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STRUCTURAL HEALTH MONITORING OF A FIXED STRUCTURE BASED ON THE ULTRASONIC TECHNIQUE

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Abstract. *In the industrial field, inspections using Non-Destructive Testing (NDT) techniques are widely employed as relevant tools for defect identification during manufacturing processes, maintenance, and final product inspection. Ultrasonic structural integrity monitoring is one of the most used non-destructive tests. The detection of discontinuities through an ultrasonic device is performed by monitoring the sonic reflections transmitted to the material through a transducer attached to the structure. In the present contribution, the ultrasonic technique was applied to a fixed structure, a 1020 steel beam, using conventional Ultrasonic transducers to identify damage in the structure and its growth. The steel beam was subjected to successive cuts in the same region, and the ultrasonic technique was used to monitor damage propagation. Transducers with different angle heads alongside the steel beam were used for this aim. Different from the commonly adopted procedure for discontinuity detection based on the ultrasonic technique, in this case, the transducers were kept fixed to follow the growth of the cuts in different positions. The preliminary results demonstrated that it was possible to identify the damage propagation using the proposed procedure. Therefore, it can be inferred that the technique can be effectively explored under different conditions.*

Keywords: *Structural Health Monitoring (SHM), Ultrasonic testing, Fault Detection*

1. INTRODUCTION

The number of techniques employed for fault detection or structural integrity monitoring has experienced significant growth in recent years. The concern over damages that can lead to catastrophic accidents and the high costs associated with repairs and maintenance have driven the expansion of Structural Health Monitoring (SHM) techniques. These techniques enable early detection of faults, facilitating timely preventive measures and reducing maintenance costs. Moreover, they enhance reliability and safety and extend the product's lifespan (Maio, 2011) (Gonçalves *et al.*, 2020).

Structural integrity assessment methods are classified as non-destructive because they enable keeping the analyzed structure's characteristics even after the evaluation test has been performed (Bray and McBride, 1992). Ultrasonic monitoring of structural integrity stands out as one of the most crucial non-destructive tests, as utilized for measuring thickness, identifying discontinuities, and evaluating corrosion, as a primary focus on assessing internal discontinuities (Santin, 2003).

The detection of discontinuities using an ultrasonic device involves monitoring the sonic reflections transmitted to the material through a transducer attached to the structure. To identify internal and surface discontinuities, a high-frequency ultrasonic sound beams (above 20 kHz) is introduced into the inspected material, reflecting off its interfaces (Santin, 2003). The transducer (sensor) connected to the specimen detects the reflections originated from inside the material using a display-equipped device that enables the determination of reflected energy intensity and interface locations. By analyzing these reflections, the inspector can ascertain the material's presence or absence of discontinuities (Cerqueira, 2009) (Costa, 2011).

The ultrasound technique can be employed using pulse-echo, or conventional ultrasound, and phased array ultrasound. Pulse-echo ultrasound can display information in three ways: A-scan, B-scan, and C-scan. The A-scan visualization represents a graph of the echo signal amplitude as a function of the sound path. The B-scan visualization depicts the cross-sectional view of the inspected surface. In this graph, one axis corresponds to elapsed time, and the other axis represents the transducer position along the contact surface of the inspected part. The C-scan visualization displays a top-down view of the examined part on the ultrasound equipment screen, enabling the determination of the position, length, and width of the discontinuity (Cerqueira, 2009) (Campbell, 2013) (Santos, 2017). The visualization methods are presented in Fig. 1.

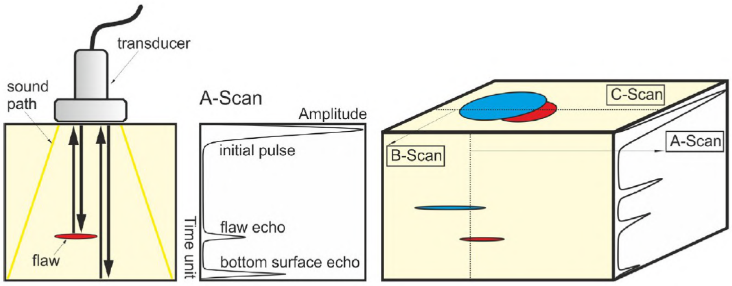
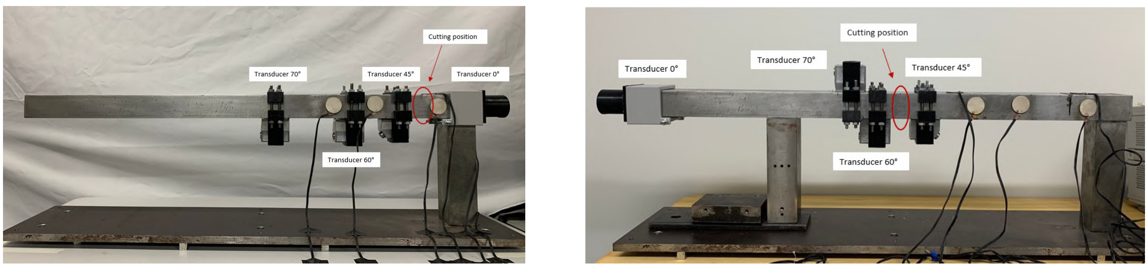


Figure 1. Modes of ultrasound visualisation. (Wronkowicz *et al.*, 2018)

This article employed conventional pulse-echo ultrasound through $A - scan$ inspection. Unlike traditional ultrasound analyses, the ultrasound transducers in this study were statically positioned to track the growth of cuts in a fixed structure. The primary goal of this analysis was to investigate the ultrasound signal behavior as the cut size increased and to identify the corresponding structural damage through these signals. Therefore, this study lays the foundation for future continuous structural monitoring, enabling early detection and tracking of emerging faults together with their progression.

2. METODOLOGY

In the experimental setup, a 1020 steel beam with dimensions of 44.45 mm thickness, 850 mm length, and 50.8 mm width was used as the test specimen. The objective was to evaluate ultrasonic signals by implementing successive cuts in two distinct steel beam regions. Ultrasonic transducers (0°, 45°, 60°, and 70°) were systematically distributed and fixed along the beam to ensure the interception of the ultrasonic sound beam at various positions along the cut growth. The transducers' configuration and the cuts' precise locations are shown in Fig. 2.



(a) First position.

(b) Second position.

Figure 2. Experimental bench.

The $A - scan$ signals were obtained using the SIUI conventional ultrasound equipment, Fig. 3. Before the first cut, baseline measurements were taken for all transducers. Subsequently, measurements were performed after each subsequent cut. A predefined gain value was applied to each transducer during the baseline measurement, which remained constant for all following measurements. By maintaining this consistent gain setting, the variation in signal amplitude, indicative of material damage, could be evaluated after each cut. Higher signal amplitudes indicated the grater region where the ultrasonic sound beam would reflect, thus facilitating the identification of damage growth in the material while keeping the transducer position fixed.

In order to assess and enhance the visualization of signal amplitude variation, it was chosen to consolidate the signals resulting from measurements at each cut and for each transducer into a single graph. The ultrasound equipment does not provide raw data but only the signal associated with the measurement. Therefore, to acquire this signal the equipment's

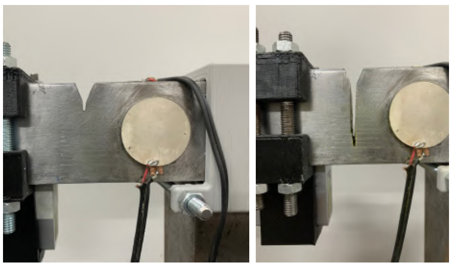
Figure 3. SIUI Smartor Flaw Detector & Thickness Gauge.

screen was recorded and subsequently used in a Python program. The pixels representing the signal data were extracted from the frames of this video . This approach allowed for the combined representation of all cuts in a single graph, making it easier to compare the signal amplitude.

Following the analysis of the ultrasound signals obtained from the first cutting region, it was observed that the signals acquired by the 45°, 60°, and 70° oriented transducers were unsatisfactory due to their position and predefined gain settings. As a result, the angular transducers were repositioned and recalibrated to evaluate a new cut. The new position was determined such that each transducer would intercept the cut along its growth, i.e., one transducer was positioned to block the beginning of the cut, another at the midpoint, and the third at the end.

3. RESULTS

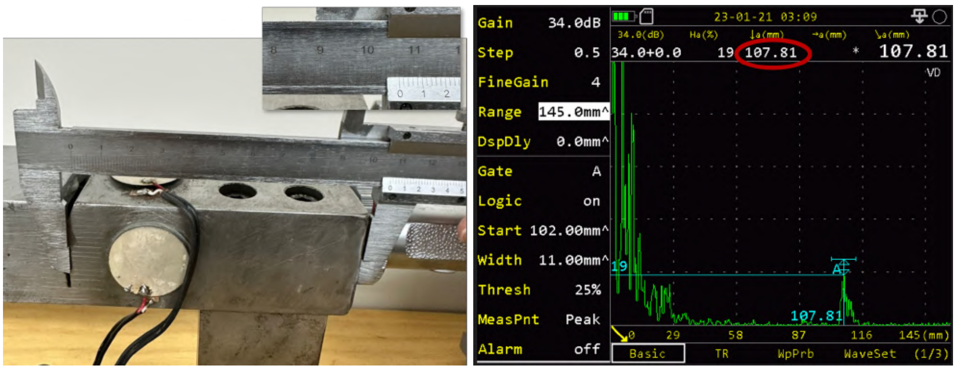
Nine consecutive cuts were performed at the first predetermined position, starting from an existing notch found in the steel beam. Ultrasonic signals were acquired and compared to the baseline measurements before the first cut. The first and last cuts performed on the steel beam at this particular region are illustrated in Fig. 4.



(a) First cut. (b) Last cut.

Figure 4. Cuts in the steel beam in the first region of analysis.

The 0° transducer was positioned at the end of the steel beam, approximately 107 mm away from the cut, as shown in Fig. 5(a). According to the measurements taken, an ultrasonic signal was detected at the same position as the transducer, as illustrated in Fig. 5(b).



(a) (b)

Figure 5. Signal position of transducer 0º

The signal amplitude progressively increased as additional cuts were performed on the steel beam, indicating amplification of material damage, Fig. 6. However, starting from the fifth cut (at a depth of 18 mm), the signal amplitude remained constant. This occurrence can be attributed to the limited beam width of the 0° transducer, which only intercepted the cut to that depth. Consequently, regions below the fifth cut were not probed by the ultrasonic sound beam, and due to the position of the 0° transducer any damage below this region remained undetectable.

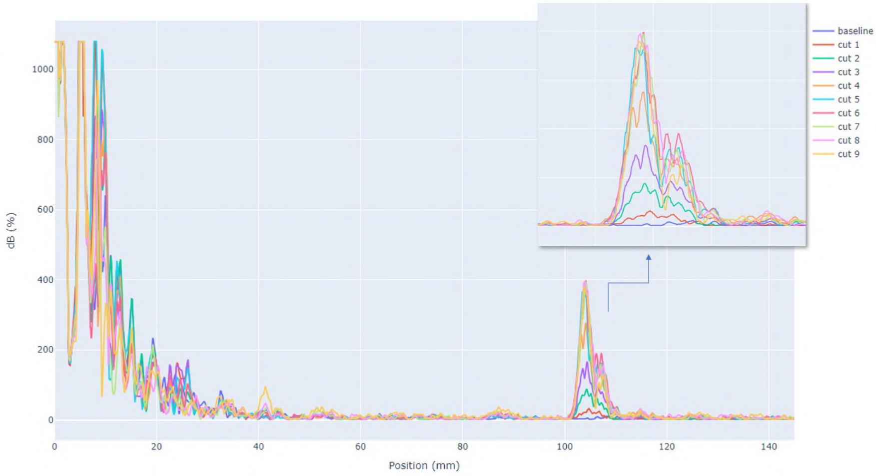
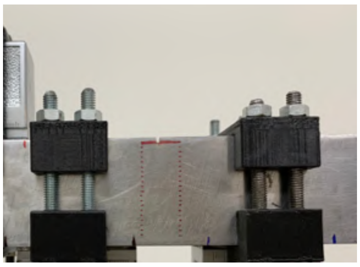


Figure 6. Signal of transducer 0º

To evaluate the signals from the angular transducers (45°, 60°, and 70°), they were employed in the second cutting region, as depicted in Fig. 2(b). In this region, 17 cuts were performed, with the first and last cuts illustrated in Fig. 7.

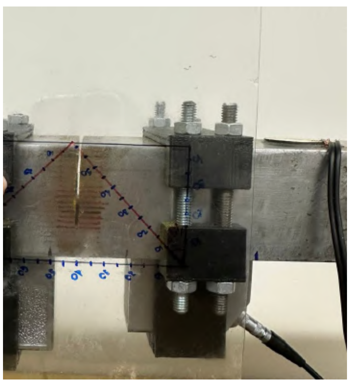


(a) First cut.

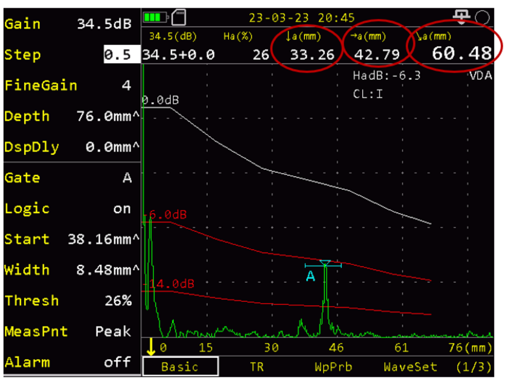
(b) Last cut.

Figure 7. Cuts in the steel beam in the second region of analysis.

The 45° transducer was positioned to ensure that the ultrasonic sound beam intercepted the initial cuts made. This position can be observed in Fig. 8(a), which illustrates the sound path (the distance traveled by the ultrasonic wave within the material), the surface distance, and the depth of the cut relative to the transducer position. The ultrasound measurements further confirmed the accuracy of transducer's position. As shown in Fig. 8(b), the equipment detected the characteristic signal corresponding to the existence of the cut in the steel beam.



(a) Position of transducer 45º.



(b) Signal indication for transducer 45º.

Figure 8. Signal position of transducer 45°.

As mentioned, the 45° transducer successfully detected the existence of damage in the steel beam from the first cut, as shown in Fig. 9. The signal amplitudes increased following the growth of the cut, reaching stability after the ninth cut. This observation indicates that the subsequent cuts no longer intercepted the ultrasonic sound beam emitted by the transducer.

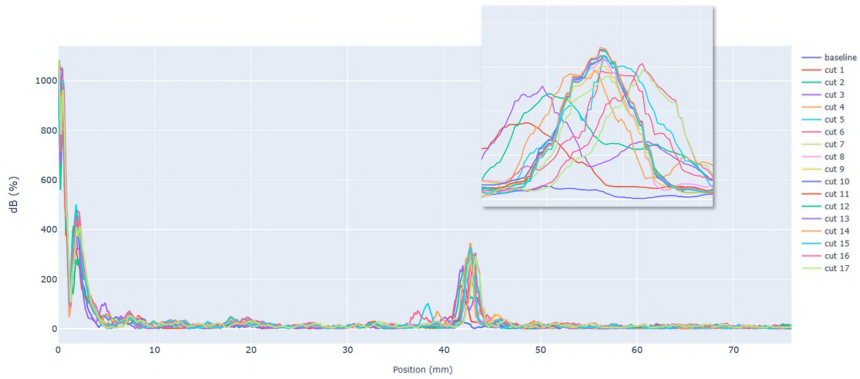
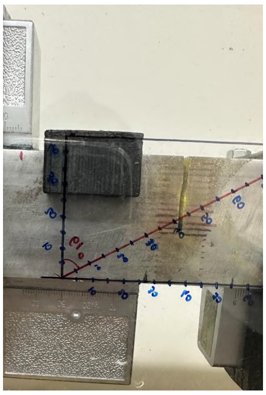


Figure 9. Signal of transducer 45º.

The 60° transducer was positioned so that the ultrasonic sound beam intersected the central region of the cut, as depicted in Fig. 10(a). The accuracy of this position is evident as given by Fig. 10(b), which displays the signal obtained by the ultrasound equipment.



(a) Position of transducer 60º.

(b) Signal indication for transducer 60º.

Figure 10. Signal position of transducer 60°.

Due to the transducer position, signals for this specific transducer were only detected from the thirteenth cut onwards, exhibiting variations in amplitude until the final cut, as depicted in Fig. 11. Consequently, as due to the limited number of cuts performed, it was not possible to determine the stability of the signal amplitude for this transducer.

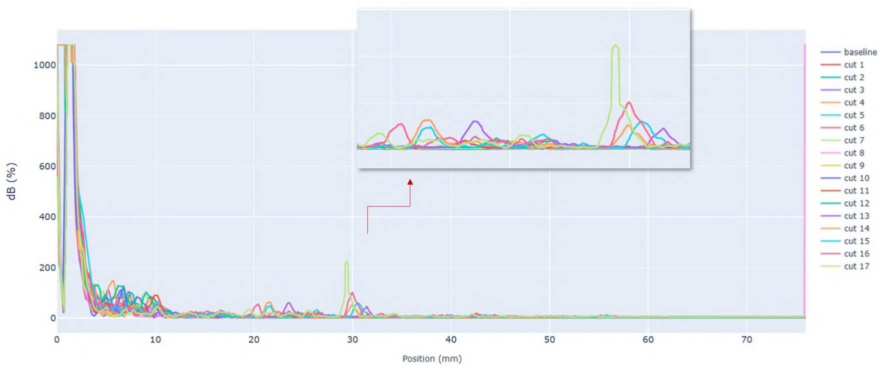


Figure 11. Signal of transducer 60º.

Lastly, the 70° transducer yielded significant signals only for the final cuts, as illustrated in Fig. 12. The acquired signals for this transducer exhibited minimal variation in the amplitude compared to the 0° and 45° transducers. This outcome can be attributed primarily to its specific position, where the ultrasonic sound beam intercepted only the final region of the steel beam's cut. This is illustrated in Fig.13(a) and Fig.13(b), which show the signal corresponding to the cut and its position relative to the transducer in terms of the surface distance and the depth, as well as the sound path, respectively.

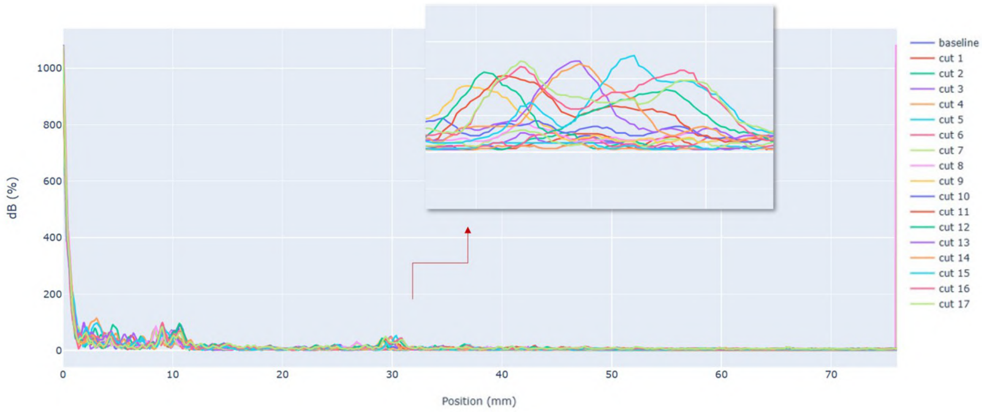
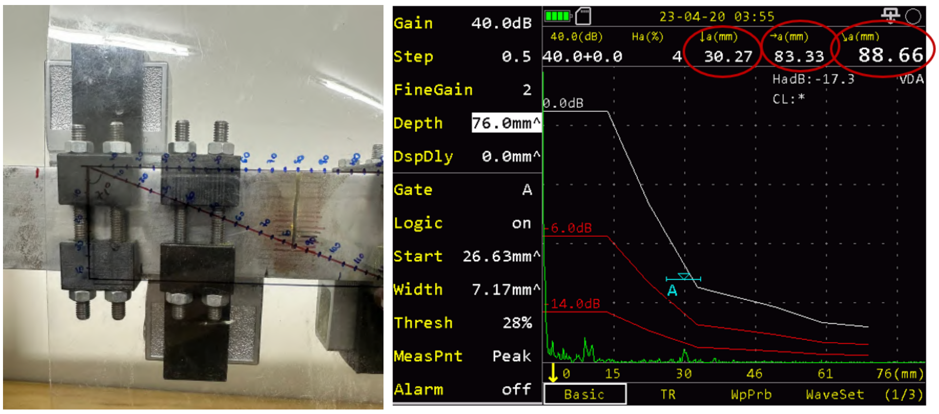


Figure 12. Signal of transducer 70º.



(a) Posição do transdutor 70º. (b) Signal indication for transducer 70°.

Figure 13. Signal position of transducer 70°.

For a more comprehensive analysis of the behavior of the 60° and 70° transducers, their positions can be adjusted to intercept the upper regions of the cut. This modification would allow for the identification of other cuts. By doing so, it would be possible to observe the variation on the amplitude of the signal and determine at which point it would reach stability.

However, the signals obtained under the pre-established condition met expectations, enabling the detection of damage signals in the steel beam using all the transducers employed. The 0° transducer showed a more distinct signal variation for each cut, indicating its sensitivity to the existence of damage. Additionally, the position of the transducers had a significant influence on the obtained signals during the analysis. For transducers whose ultrasonic sound beam is projected towards the upper regions of the cut, the received signal exhibits both higher amplitude and higher variation with respect to the length of the cut, in contrast to transducers positioned towards the lower regions of the cut. Additional tests will be conducted to explore the effects of modifying the position of the transducers. The objective is to optimize their placement to enhance the sensitivity and accuracy of damage detection on the structure.

4. CONCLUSION

The preliminary results presented in this article demonstrated that it was possible to identify the signals of the cuts made in the steel beam using all the transducers employed. It was observed that the position of the transducers significantly affected the signal intensity, highlighting the need to determine their location according to the analysis objectives. Clearly, this behavior follows the physical expectations involved in this type of structural testing.

Adapting the position of the transducers enables the identification of the existing damage signal in the structure and the evaluation of its growth. Thus, based on the acquired signals, the proposed procedure demonstrates that the technique can be satisfactorily employed in non-conventional tests.

In order to obtain additional data and perform further analyses, new incisions in alternative regions of the beam are scheduled. Various positions for the ultrasound transducers will be investigated.

5. ACKNOWLEDGEMENTS

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