3 shows a schematic of the experimental setup used in this study. The effect of clamping force on EMI signatures, and its sensitivity to manufacturing defects, is evaluated at various clamping force levels.

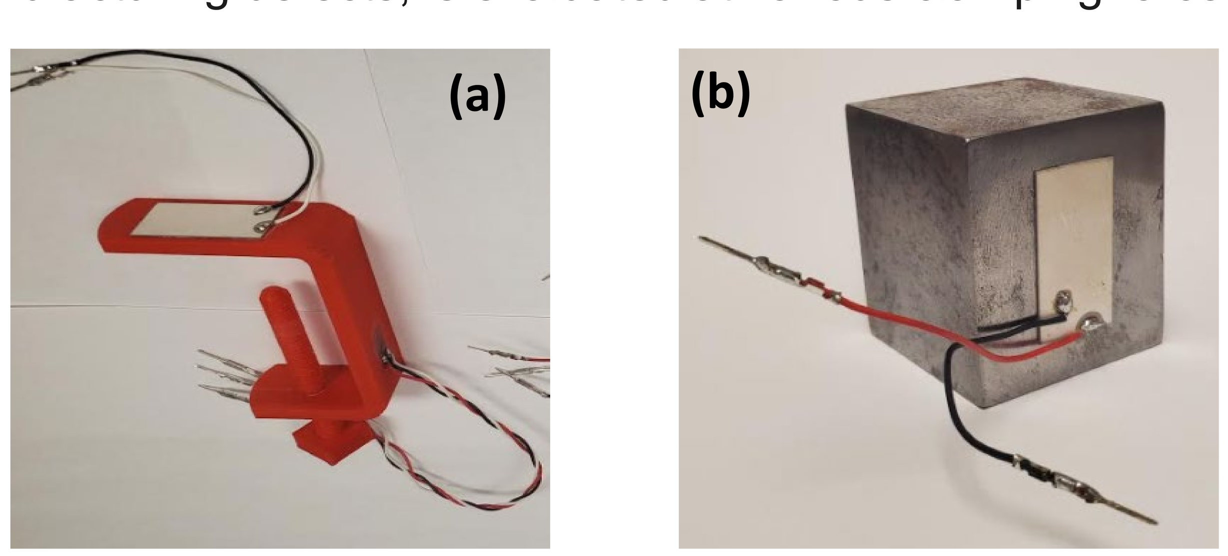

Figure 2. Instrumented (a) 3D Printed clamp (b) Steel Specimen

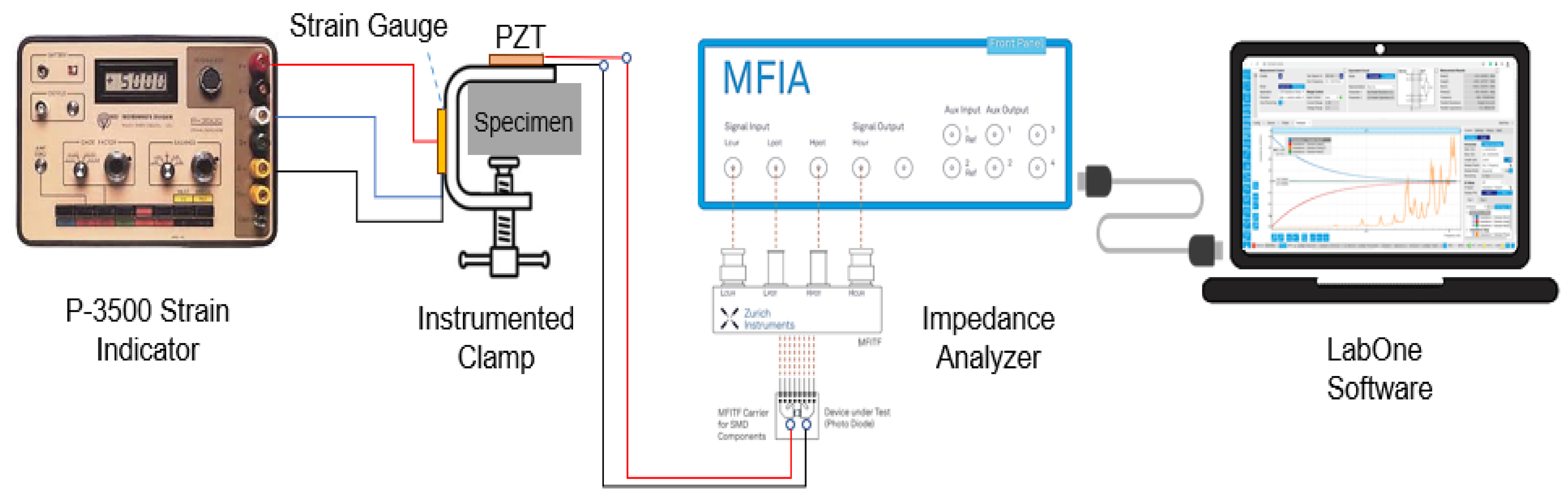

Figure 3. Experimental Setup for indirect EMI Measurement.

Results and Discussion

EMI signatures of the coupled part-fixture system measured at various clamping force levels are shown in Figure 4. As the results suggest, the impact of clamping force on EMI signatures decreases as the excitation frequency increases. This can be ascribed to the fact that an initial state of stress impacts wave propagation in the structure, and thus its dynamic response, more at low frequencies. Thus, higher frequencies are more robust to variations in clamping force between the fixture and the part under test. Given the high damping in polymer AM materials, EMI peaks are significantly attenuated at higher frequencies.

The impact of clamping force on defect detection capabilities is assessed by comparing the EMI signatures of the defect-free parts to that of the defective one at a given clamping force value. The results with the 10N and 40N clamping force values are shown in Figure 5. The variations in EMI signatures of defective parts as compared to the defect-free responses are quantified using the Root Mean Square Deviation (RMSD) damage metric. The results are summarized in Figure 5c. for the various clamping force values considered in this study. As suggested by the results, defective parts are successfully detected with this indirect EMI measurements. The sensitivity to manufacturing defects seems to improve at lower frequency ranges. This is a result of the high damping in the fixture with suppresses the dynamic response at high frequency. Furthermore, there is no clear trend in the RMSD damage metric with the clamping force. This is can be ascribed to the inherent limitations in RMSD definition. More advanced damage metrics will be investigated in future studies to further study the effect of clamping force on defect detection capabilities.

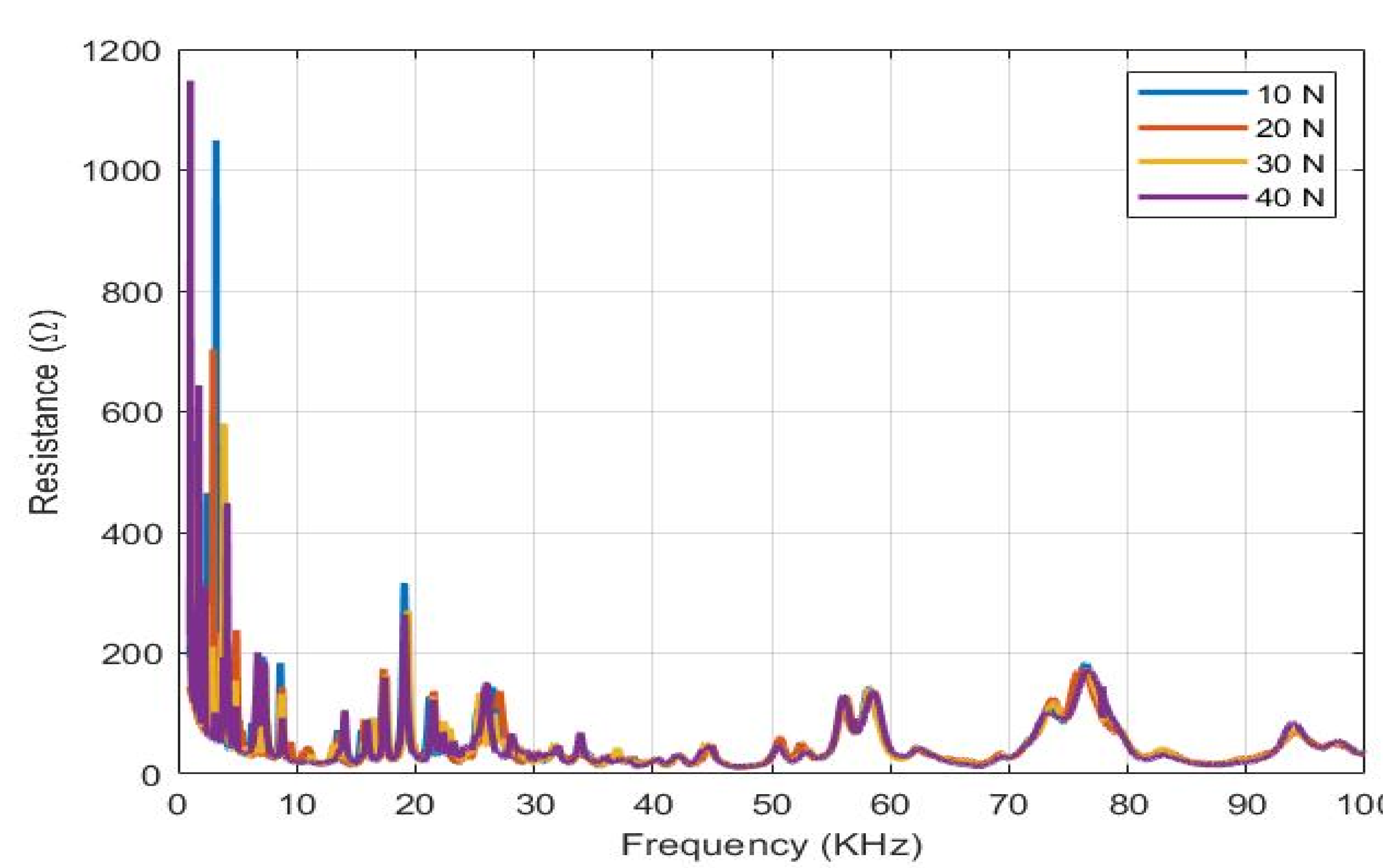

Figure 4. Signature sensitivity to clamping force for defect-free parts

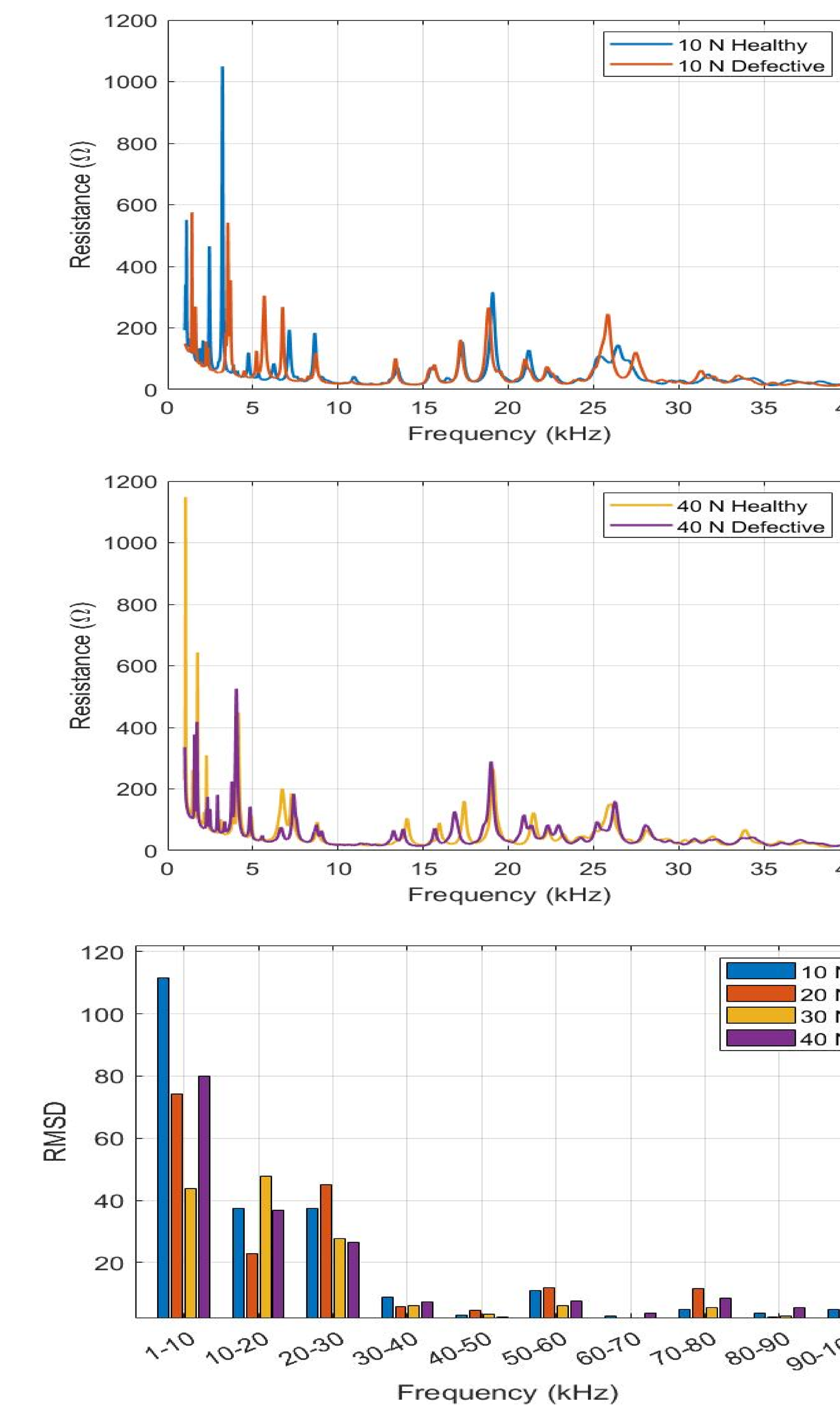

Figure 5. EMI signatures of defect-free and defective parts at (a)10 N and (b) 40 N, and (c) the corresponding RMSD values

Conclusions

This study investigated the feasibility of using indirect EMI measurement, through an instrumented fixture, for NDE of manufactured parts. The focus was on studying the effects of clamping force on defect detection capabilities.

As suggested by the results, defective parts are successfully detected with indirect EMI measurements. EMI signatures are found to be robust to changes in clamping force at high frequency ranges. No clear trend between sensitivity to part defects quantified using the standard RMSD definition, and clamping force was observed. More advanced damage metrics will be investigated in future studies.

References

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