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Source location of acoustic emission in diesel engines

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Abstract

This paper is the third in a series developing methods of mapping acoustic emission (AE) signals and wave propagation in engines and focuses on source location techniques for the multi-source signals on relatively complex structures typical of machinery applications. Two source location techniques, a traditional wave velocity-based and an AE energy-based technique, using triangular sensor arrays, are used to locate source positions on the cylinder head of a 74 kW diesel engine using simulated sources (pencil lead break) and real sources (e.g. injectors (INJs) and exhaust valves during engine running).

Source location using both techniques is demonstrated on the cylinder head of a 74 kW four-stroke diesel engine. The velocity-based technique uses AE wave speeds and time-of-flight (wave arrival time) to locate source position and is found to be most effective for single source signals with a sharp rising edge and good signal to noise ratios. The energy-based technique is based on a simple absorption attenuation model and was found to be useful for multiple source signals such as INJ signals, although structure-specific attenuation coefficients need to be measured for accurate source location.

Keywords: Acoustic emission; Condition monitoring; Diesel engines; Attenuation; Source location

1. Introduction

Typical acoustic emission (AE) signals acquired from engines arise from a number of sources associated with mechanical impact, sliding contact and fluid flow processes including injection, combustion and valve operations as well as the functioning of ancillary equipment. The typical source characteristic is therefore quite complex and can be further confused by reflection, mode conversion and attenuation of waves as the source disturbance propagates to the sensor. Whereas there are no published instances of spatial location of these sources, it is commonplace to locate sources in the engine cycle, using crank angle and/or TDC pulses as reference signals [1–4].

Attenuation of AE in diesel engines has been mentioned by a number of authors [1–4] noting that the highest amplitude AE signals can be seen with sensors placed closest to the source. In two previous papers, Nivesrangsan et al. [5,6] investigated attenuation of AE waves propagating through simple and complex cast iron objects where they found that a simple energy-based absorption model (exponential decay with distance)

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could be used to determine attenuation factors from experimental data using simulated and real (engine running) sources whilst recognising that contributions to attenuation could come from a range of mechanisms. They also demonstrated a method of using appropriate AE wave speeds, event arrival times and attenuation coefficients to reconstitute source signals if the position of the source is known [6]. In this work, methods of automatically locating the position of various sources are developed. A more general review of literature relating to AE wave propagation is given by Nivesrangsan et al. [5,6] and is not repeated here.

In general, source location techniques are applied to structures with one or more large dimension, such as pipes [7], plates [8–12], I-beams [13,14] and cylindrical vessels [15]. These traditional velocity-based techniques rely on the difference between wave arrival times at sensors, wave speed (if known), and sensor positions [16]. In this work, where the dimensions are relatively small, planar source location techniques using a triangular sensor array are considered as well as an AE energy-based technique based on the absorption model mentioned above. These source location techniques are applied to signals acquired using simulated sources and 'real' engine running sources on the cylinder head of a 74 kW diesel engine in order to determine which is the more suitable approach. The engine and sensor system used in this work are the same as those described previously [6].

2. Source location techniques

Typically, planar source location in two-dimensions uses a triangular sensor array to determine the location of the intersection of two-hyperbolae as shown in Fig. 1, and here we apply the same geometrical approach to the traditional velocity-based technique and an energy-based technique. Three sensors (S1, S2 and S3) are located at positions (x_1, y_1), (x_2, y_2) and (x_3, y_3), respectively and record the arrival time of an event at t_1, t_2, and t_3, respectively. To locate a source at position (x_s, y_s) using the velocity-based technique, two-wave arrival time differences between sensors S2 and S1 $\Delta t_1 = t_2 - t_1$ and S3 and S1 $\Delta t_2 = t_3 - t_1$, AE wave speed, c, and the source–sensor distance d_i shown in Fig. 1, are used to define the two hyperbolae, the intersection of which gives the position of the source. The solution of two hyperbolae (with foci at S1–S2 and S1–S3) can be given by applying basic geometry to Fig. 1. The distance between sensor S1 and the source (x_s, y_s) can be given by [16],

$$d_1 = \frac{D_1^2 - \delta_1^2}{2(\delta_1 + D_1\cos(\theta - \theta_1))} \tag{1}$$

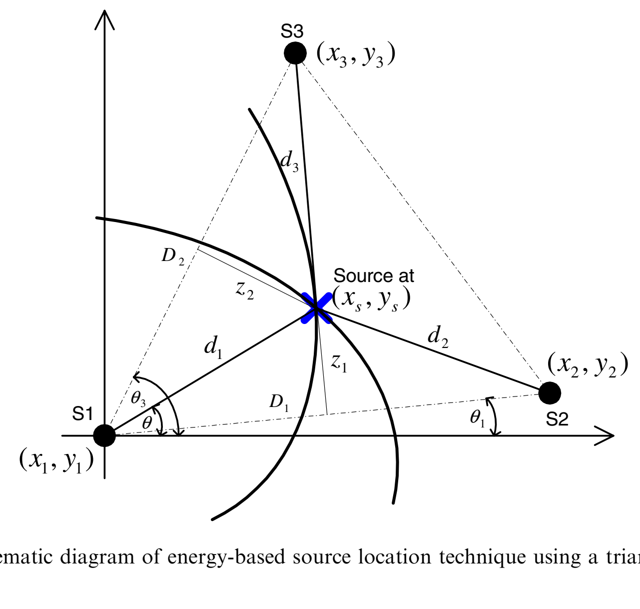

Fig. 1. Schematic diagram of energy-based source location technique using a triangular array.