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Acoustic emission source location in dispersive media

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Abstract

In this paper, the acoustic emission source (AE) is located by a non-iterative method using the time-of-arrival (TOA) of several events, received in an array of sensors arbitrary positioning in the 3D space. If at least two event velocities are different, a common property in dispersive propagation, and the array of sensors is not lying in a plane, a close-form estimation of the source–sensors distances, AE time and material constant is derived. Moreover, a direct estimation of the source position is achieved using the multidimensional scaling approach. In simulation experiments, the proposed method detects accurately the location of AE sources, reducing also the ambiguity introduced by noisy arrival times.
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Keywords: Acoustic emission; Source location; Time-of-arrival; Dispersive materials

1. Introduction

Acoustic emission (AE) methods are based on the processing and information extraction from the ultrasonic waves generated by pressure forces and damage events, and it is used for monitoring, damage location and fracture analysis of composites using array of sensors [1–3]. A great number of studies are presented and a number of commercial systems are operating in real constructions for real-time identification and AE source location. A number of authors [8,12,13] have demonstrated how the extensional and the flexural waves modes can be acquired by piezoelectric sensors. The extensional mode waves are propagated at a higher velocity and exhibit little or no dispersion, meaning that all frequency components have approximately the same velocity. The flexural waves are propagated at lower velocities and the harmonic components of the signal are dispersive, i.e. the velocity of propagation are frequency dependent.

Based on the arrival-time differences, observed in an array of three sensors, Tobias [4] derives an exact solution for the configuration of three sensors in a planar surface. The AE source is located at the intersection points of two hyperbolae. Using the differences in time-of-arrival (TOA) from an AE source to three sensors [5], the position of the source is calculated through the use of special coordinates on the surface of the pressure vessel and planar surfaces by increasing the radius of the sphere to infinity. In both types of surfaces, source location may be ambiguous and a fourth sensor is needed. In a similar approach, Barat et al. [7] developed a mathematical method for the calculation of the coordinates of an AE source on cylindrical surfaces on the concept of geodesics. In [6], a generalized mathematical formalism for the path

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traveled by an acoustic wave in the surface of a structure is presented, and a direct method for the calculation of the coordinates of an AE source on a cylindrical surface by three sensors is evaluated. In [8], the dispersion characteristics of the AE wave modes are predicted and the wavelet transform theory were used to derive the arrival times of the different modes through modal analysis of the propagation of elastic waves in a thin plate. By taking into account the modal nature of AE signals, the minimum number of sensors needed in an AE source location can be reduced [12]. Using the signals obtained during tensile and bending tests, performed on a number of cross-ply and unidirectional carbon fibre-reinforced polymer lay-ups, it is shown how a linear source location can be calculated using only one sensor. A two-dimensional source location method, based on the measured Lamb group velocities with only two AE sensors, is evaluated in [13] using the pencil lead fracture.

A method for position detection of a friction source was presented in [9], based on a location source database. The deviation of the arrival time is detected accurately by calculating the phase shift based on the cross-correlation of two sensor signals. Two alternative but equivalent procedures for the best estimation of the source location, corresponding to the ellipse's centre for three or more microphone clusters are presented in [10]. A novel identification method of the source position generating impulsive periodic signals is proposed in [15], requiring a minimum of three microphones to identify impulsive sources in 2-D space, while in 3-D space at least four microphones must be used. A source location method of impacts on elastic plates is presented in [11], based on principles of dispersive-waves propagation in isotropic plates. The maxima of the wavelet magnitude are used to calculate the arrival times of the waves and the coordinates of the impact location; the time lag and the group velocity of the flexural waves are obtained by solving a system of four non-linear equations.

The proposed method derives the location of an AE source in dispersive materials using the TOA of N events at M sensors, $M>4$ arbitrary positioning in the 3D space. The complete method consists of three successive estimators:

- A close-form solution derive the normalized distances R_i, $i=1$, M between the AE source and sensors from the arrival time of N events by minimizing the least square error (LSE) between the actual and the expected arrival times. In the same minimization problem, a direct estimation of the AE time can be obtained.
- The minimization of the LSE between the real and the estimated source–sensors squared Euclidean distances leads to a close-form estimation of the material constant G, using the sensor positions and the normalized distances R_i. Consequently, the source–sensors distances are derived in a direct manner.
- The multidimensional scaling method (MDS) is used to locate the AE source using the estimated source–sensors distances and the sensor positions.

2. Location of AE events

If an AE impulse is generated at time T in an isotropic and dispersive material, several events, propagated at different velocities c_n, $n = 1, N$ can be identified in sensors signal. In many applications, the event velocity depends on material properties which is described in our problem by the constant G: $c_n = Gf_n$. A typical example of this relation can be found in the mass density: denser materials decrease the harmonic waves velocity by the same factor [16]. If the event velocities f_n is assumed to be known, the event n is arrived at time $t(n, r)$ at sensor m, placed at distance r from the source:

$$t(n,r) = \frac{r}{Gf_n} = \frac{r}{G} q_n = Rq_n, \tag{1}$$

where R is the normalized distance ($R = r/G$) between the AE source and the sensor, and $q_n = 1/f_n$.

2.1. Estimation of the AE source– sensors normalized distances

If the events velocity f_n, $n = 1, N$ are known, the LSE between the TOA O_{mn}, $m = 1, M$, $n = 1, N$ of an AE event at M sensors (estimated by processing the signal received at sensors), and the theoretical TOA $t(n, R) = R/f_n = Rq_n$ of an arbitrary AE source, positioning at normalized distances R_1, $R_2, \ldots, R_m, \ldots, R_M$ from sensors, is

$$E_t(R_1, \ldots, R_M, T) = \sum_{m=1}^{M}\sum_{n=1}^{N}(t(n, R_m) + T - O_{mn})^2, \tag{2}$$

where T is the time where the AE source release the impulse. In typical applications, value of T is also

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