Mechanical Systems and Signal Processing 84 (2017) 717–730

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Comparison of alternatives to amplitude thresholding for onset detection of acoustic emission signals

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ARTICLE INFO

Article history:
Received 4 December 2015
Received in revised form
1 September 2016
Accepted 3 September 2016
Available online 10 September 2016

Keywords:
Onset detection
Acoustic emission
Structural health monitoring

ABSTRACT

Acoustic Emission (AE) monitoring can be used to detect the presence of damage as well as determine its location in Structural Health Monitoring (SHM) applications. Information on the time difference of the signal generated by the damage event arriving at different sensors in an array is essential in performing localisation. Currently, this is determined using a fixed threshold which is particularly prone to errors when not set to optimal values. This paper presents three new methods for determining the onset of AE signals without the need for a predetermined threshold. The performance of the techniques is evaluated using AE signals generated during fatigue crack growth and compared to the established Akaike Information Criterion (AIC) and fixed threshold methods. It was found that the 1D location accuracy of the new methods was within the range of <1–7.1% of the monitored region compared to 2.7% for the AIC method and a range of 1.8–9.4% for the conventional Fixed Threshold method at different threshold levels.

1. Introduction

Acoustic Emission (AE) detection is a Structural Health Monitoring (SHM) technique which can be used to perform continuous monitoring of structures to detect the presence of damage via permanently installed sensors. As a structure is subjected to mechanical load, AE stress waves are dynamically excited from defects such as cracks in metals or broken fibres and cracked matrix in composite materials. These waves propagate through the structure and can be detected by monitoring surface displacements at a particular location using piezoelectric or fibre optic transducers for example. In thin plate like structures these waves are also referred to as Lamb waves [1]. They typically exhibit a characteristic behaviour where their wave velocity changes with frequency. This is also known as dispersion [1]. The detection and location of damage by sensing AE signals could serve as a form of automated structural inspection, with the potential to reduce inspection time, maintenance cost and also increase availability. The location of the source of AE events (and hence the location of damage) can be determined using measurements of Time Difference of Arrival (TDOA) of the signals detected at different sensors in an array. Other inputs in the calculation are the propagating wave velocity (V_g) and the sensor coordinates (x_i, y_i) as expressed in Eq. (1) [2].

$$(x_i - x_o)^2 + (y_i - y_o)^2 = (V_g \cdot \Delta t)^2 \tag{1}$$

where,

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http://dx.doi.org/10.1016/j.ymssp.2016.09.004

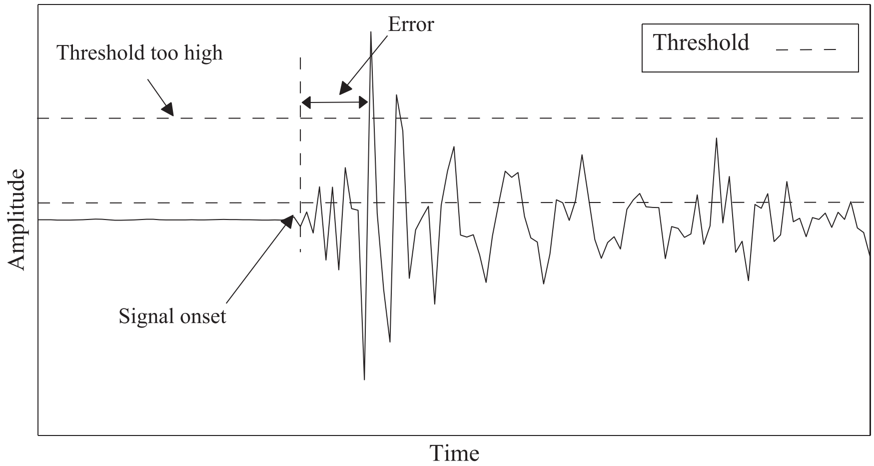

Fig. 1. Schematic of potential errors in detecting the onset of AE signals using the Fixed Threshold detection method.

x_o, y_o and (x_i, y_i) are the coordinates of source and sensors for i = 1, …n, Δt is the time difference of arrival of signal between different sensors, V_g is the propagating wave velocity.

Errors in estimating the location of damage can arise from any of these parameters. The wave velocity (V_g) for example is known to be dependent on the propagating media geometry as well as material properties; structures with complex geometry and anisotropic materials properties can be expected to experience significant variations in wave velocity even at a particular frequency. Assuming an incorrect value of wave velocity will yield errors in location estimation. Also, due to the absence of standardised approaches for sensor installation as well as human factors, inaccuracies in mapping the sensor coordinates can also yield errors in location estimation. This paper, however, is focused on the consideration of errors associated with TDOA measurements as a function of AE signal onset detection.

Currently, AE signal onset detection is most commonly performed using a fixed threshold, where the first point in time of signal amplitude exceeding a selected value marks the onset of the signal [3,4]. The main challenge in using this method is the appropriate selection of the threshold with respect to the background noise. Selecting a value too low might result in premature triggering by the preceding background noise and selecting a value too high might result in missing the time of actual signal onset as illustrated in Fig. 1. The value of detection threshold may be optimised for particular values of signal to noise ratio (SNR), if known beforehand; however in real applications a wide range of SNRs can be expected which invariably implies a vulnerability to measurement errors.

Other methods for determining the onset of AE signals have been developed in both the time as well as the time-frequency domains [2,4–9]. In the time domain, Akaike [10] developed a statistical method to determine the transition point in a time series between noise and a coherent signal, using the Akaike Information Criterion (AIC) as expressed in Eq. (2), also referred to as AIC picker [6].

$$AIC(t) = t\log_{10}(var(x[1;\ t])) + (N - t - 1)\log_{10}(var(x[t;\ N])) \tag{2}$$

This involves partitioning the signal $x(t)$ into two sections at a point t and calculating the AIC value. This process is repeated for all points within a time window of length N and the minimum value of AIC indicates the estimated point of signal onset. Sedlak, P. et al. [4] reported that the performance of this method is strongly dependent on the choice of the time window duration N. Typically, the window size N is determined by firstly using fixed threshold detection to obtain a 'rough estimation' of onset time, and then a portion of the signal - several hundred samples - is selected before and after this point as the window duration [4,6]. Improvements to the performance of this method have been demonstrated by firstly pre-processing the signal to increase the SNR and then shortening the duration of N to a smaller range. The criterion for choosing the new time window is however based on trial and error [4].

Other statistical methods have been developed in the time domain such as the Hinkley criterion [5], where the partial energy of a time series is calculated for all samples of the signal as expressed in Eqs. (3) and (4). The introduction of a negative trend δ modifies the resulting partial energy function in such a way that its global minimum is representative of the signal onset. It should be noted, however, that the parameter α is determined by trial and error; the chosen value of α can significantly influence the results obtained [6].

$$S_i' = S_i - 1\cdot\delta = \sum_{k=0}^{i} R_k^2 - i\cdot\delta \tag{3}$$