



24th COBEM - 2017



24th ABCM International Congress of Mechanical Engineering
December 3-8, 2017, Curitiba, PR, Brazil

COBEM-2017-2192

USE OF LAMB WAVES TO DETECT DAMAGE TO METAL BEAMS

A.P.L. Silva Jr

P.R. Novak

Federal Technological University of Paraná, Post-Graduation Program in Civil Engineering, PR, Pato Branco, Brazil
novak@utfpr.edu.br; pedroleirias@gmail.com

Abstract. We present in this paper a study monitoring technique and detection of the structural integrity of a metal beam using piezoelectric actuators and receivers attached. The piezoelectric material used is lead zirconate titanate (PZT) attached to an aluminium beam. The technique consists in the observation of Lamb wave propagation in solid media. Lamb waves are formed as electrical pulses and applied in a PZT actuator which makes mechanical excitation. This excitation is transmitted along the structure (Rafter), being finally caught by PZT receiver. This study was first tested the structure and then applied a localized damage. The reading of data collected in the structure are features different parameters of the collected in structure with flaws, so the damage is identified by comparing the received signals. Verification of the results of the two readings is through Continuous Wavelet transform (CWT).

Keywords: Lamb Waves, Damage, Piezoelectricity

1. INTRODUCTION

Currently the spans of the structures of buildings has increased significantly adapting the architectural and construction cost requests, generating greater deformations and susceptibility to vibration effects, which ultimately increases the incidence of damage along the lifetime of the structure. The techniques to monitor the condition of these structural systems, as well as your integrity, have become a very interesting area of research, with the objective of safety and performance over time of these structural systems.

As an option for a nondestructive evaluation, we have the methodologies such as ultrasonic Lamb waves that are already used to detect damage in several areas of Engineering (Franco, 2009).

The use of Lamb Waves allows the inspection of elements quickly, once you have control over your dispersion and their modes of vibrating, which represents ease of interpretation, requiring a specific methodology for this purpose (Farias *et al.*, 2011).

The techniques studied by Leucas (2009) and Santos *et al.* (2016) demonstrate the use of the methodology pitch-catch (Raghavan and Cesnik, 2005), however there is no dissipation of energy generated by the mechanical wave disturbance in structure, which increases the difficulty of signal detection. The use of the Transformed Wavelet is still conducting the probes in the detection of changes interpretations in the received signal, improving the standard of reading the mechanical signal received.

The propose of this work is the observation of a damage of the structure through a non-destructive technique. This technique uses the Lamb wave technique to detect damages in an aluminum beam using piezoelectric ceramics as actuator and receiver.

2. THEORETICAL BACKGROUND

2.1 Lamb Waves

Lamb waves have been used in ultrasonic testing and evaluation of materials for several decades, and numerous surveys were undertaken to study the methods of generation and approval of these types of waves and their propagation characteristics in plates type structures (Franco, 2009).

Lamb waves are elastic waves that are associated with the propagation modes of structures. Are related to disturbances propagation in elastic solids with edges or free interfaces. Noting that the thickness of the studied element must have the order of magnitude of the existing wavelengths, producing movement in the direction of propagation and perpendicular to this.

Lamb waves, also known as flat waves or guided waves, represent two-dimensional vibration plates (Alleyne, 1992).

2.2 Wavelet

A wavelet is a brief oscillation with amplitude starting and ending in zero. In most of the cases are intentionally generated with specific properties, such as period and frequency, with goals of digital processing. Can be combined with signs known for extracting information of unknown signals.

2.3 Wavelet of Morlet

The wavelets can have different formats, depending on the oscillation characteristic being studied. However the choice of model to be used can alter the results obtained in order to emphasize a certain feature of the analyzed signal. There are kinds of Haar, Maar, Meyer, Molet and other.

In this work we opted by the Wavelet of Morlet depending on the position of your central frequency, being useful in determining your scale.

Specifically the Wavelet of Morlet is a plane wave modulated by a Gaussian function, written as:

$$\psi(t) = \exp\left(\frac{-t^2}{2\sigma^2}\right) \exp(i\omega_0 t). \quad (1)$$

The wavelet function of Morlet is a complex function, which lets you analyze phase and the decomposed signal module (Domingues *et al.*, 2016).

2.4 The Wavelet Transform Continues (CWT)

The continuous wavelet transform is a linear integral transform that can be used in the operation of non-stationary signal characteristics to extract information from variations in certain frequency bands and/or detect local structures present. (Antoine *et al.*, 2008)

Given a sign f , your integral transform is defined as:

$$\mathcal{W}_f^\psi(a, t) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} f(t) \overline{\psi\left(\frac{t-\tau}{a}\right)} dt \quad (2)$$

in the parameter a (> 0) refers to scale and τ the translation or localization of the wavelet function-analyzing ψ , being a and $\tau \in \mathbb{R}$. The parameter controls the expansion/contraction of the analyzing wavelet-function. As the parameter τ ranges, the signal f is analyzed locally around it. So, can-analyzing the multiscale aspects of the signal stationary not studied. The upper trace in ψ denotes the complex conjugate function $\psi \in W_f^\psi(a, \tau)$ is known as wavelet coefficient. This transformation is called continuous, because these scale parameters takes continuous values of τ location in this representation (Domingues *et al.*, 2016).

2.5 Piezoelectric Materials

Are materials that can be relate to mechanical strain with electric potential. It's called piezoelectric effect when a direct material develops electricity (in the form of electric potential difference) to suffer mechanical effort, and inverse piezoelectric effect when a mechanical stress is produced through an electric potential in material (Tsuruta, 2008).

Piezoelectric materials can be performed in various ways, being as the need for your use, applied as actuator mechanical stress or receiver. In addition, the piezoelectric materials exhibit on insensitivity to thermal variations, since they are operating below the Curie temperature (Banks, et al, 1996).

Electric field/deformation relationship is approximately linear for low intensity of the electric field and, since in general the practical applications are limited to linear regime, using the piezoelectric effect in control systems is advantageous (V.R. Franco, 2009).

3. METHODOLOGY

The technique consists in generate a pulse formed by a Wavelet type of wave through a routine in Matlab ® software (Figure 01). Initially, a sweep frequency (0 up to 10 kHz) was applied in a structure to identify the frequency with the greater energy. The frequency found was approximately 2800 Hz. The Morlet wavelet generated is transformed into electrical pulse. The pulse generated is preamplifier and is monitored by an oscilloscope (Figure. 02).

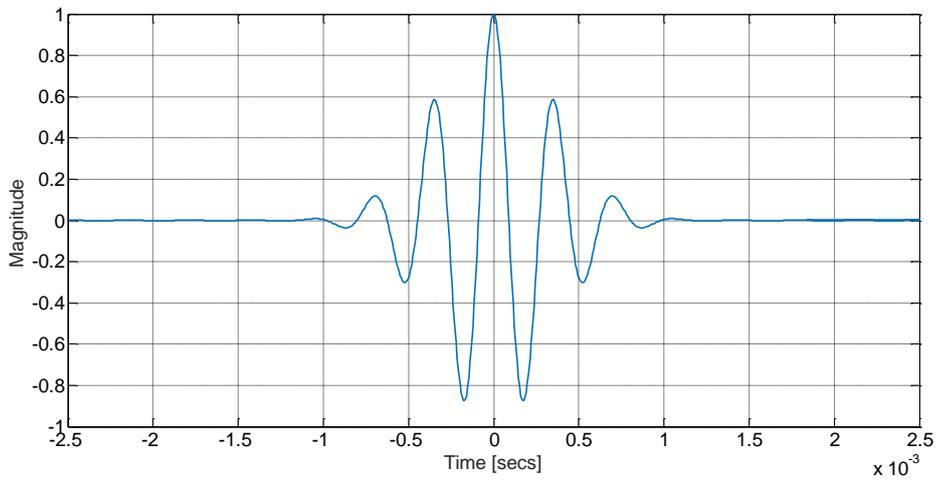


Figure 01. Lamb wave (Morlet Wavelet) generated by Matlab® routine.

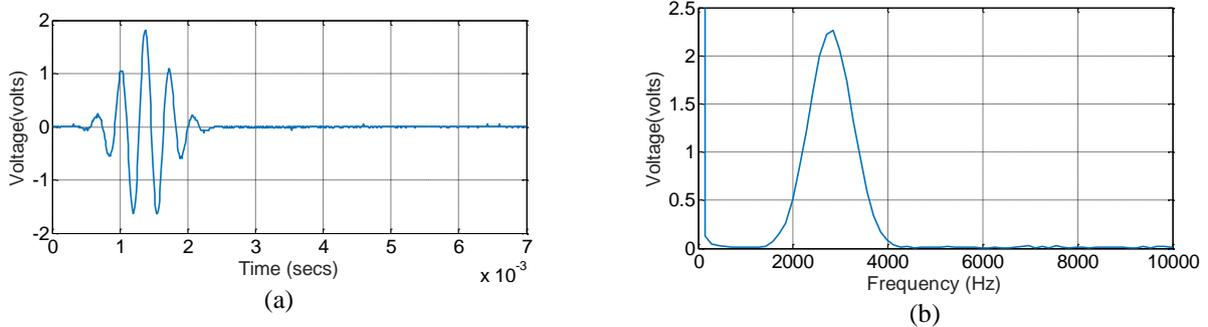


Figure 02. Pulse generated by PZT actuator: (a) Time domain (b) Frequency Domain .

The experimental setup consists of a bi-supported aluminum beam with dimensions of 37.0 mm x 4 mm x 0, 79 mm, as shown Fig. 03. The oscilloscope used is Tectronix TDS 2012C. Two channels are used to measure the actuator (yellow line) and receiver signal (blue line).

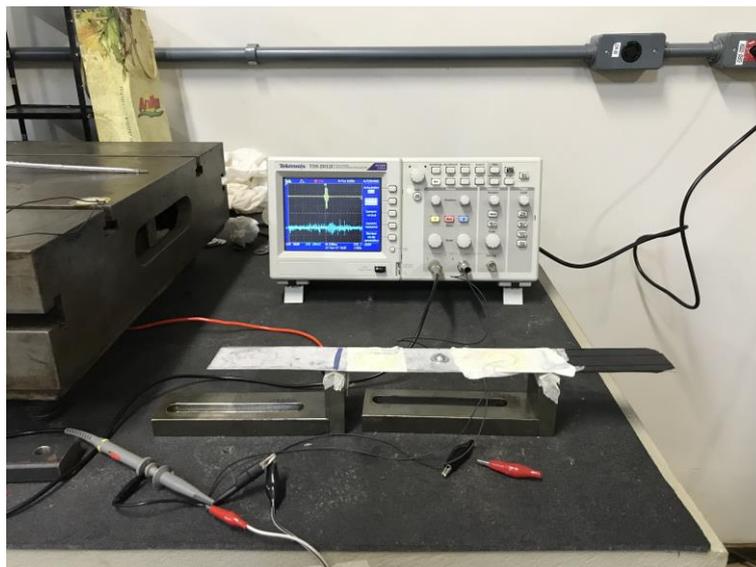


Figure 03. Experimental setup.

The Pitch-Catch method, showed in the Fig. 04, was utilized for the PZT position.

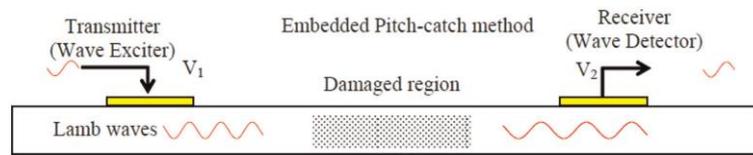


Figure 04. Pitch-Catch scheme (Gresil, and Giurgiutiu, 2013).

The damage simulation was performed with a 5.0 mm diameter hole in the center of the aluminum beam. The situation admitted as no damage is with a screw with a diameter of 4.8 mm fixed in this opening, and the situation with damage is considered without the screw. Measurements of the structure were made with and without the screw. The experimental procedure of the technique used is showed in the Fig 07.

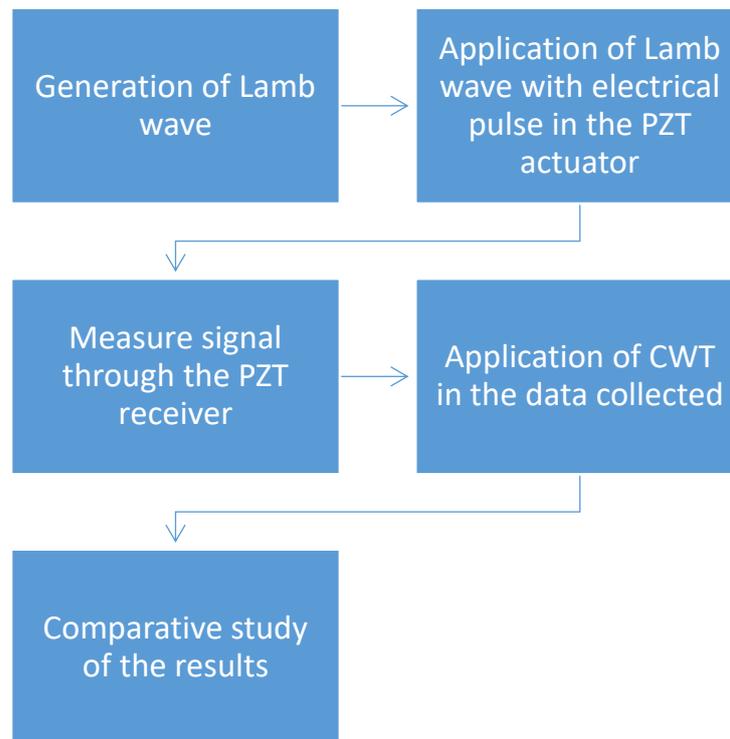


Figure 05. Experimental procedure.

4. RESULTS AND DISCUSSIONS

The Figures 06 and 07 shows the measured signal by receiver whit and without screw in the time and frequency domain, respectively.

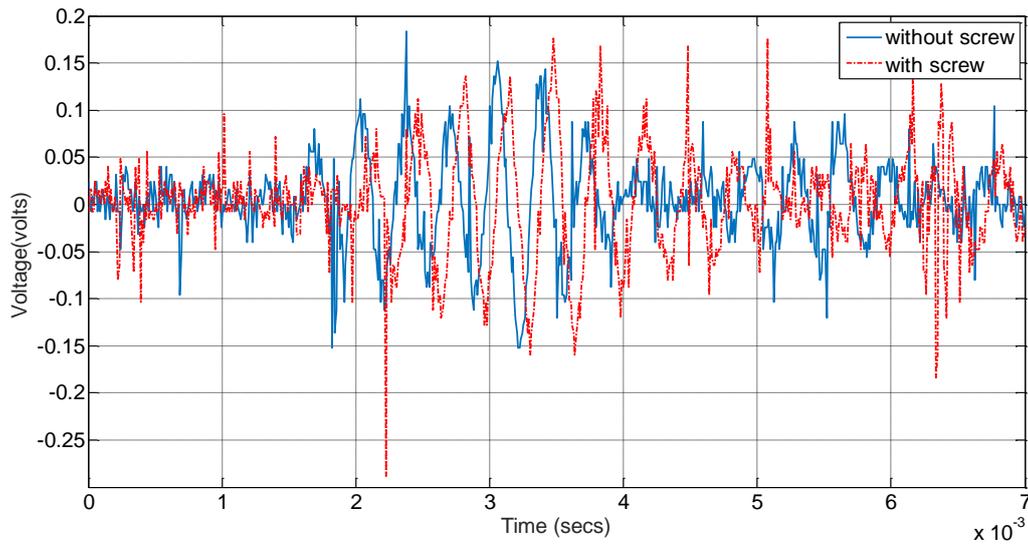


Figure 06. Signal measured from receiver in the time domain.

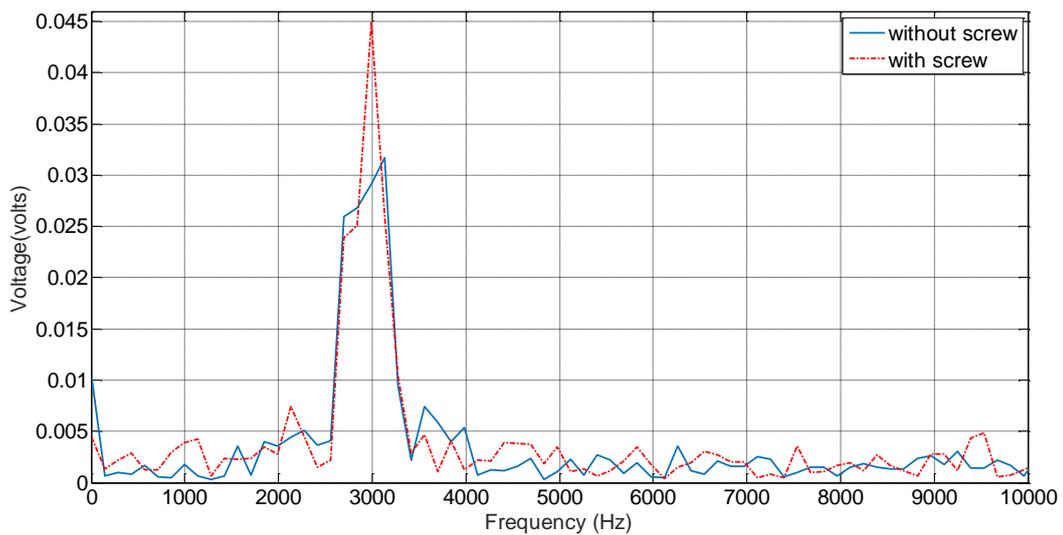


Figure 07. Signal measured from receiver in the frequency domain.

It is observed that the system's screw response has a frequency of 2987 Hz and amplitude of 0.045 Volts while the system without the screw (with damage) presented a frequency of 3129 Hz and amplitude of .032 volts. It is possible that the difference noted is due to damage.

The Figures 08 and 09 shows the CWT scalogram of the receiver signal without and with screw, respectively.

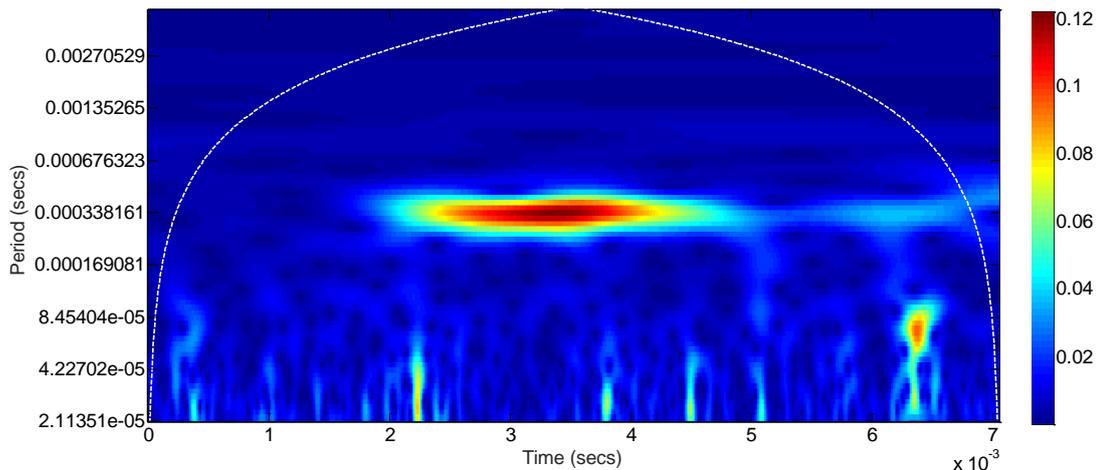


Figure 08. Magnitude scalogram with screw (no damage).

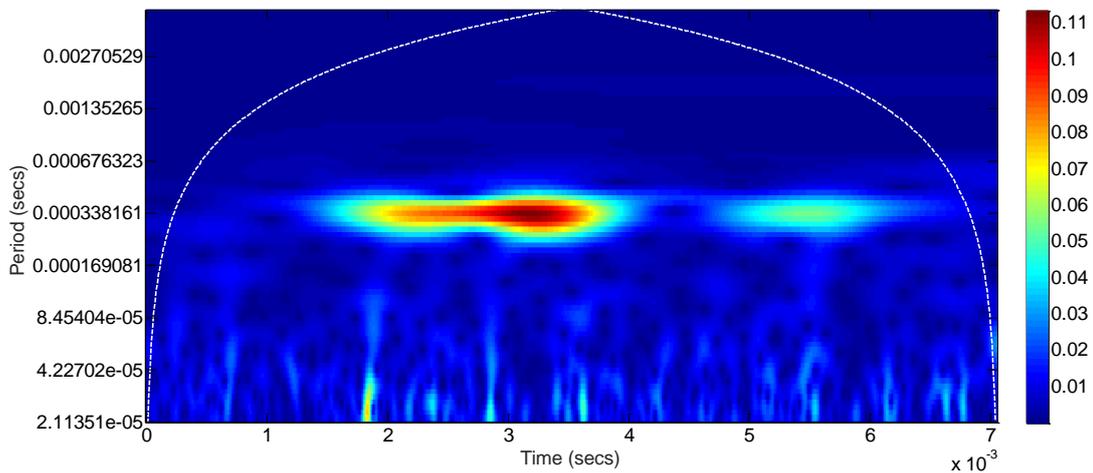


Figure 09. Magnitude scalogram without screw (damage).

5. CONCLUSION

This work uses the Lamb wave technique to detect damages in an aluminum beam using piezoelectric ceramics as actuator and receiver.

The result demonstrates that the technique detected a variation of the signal in the frequency domain, which is possibly related to damage. To prove the result obtained it is intended in the future to use the damage index.

6. ACKNOWLEDGEMENTS

The authors would like to acknowledge the UTFPR Câmpus Pato Branco, the Fundação Araucaria, the Secretaria de Estado da Ciência, Tecnologia e Ensino Superior do Paraná (SETI) and CAPES for the infrastructure and financial support provided for this study.



7. REFERENCES

- Stubbs, N., Kim, J.T. and Farrar, C.R., 1995. Field verification of a nondestructive damage localization and severity estimation algorithm. In: *International Modal Analysis Conference IMAC*.
- Franco, V.R., 2009. *Monitoramento da integridade em estruturas aeronáuticas*, Unesp, Ilha Solteira.
- Farias, C.T.T., Paranhos, R.S., Silva, I.C., Simas Filho, E.F., Menezes, I. and Dias, J.D.C., 2011. Estudo da propagação das ondas de Lamb em chapas de alumínio com furos de diferentes profundidades. In *5th Pan American Conference for NDT*.
- Leucas, L.F., 2009. *Utilização das técnicas de impedância eletromecânica e ondas de lamb para a identificação de dano em estrutura com rebites*, UFU, Uberlândia.
- Santos, J.G.F., Borges, D.M., Neto, R.M.F. and Rocha, L.A.A., 2016. Monitoramento utilizando a técnica de ondas de lamb para detecção de dano em estruturas metálicas, In *XXVII Iberian latin American Congress on Computational Methods in Engineering*.
- Raghavan A. and Cesnik, C.E.S., 2005. Lamb-Wave Based structural health monitoring, Damage prognosis for aerospace, civil and mechanical system, Wiley, Cap. 11, pp 235-274.
- Alleyne, D. N. and Cawley, P., 1992. Optimization of Lamb Wave Inspection Techniques. *NDT & E International*. Vol. 25 n1, pp. 11-22.
- Domingues, M.O., Mendes, O., Kaibara, M.K., Menconi, V.E. and Bernardes, E., 2016. *Explorando a transformada wavelet contínua*, Revista Brasileira de Ensino de Física, vol. 38, nº 3, e3314
- Antoine, J.P., Murenzi, R., Vandergheynst, P. and Ali, S.T. 2008. *Two-Dimensional Wavelets and Their Relatives*, Cambridge University, Cambridge.
- Tsuruta, K. M., 2008. *Monitoramento de Integridade Estrutural de Materiais Compostos Sujeitos a Impactos Empregando a Técnica da Impedância Eletromecânica*, Universidade Federal de Uberlândia, Uberlândia.
- Banks, H.T., Smith, R.C. and Wang, Y. , 1996. *Smart Materials Structures – Modeling, Estimation and Control*. Paris: John Wiley & Sons.
- Gresil, M. and Giurgiutiu V., 2013. *Time-domain hybrid global–local concept for guided-wave propagation with piezoelectric wafer active sensor*, In *Journal of Intelligent Material Systems and Structures*, University of South Carolina, Columbia.

8. RESPONSIBILITY NOTICE

The author(s) is (are) the only responsible for the printed material included in this paper.