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A method for acoustic source location in plate-type structures

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In this study an algorithm based on Shannon entropy, cross-time frequency spectrum (CTFS) and frequency varying velocities was proposed for structure health monitoring in two-layer plate. A linear array of two sensors is applied to capture the signals. By reducing the number of sensors we used a secondary pattern to get enough information for source locating. For this purpose a pattern for secondary points based on Shannon entropy and cost function was developed. Then to estimate the time delay of signals, cross-time frequency spectrum function was taken from captured signals. The time delay was calculated when CTFS function reached the maximum value. By taking short time Fourier transform of cross correlation function of captures signals and using dispersive curves, time delay and corresponding frequency dependent velocity are estimated. The experiments were carried out and the results showed high precision of presented algorithm.

1. Introduction

In today's economy, structures must remain in operation for long periods of time. Monitoring of corrosion, erosion and crack growth in these structures are becoming significant and must be accounted for in the decisions made regarding usage and maintenance of them. Acoustic emission is a technique which is being used increasingly in the field of structural integrity monitoring using fracture mechanics. This technique has been widely used in industries for detection of defects in pipe and plate type structures. Tobias [1] derived an exact solution for the configuration of three sensors in a plate. The location of the source on the plate is determined at the intersection points of two hyperbolas. Mostafapour et al. [2] used the theories of wavelet transform and cross-time frequency spectrum to locate AE source with frequency-varying wave velocity in plate type structures. They used rectangular array of four sensors on plate. Yang et al. [3] proposed an acoustic emission analysis method based on multiple signal classification method (MUSIC) to calculate the direction of arrival of the wave signal in plate type structures. They estimated the direction of arrival using the multiple signal classification and the time delay of the wave was gained using the continuous wavelet transform. Sedlak et al. [4] compared the first-arrival determination results for thin plate obtained from two-steps AIC picker with Kurz's method, STA/LTA method and standard threshold crossing technique. Jiao et al. [5] proposed a technique based on the theory of modal acoustic emission for plate structure source location with one sensor. Based on dispersion characteristics of guided wave propagation, they isolated two modes in acoustic signal captured by one sensor. Jumaili et al. [6] presented an improved automatic delta T mapping technique using a clustering algorithm to automatically identify and select the highly correlated events at each grid point. They used minimum difference approach to determine the AE source location. Kundu et al. [7] proposed a technique to locate the acoustic source in large anisotropic plates with the help of six sensors without knowing the direction dependent velocity profile in the plate.

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For isotropic plates the required number of sensors can be reduced from 6 to 4. Aljets et al. [8] developed an AE source location method for large plate-like structures using a combined time of flight and modal source location algorithm. They used three sensors in a triangular array with a sensor to sensor distance of just a few centimeters. By analyzing the A_0 and S_0 components of the signal, the arrival times and the distances can be evaluated using mode separation. Jiang et al. [9] used acoustic emission tomography based on simultaneous algebraic reconstruction technique which combined the traditional location algorithm with the SART algorithm using AE events as its signal sources. They examined two-mode damage source location in the Q235B steel plate to validate the algorithm effectiveness. Ernst et al. [10] presented an approach which required one sensor to identify and localize the source of acoustic emission in plates. They used the time reversal principle and dispersive nature of the flexural wave mode. The signal shape of the transverse velocity response contains information about the propagated paths of the incoming elastic waves. The information was made accessible by a numerical time reversal simulation. It was analyzed for an infinite Mindlin plate then by 3D FEM simulation. Surgeon and Wevers [11] investigated the modal nature of AE signals to locate AE source during tensile and bending tests. They used two different plate wave theories (simple and higher order plate wave theories) to calculate the propagation velocities of extensional and flexural modes and theoretically they estimated the arrival time differences between two modes. Mostafapour and Davoodi [12] proposed a method for continuous leakage source location with one sensor in gas-filled pipe and noisy environment based on wavelet analysis and modal location theory. By wavelet decomposition a frequency range was selected and flexural and extensional modes were analyzed. Masoumi and Ashory [13] used two approaches to identify damage in plate-type structures. The first one was to form uniform load surface by using mode shapes of damaged structure and then using 2-D wavelet transform for detecting damage. The second one was based on forming generalized flexibility matrix using mode shapes of damaged structure and then 2-D wavelet transform was applied.

In this study a new algorithm based on using a linear array of two acoustic sensors for health monitoring of plates is developed. By reducing the number of sensors into two, first a pattern for secondary points was developed. In this pattern a database was gathered from Hsu-Nielsen source. Then space feature based on entropy of wavelet transform coefficient signals was extracted. A combination of cross time frequency spectrum with frequency dependent wave velocity was used to calculate the time delay and acoustic source location. The experiments were carried out to validate the proposed algorithm.

2. Experimental set-up

In this study to validate the proposed method, some laboratory experiments were carried out on a two-layered thin plate with different acoustic impedances of layers. An aluminum plate with dimensions of $70 * 70$ cm and 3 mm thickness was considered. A polyethylene layer of 1 mm thickness was hot coated on a surface of $70 * 60$ cm on aluminum plate. The mechanical and acoustic properties of materials are shown in Table 1.

Hsu-Nielsen source is an aid to simulate an acoustic emission event using the fracture of a brittle graphite lead in a suitable fitting. This test consists of breaking a 0.3 mm diameter pencil lead approximately, 3 mm from its tip by pressing it against the surface of the plate as shown in Fig. 1. To capture the acoustic signals, two R15a sensors were installed in a linear array as shown in Fig. 2.

3. Acoustic source location principle

3.1. Wavelet transform

New aspects of image and signal processing over the past few years were introduced by the wavelet transform. Wavelet transform is as an effective method for acoustic signal analysis. Wavelet analysis defined as decomposing a signal into two parts of low frequency named as approximation and high frequency as detail. In discrete wavelet, details do not analyze again instead, in packet wavelets approximations and details are divided in two parts. In this study both discrete and packet wavelets are used. Wavelet transform of $F(t)$ is as:

$$CWT(f,\zeta) = \int_{-\infty}^{\infty} \frac{1}{\sqrt{f}} F(t)\psi^{*}\left(\frac{t-\zeta}{f}\right)dt \tag{1}$$

which f, ζ and ψ^* show frequency, time shift and the complex conjugate of wavelet, respectively [14]. Packet wavelet transform is shown as $\psi^i_{j,k}$ which i, j and u are modulation, dilation and translation parameters respectively:

$$\psi^i_{j,u} = 2^{-j/2}\psi^i(2^{-j}t - u) \tag{2}$$

Table 1
Mechanical and acoustic properties.

Material	Young's modulus (GPa)	Shear modulus (GPa)	Poisson's ratio	Density (g/cm^3)	Acoustic impedance (g/cm^2·s * 10^5)
PE (HDPE)	0.7	0.31	0.46	0.95	2.93
Al (AA5052)	70.3	25.9	0.33	2.68	17.8