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Structural health monitoring in cylindrical structures using helical guided wave propagation

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Abstract

Defect detection and characterization are critical tasks for structural health monitoring of pipe-like engineering structures. Propagation and detection of ultrasonic helical Lamb waves using macro fiber composite (MFC) sensors is studied. Experiments for defect detection and characterization on an aluminum hollow cylinder (114 mm in outer-diameter and 6 mm of wall thickness) were carried out. An experimental setup using MFC sensors coupled to the cylinder’s surface in a pitch-catch configuration is presented. Time-frequency representation (TFR) using wavelets is employed to accurately perform mode identification of the ultrasonic captured signals. The initial results indicate that the use of helical waves could allow the monitoring of damage in difficult to access critical areas by locating the sensors only on a small region of the periphery of the cylindrical structure under inspection.

Keywords: Helical propagation; Guided waves; Cylinders; Entropy

1. Introduction

The use of ultrasonic helical guided waves propagation in Structural Health Monitoring (SHM) for defect detection and characterization in cylindrical structures has been recently investigated (Balvatin, Baltazar, & Kim, 2012). It is also known that dispersion phenomena and the existence of an infinite number of vibrational modes propagating in a structure complicate the study of guided waves and their practical implementation (Rose J., 1999) (Alleyne & Cawley, 1996).

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However, in hollow cylinders, where the thickness is much greater than the wavelength, ultrasonic wave propagation can be considered as Lamb wave propagation which simplifies the modeling. Furthermore, helical propagated waves follow the curvature of the structure and can be directed along any desired circumferential helical path. Recently, the use of Lamb waves has sparked an interest of their application for structural health monitoring in pipe-like structures (Cawley, Lowe, Alleyne, Pavlakovic, & Wilcox, 2002).

Practical signal generation and capture process of ultrasonic signals requires a good coupling between the ultrasonic transducers and the curve surface of the cylinder. Poor coupling conditions can lead to amplitude variations of generated dispersion modes leading to measurement errors. New developments in piezoelectric sensors to make them more cost/effective have been investigated. Nanocomposite piezoelectric sensors have been designed, studied, and proposed as potential sensors to detect cracks, corrosion and other aging effects in pipelines used by the gas and petroleum companies (Meyers, Loh, Doods, & Baltazar, 2013). Also, the use of Macro fibers composite (MFC) sensors for damage detection in hallow cylinders has been studied (Thien, Puckett, Park, & Farrar, 2006).

In this work, we study helical Lamb propagation in a hollow cylinder. The objectives of this work are: first, to generate helical Lamb guided waves using MFC sensors; second, to identify damage presence in an aluminum cylinder by analyzing the gathered signal with a proposed discrete wavelet technique (STWE).

2. Helical guided waves

Helical propagation of Lamb waves in hollow cylinders has been reported (i.e. Balvantin et al., 2012) they corroborate the directionality of helical propagation of Lamb based on the short time Fourier transform (STFT) analysis. Also, they implement the helical propagation of the waves to identify contact conditions of two cylinders in axial contact. Helical guided wave propagation can be generated using arrays of contact transducers placed in the circumference of the cylindrical structure in a pitch-catch configuration with water as a coupling or dry-coupled transducers (Alleyne & Cawley, 1996) (Lowe, Alleyne, & Cawley, 1998).

3. Short time wavelet entropy (STWE)

In order to identify the generated mode, a signal preprocessing is required. The use of time-frequency representation (TFR) for parameter identification of captured signals has been widely used (Niethammer, Jacobs, Qu, & Jarzynski, 2001). Here, STWE technique is used to characterize the signals. STWE is a signal decomposition analysis based on the discrete wavelet transform (see Rojas, et al. (2015) for details). The wavelet analysis
decomposes the signal in levels called details(Fig. 2a). Each detail is processed to obtain its energy distribution and calculate the time evolution of entropy for the analyzed signal (Fig. 2b).

Fig. 2. (a) Details of discrete wavelet transform; (b) signal’s entropy distribution using STWE (red arrow indicates amplitude in entropy).

4. Experimental setup

The experimental setup (Fig. 3a) consists of an aluminum hollow 100 cm long cylinder (114 mm in outer-diameter and 6 mm of wall thickness). To generate an artificial damage, a thickness reduction (2 mm) in the cylinder is made (Fig. 3c). Also, two macro fiber composite (model MFC-M2814) sensors manufactured by Smart Material Inc., with an active area of 28 mm x 14 mm and a bandwidth of 750 kHz, are used. The sensors are attached to the cylinder using typical double side tape. The MFC sensors are implemented in a pitch-catch configuration (Fig. 3b). A six cycle tone burst, at 500 kHz, is generated by a function generator (Agilent 33220A), then, the signal is gathered by a broadband receiver (Ritec Broadband BR-640A) and averaged (64 times) with an oscilloscope (Tektronix DPO 3012). The distance between sensors and the directionally angle of the sensors were Δx=166 mm and θ=65°, respectively. With these parameters Lamb wave is propagated only one helical loop.

Fig. 3. (a) Experimental setup; (b) MFC sensors attached to cylinder; (c) discontinuity in aluminum cylinder.

5. Results and discussion

Figures 4 shows the results of STWE and STFT for a signal taken from a sample with and without damage. In Fig 4a and b, the arrow indicate the maximum in entropy, which seems to be related to the arrival in one loop of the propagated helical wave. To corroborate that the gathered signal corresponds to one loop of the helical wave, the theoretical time of arrival of the signal (A0 mode at 500kHz) was obtained based on the traveled distance (394 mm) of the helical path as 129.4 μs which is closed to the experimental value (136.6 μs).

The entropy distribution of the signal due to the presence of damage is modified as can be seen in Fig. 4b. The STFT analysis also detects changes in the gathered signals; however, the computational cost is larger than the proposed
method (Ibáñez, Baltazar, & Mijarez, 2015). Theoretical dispersion curves are plotted in Fig. 4d to compare the time of arrival of the signal with and without damage (blue and black dashed lines, respectively). As can be observed, a time delay in the gathered signals is generated due to the presence of damage in cylinder (Fig. 4d).

Fig. 4. (a) and (b) baseline signal and signal with damage (arrows indicate maximum in entropy); (c) and (d) signal’s STFT from (a) and (b) respectively (arrows indicate the propagated A0 mode).

6. Conclusions

It was shown that MFC sensors can be easily adapted to the curvature of the tested hollow cylinder due to their flexibility characteristic. It was found that they are capable of generating Lamb waves with helical propagation. In the presence of damage, the proposed STWE analysis allows defect detection by analyzing the entropy evolution which is a 1D analysis making it a fast algorithm for detection of damage.

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References

Alleyne, D., & Cawley, P. (1996). The Excitation of Lamb Waves in Pipes Using Dry-Coupled Piezoelectric Transducers. J. Non-Destruct. Eval., 15, 11-20.
Balvaintin, A., Baltazar, A., & Kim, J. (2012). A study of helical Lamb wave propagation on two hollow cylinders with imperfect contact conditions. AIP Conference Proceedings, 1511(1), 67-74.
Cawley, P., Lowe, M., Alleyne, D., Pavlakovic, B., & Wilcox, P. (2002). Practical long range guided wave inspection—application to pipes and rails. Materials Evaluation, 60, 66-74.
Ibáñez, F., Baltazar, A., & Mijarez, R. (2015). Detection of damage in multiwire cables based on wavelet entropy evolution. Smart Materials and Structures.
Lowe, M., Alleyne, D., & Cawley, P. (1998). Defect detection in pipes using guided waves. Ultrasonics, 36, 147-154.
Meyers, F., Loh, K., Doods, J., & Baltazar, A. (2013). Active sensing and damage detection using piezoelectric zinc oxide-based nanocomposites. Nanotechnology, 24(18), 1-10.
Niethammer, M., Jacobs, L., Qu, J., & Jarzynski, J. (2001). Time-frequency representations of Lamb waves. J. Acoust. Soc. Am., 109, 1841-1847.
Rojas, E., Baltazar, A., & Loh, K. (2015). Damage detection using the signal entropy of an ultrasonic sensor network. Smart Materials and Structures.
Rose, J. (1999). Ultrasonic waves in solid media (First ed.). Cambridge: Cambridge University Press.
Thien, B., Puckett, A., Park, G., & Farrar, C. (2006). Detecting and Locating Cracks and Corrosion in Pipes using Ultrasonic Guided Waves. Proceedings of 3rd European Structural Health Monitoring Conference, 1045-1053.