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SIMPLE ATTEMPT TO COMPENSATE TEMPERATURE VARIATION IN STRUCTURAL HEALTH MONITORING SYSTEM USING LAMB WAVE INSPECTION

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Abstract. *The temperature variation during the performance of a Structural Health Monitoring using Lamb wave inspection can lead to false positives due to differences in between base line and the verification. In order to avoid the false positive, this work shows a simple technique to correct the experimental data to eliminate the false positive under the temperature variation. The proposed technique was tested in a square composite plate using Lamb wave inspection based in two inspection methods the first method is based on the construction of the wave propagation map calculated using the group velocity of the wave propagation and the Hilbert Transform. The second method is based on the comparison of the Power Spectrum Density of the signal measured by the sensors.*

Keywords: *Structural Integrity, Structural Health Monitoring, and Damage Detection*

1. INTRODUCTION

In SHM using Lamb wave inspection it is usual having a baseline, which represents the structure undamaged. When performing an inspection, the measured verification is compared with the baseline but, due to environmental conditions or even changes in the dynamic behavior of the structure, the baseline and the verification can slightly differ from each other even when there is no damage in the structure. For more details see Konstantinidis et al. (2006).

In order to overcome this situation, it is introduced in the comparison methodology the “threshold”, that is a small variation in between the baseline and the verification that it is acceptable as a difference to not be considered as damage. For more details see Lee et al. (2011).

Supposing that there is damage in the structure, when the inspection is performed the sensors near the damage will present a difference greater than threshold while the sensors far away will present a difference less than the threshold, indicating that the change in the sensors levels due to damage is locally observed.

2. PROPOSED TECHINIQUE TO OVERCOME THE TEMPERATURE VARIATION

When the temperature suffers some variation form the moment of acquiring the baseline and the moment of performing the verification, all the structure sensors present a level great than the threshold, consequently, all sensors will indicate the presence of damage.

The technique proposed here to overcome the situation where all sensors present results great than the threshold consists in perform an average over the value measured by the sensors and summing this average in the pre-stablished threshold to form a new threshold that takes into account the temperature variations in the inspection.

For example, supposing that the threshold was defined as 2%, if the average of the variation over the sensors was 3%, meaning that each sensor suffered a variation of 3% from the baseline in average, then the new threshold is the sum of the stablished threshold and the average of variation, so, the new threshold is automatically defined as 5%.

The proposed methodology was implemented and tested in software being developed in the Gravi (Grupo de Acústica e Vibração)Group of UFMG, and was named “LaWade$_{\text{UFMG}}$” (Lamb Wave Detection).

3. DAMAGE DETECTION METHODOLOGIES

In the LaWade$_{UFMG}$ were implemented two techniques to damage detection. The first method is based on the construction of the wave propagation map calculated using the group velocity of the wave propagation and the Hilbert Transform, Konstantinidis et al. (2006). The second method is based on the comparison of the Power Spectrum Density of the signal measured by the sensors, Lee et al. (2011), Sohn et al. (2004), and Ihn et al. (2004).

The two methodologies were chosen because both of them are simple to be implemented, they require a same base-line and the most important is that they use the same configuration of the actuators and sensors. Besides, the use of more than one methodology provides a comparison between then.

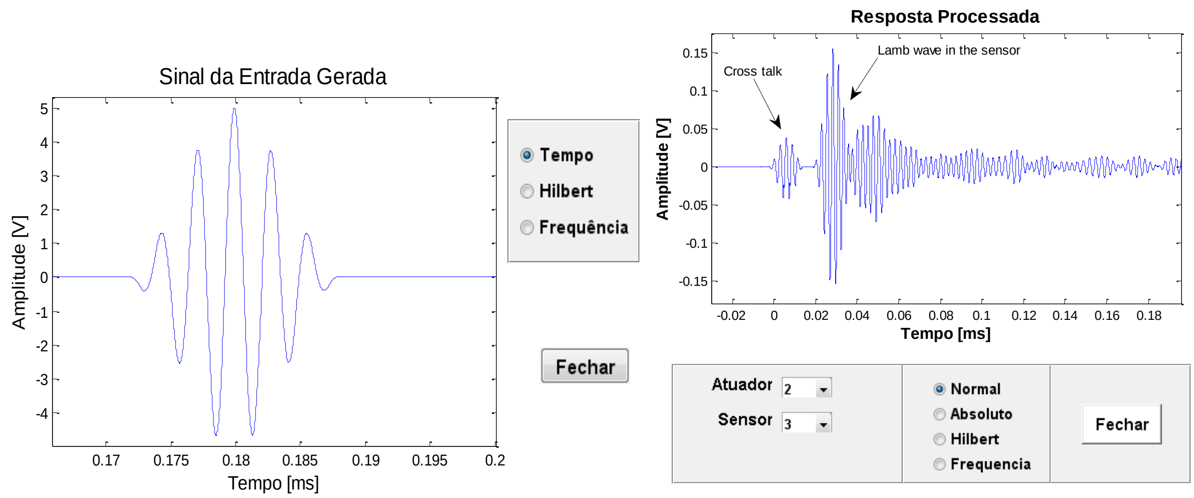
The methodologies are based on a mesh of piezoelectric (PZT) spread over the structure being the sensing system. To inspect the structure, one of them is being used as actuator and the others as sensors, so working usually called pitch-catch configuration where it has one PZT generating the lamb wave and one or more sensors receiving the signal. Then, the actuation point is changed until all the PZTs had being worked as actuator to perform the entire inference in the analyzed structure.

3.1 Lamb wave Generation and Acquisition

The process of Lamb wave generation can be done taking a base frequency windowed by hanning window, Konstantinidis et al. (2006). In order to implement the generation, it was chosen construct the signal using three parts, the first part containing only zeros to observe the presence of vibration from the past signal, the second part containing the base frequency multiplied by the hanning window and the third part containing only zeros and long enough to assure that the structure vibration had been vanished.

This methodology of constructing the excitation was chosen because the system continuously generates the input and the software acquires using trigger in the input signal. Figure 1(a) shows an example of input signal to generate Lamb waves in the structure, observe that in this case it was chosen 0.2 ms as a length in time.

The process of measurement was performed using STMR (Single-Transmitter, Multiple-Receiver), and it was used repetitive measurements to perform a average in the data to eliminate noise. An example of measured data can be seen in Fig. 1(b).



(a) input signal (b) measured signal

Figure 1: Example of input and measured signal

3.2 Hilbert Envelop methodology

The HE (Hilbert Envelope) methodology consists in apply the Hilbert transform in the signal measured by the sensor. The transformation allows estimating the TOF (Time of Flight) of the travelling wave from the actuator to the sensor. With this information it is possible to construct a propagation map of the wave in the structure using the velocity group of the wave and the relative position of points in the structure. This procedure is performed to all pair of actuator and sensor in the structure. Summing the maps over the actuators and sensors, a general map of propagation is generated.

Subtracting the general propagation map of the verification from the propagation map generated by the base line, it is possible to identify the damage location. For more details see Konstantinidis et al. (2006). The threshold of 1% was considered to indicate that there is damage. Thus, this methodology gives indication of the exact location of the damage in the structure.

3.3 Power Spectrum Density methodology

The PSD (Power Spectrum Density) methodology consists in calculating the power density using the welch method of the signal measured by the sensor, so representing the PSD in between the actuator 'i' and the sensor 'j'. The same process is performed to the base line. The threshold of 1% was considered as difference to indicate that there is damage in the path. For more details see Lee et al. (2011), Sohn et al. (2004), and Ihn et al. (2004).Therefore, the PSD indicates a region where is possible to have damage and not the true location.

4. EXPERIMENTAL SETUP

The experiment consists of a simple squared composite plate of 1m x 1m made using 16 layers in a 45° configuration. It was used 16 PZTs separated by 200 mm from each other according to Fig. 2, but due to the experimental conditions and symmetry it was used only the firsts 12 PZTs.

Figure 2: Composite plate used in the experimental analysis

The input signal was generated using sample frequency of 60MHz, base frequency of 300 kHz with 6 periods windowed by hanning window, 5 Volts of amplitude during 4 ms. The signal is zero in between 0 and 0.2 ms and in between 0.22 ms and 4 ms.

In order to verify the influence of the temperature in the damage detection procedure, it was preformed two measurements in different days. In day #1 was measured the Baseline#1 and the Verification#1 including a simulated damage located at position (x,y) = (0.35,0.65) with 0.75 inches of size. In day #2 was measured the Baseline#2 and the Verification#2 including a simulated damage located at position (x,y) = (0.50,0.50) with 1.50 inches of size. The location of the damages can be seen in Fig 3.

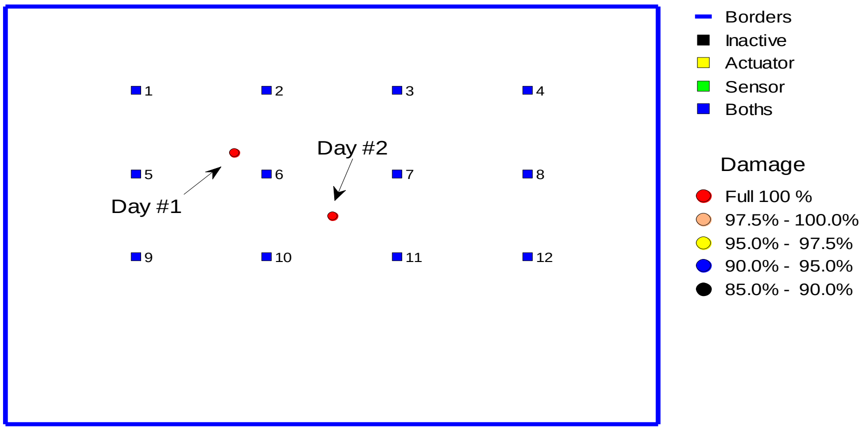
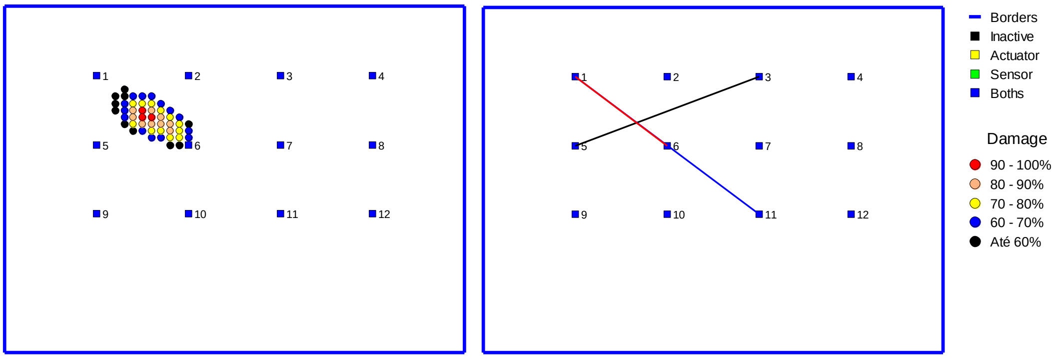


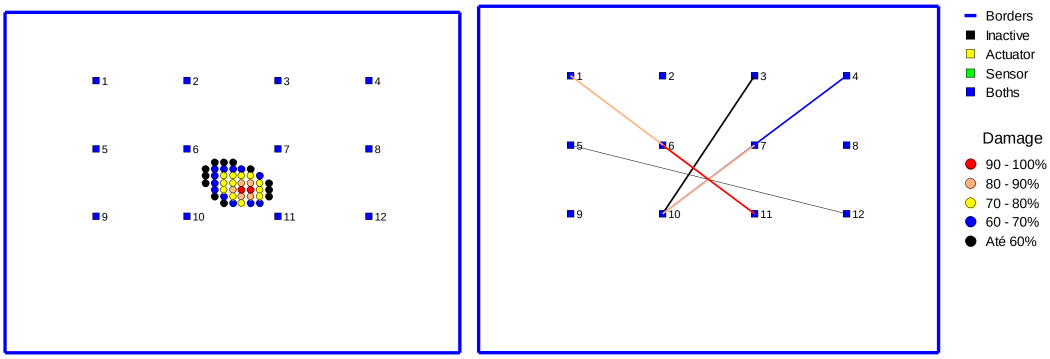
Figure 3: Position of the simulated damages

In order to verify the methods, it was performed the identification using the baseline measured at the same day of the verification, Fig. 4 and Fig. 5, it can be observed that the methods could perfectly identify the damage for both positions.



(a) Hilbert Envelope (b) Power Spectrum Density

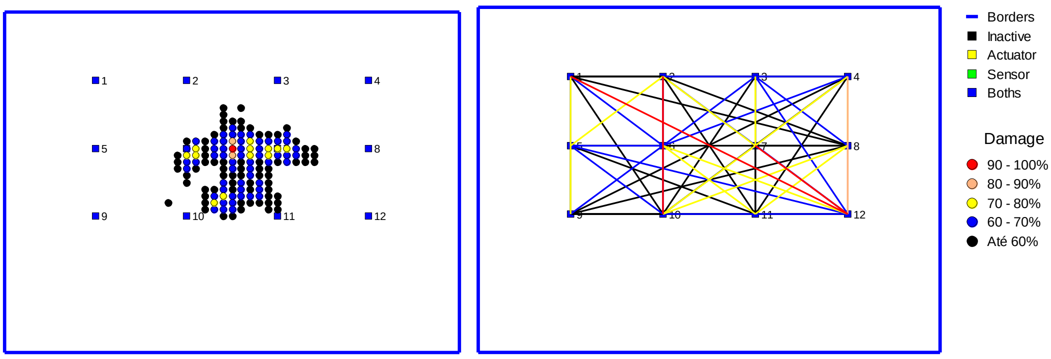
Figure 4: Identification using baseline#1 and verification #1 – normal threshold



(a) Hilbert Envelope (b) Power Spectrum Density

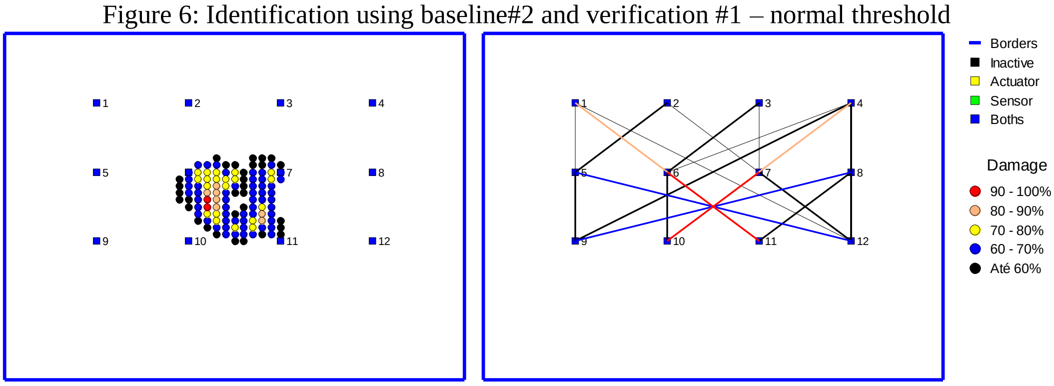
Figure 5: Identification using baseline#2 and verification #2 – normal threshold

However, when it is used the baseline #1 with the verification #2 or the baseline #2 with the verification #1, Fig. 6 and Fig. 7, it is observed that the methods were able to identify the damage position but it was not a prefect identification because other points appeared as possible location to the damages.



(a) Hilbert Envelope (b) Power Spectrum Density

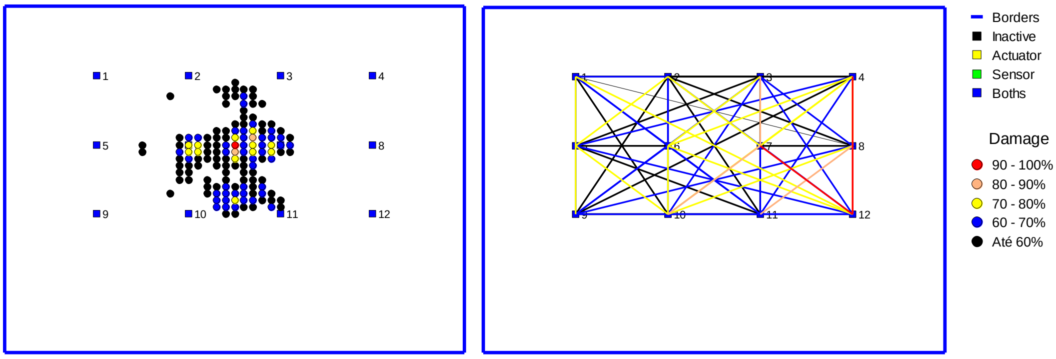
Figure 6: Identification using baseline#2 and verification #1 – normal threshold



(a) Hilbert Envelope (b) Power Spectrum Density

Figure 7: Identification using baseline#1 and verification #2 – normal threshold

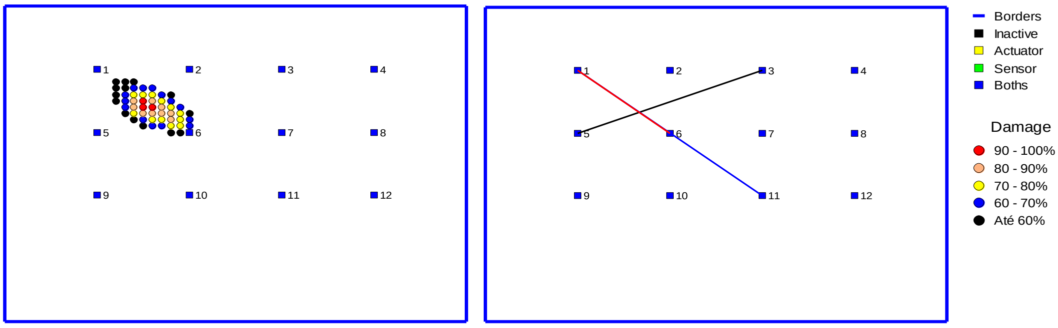
The most important observation arise from Fig. 8 where it is compared both baselines, which several points can be identified as damage positions, this situation is defined as false positives, where there is no damage but the method indicates damage. As defined in the beginning, due to environmental conditions all sensors presented values great than the threshold, so all of them indicate that there is damage in the structure.



(a) Hilbert Envelope (b) Power Spectrum Density

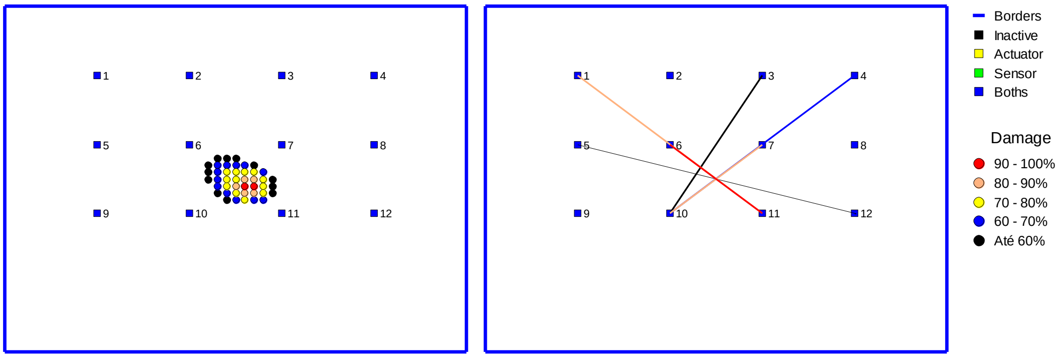
Figure 8: Identification using baseline#1 and baseline #2 – normal threshold

Now, using the methodology of increasing the threshold by the average over the sensors, the results are presented in Fig. 9 for the baseline #1 and verification #1 and in Fig. 10 for the baseline #2 and verification #2. It is observed that there is no change in the results if compared to those presented in Fig. 4 and Fig. 5. Therefore, the method does not interfere in the procedure of inspection.



(a) Hilbert Envelope (b) Power Spectrum Density

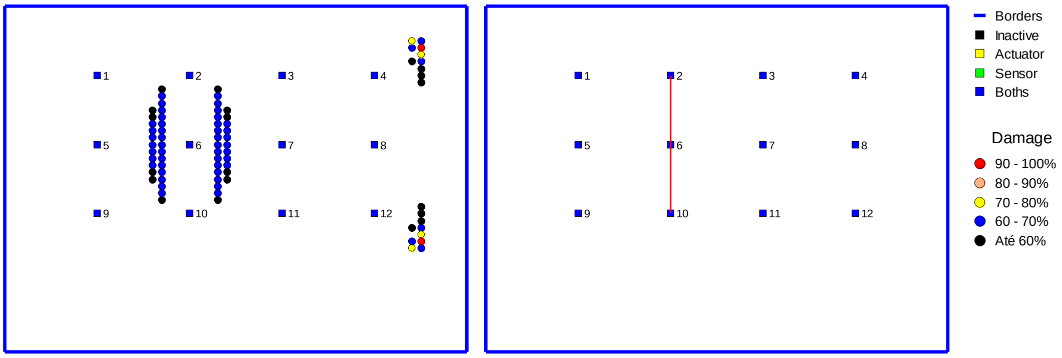
Figure 9: Identification using baseline#1 and verification #1 – modified threshold



(a) Hilbert Envelope (b) Power Spectrum Density

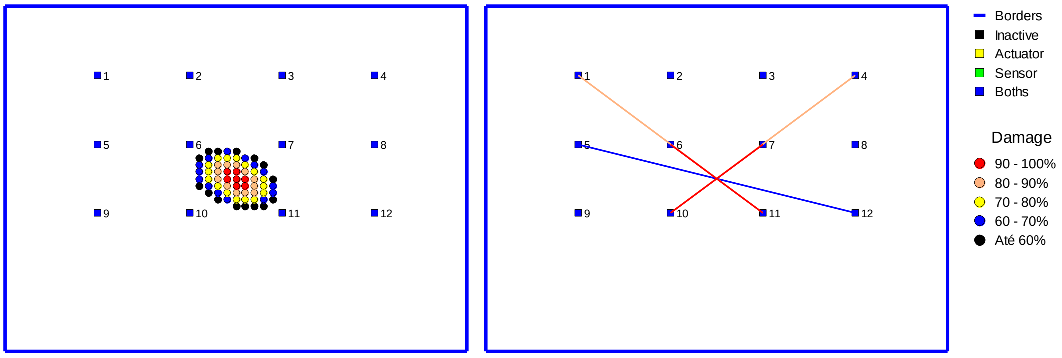
Figure 10: Identification using baseline#2 and verification #2 – modified threshold

However, when testing baseline #2 and verification #1, Fig. 11, only appears a possible identification of damage, but when testing baseline #1 and verification #2, Fig. 12, the identification was the same as that observed in Fig. 5. These results show that the modification in the threshold decrease the capability of identify the damage because it could identify the damage of 1.50 inches but not perfectly identified the damage with 0.75 inches.



(a) Hilbert Envelope (b) Power Spectrum Density

Figure 11: Identification using baseline#2 and verification #1 – modified threshold



(a) Hilbert Envelope (b) Power Spectrum Density

Figure 12: Identification using baseline#1 and verification #2 – modified threshold

The most important result of the proposed methodology is presented Fig. 13 where it is compared the baseline#1 with baseline #2 and shows no identification that means that the false positive was avoided.

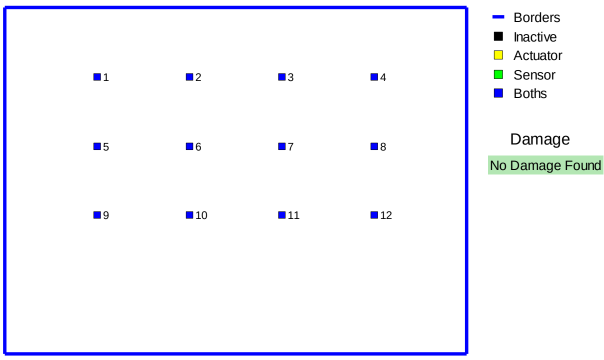


Figure 13: Identification using baseline#1 and baseline #2 – modified threshold

5. FINAL REMARKS

This work presented a simple method to overcome the temperature influence in SHM using Lamb wave inspection. The proposed solution was tested in a simple squared composite plate and the results shown that the technique is promising.

Despite of the technique had lost accuracy when testing the small damage of 0.75 inches, it avoided of appearing the false positive when comparing both baselines.

6. ACKNOWLEDGEMENTS

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