SOURCE IDENTIFICATION USING ACOUSTIC EMISSION ON LARGE BORE CYLINDER LINERS

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ABSTRACT

In this paper, we demonstrate ways of identifying sources of acoustic emission (AE) in the liners of large (10MW) diesel engine cylinders. A set of experiments using simulated sources of AE were carried out on a cylinder liner of around 600mm bore, allowing the development of techniques to accurately identify wave arrival time, attenuation and effects of geometric changes on propagating waves.

The experiments with simulated AE sources were used to characterise the signal propagation to chosen locations on the liner surface. Wave propagation within the liner is complex due to variations in wall geometry and is further complicated when a number of waves can propagate around the liner and arrive at the sensor at the same time.

A technique for source identification on the cylinder liner has been developed based on wave arrival time. In a practical application of the technique to running engines we also make use of knowledge about the timing and duration of the mechanical events which occur during normal running.

The results are applied to identification of AE events associated with piston ring / cylinder liner interaction on an in-service power generation engine. Two significant AE events associated with an oil groove and scavenging port have been identified automatically.

(Keywords: Acoustic Emission, Condition Monitoring, Diesel Engines, Attenuation)

INTRODUCTION

Acoustic Emission (AE) has been shown to be very useful for the monitoring of reciprocating machinery [1-3]. Other systems currently exist to monitor engine parameters such as oil temperature, exhaust temperature or in cylinder pressure but these only monitor the symptoms of problems. Using AE it is thought possible to monitor directly the processes leading to fault conditions using a non-invasive technique. Furthermore, since propagation of AE occurs from the originating source to the sensor location it can therefore be used to improve the specificity of diagnosis using a kind of dynamic source location. In this work we concentrate on events associated with piston ring and cylinder liner interaction.

Initial studies of AE wave propagation on a cylinder liner were carried out using a simulated AE source (pencil lead break). These tests were used to determine the wave propagation characteristics before the development of an algorithm to automatically identify events. Despite its macroscopic geometric simplicity, the propagation of waves within the cylinder wall is inherently complex due to the nature of the cylinder wall geometry but it was expected that some form of source location method could be developed based on wave arrival time at the two sensors.

Results from this analysis are applied to data acquired on a running diesel engine operating at constant speed in a power plant. Automatic identification of events within the diesel cycle based on event timing and amplitude analysis is shown.

The long-term goal of this research is to develop a tool for the condition monitoring of large bore diesel engines using an array of sensors.

AE WAVE PROPAGATION STUDIES

In this work, as a preliminary step, a sensor array was mounted on the external surface of a cylinder liner removed from a large (10MW) power generating diesel engine. The limited sensor positions available when the liner was in-service determined the array placement on the removed liner. Hence, sensors were only mounted on the exposed liner locations as shown in Figure 1. Figure 1 also shows the axial positions from which events are expected to arise during normal running.

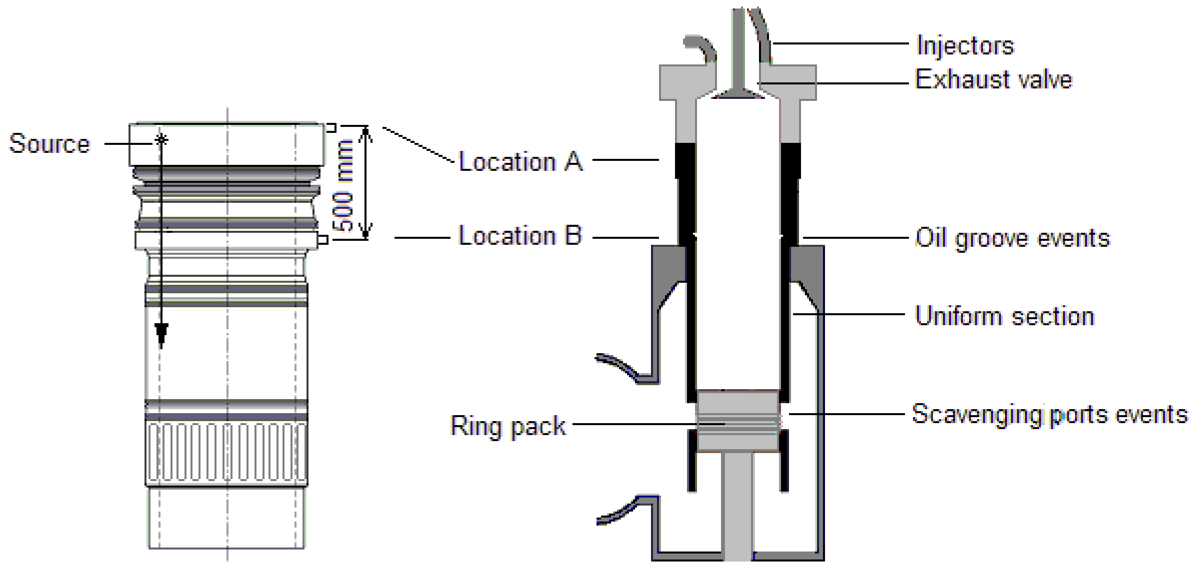

Figure 1: Sensor mounting points and approximate locations of major AE events

For the pencil lead break tests, a four channel National Instruments DAQ card was used to acquire raw AE data with a sampling frequency of 5MHz and a record length of 100,000 data points. Two PAC Micro 80D sensors were attached to the external surface of the cylinder liners using magnetic clamps at the locations shown in Figure 1. High vacuum grease was applied as a couplant to ensure good signal conductivity from liner to sensor. A further sensor was placed as close to the AE source as possible to acquire the source event.

Tests were carried out where the source was moved along the inside surface of the liner in approximately 50mm increments down the whole length of the liner (1.8m). At each source location the lead break test was repeated 10 times. The energy in each record was calculated using the equation:

$$E = \int_0^t v^2(t)dt \qquad (1)$$

where *E* is the AE signal energy, *V* is the AE waveform amplitude voltage and *t* is the time in seconds.

This energy was used to calculate the attenuation rate of the signals along the liner assuming that the AE signal energy decays with increasing distance according to the simple absorption equation:

$$E(x) = E_o e^{-kx} \qquad (2)$$

Where *E(x)* is the energy at distance *x* from the source, E_0 is the energy of the source and *k* is the attenuation factor. Figure 2 shows the logarithm of the energy plotted against distance, indicating an attenuation factor of $k = 2.1\text{m}^{-1}$.

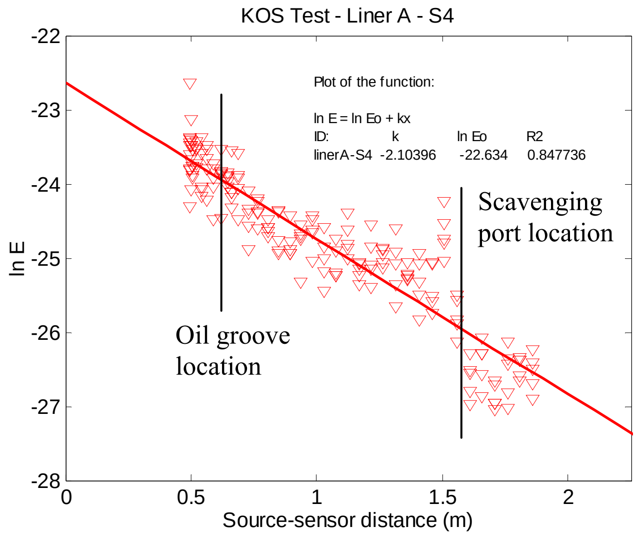

Figure 2: Attenuation of pencil lead AE energy with distance from source

An algorithm was developed using thresholding techniques (percentage of peak amplitude) to determine the arrival time of the main component of the AE wave. This allowed the time of flight for waves travelling between a sensor located close to the source and sensors at locations A and B to be found.

The estimated time of flight between the source and sensors A & B was calculated for the shortest possible path on the surface of the cylinder wall using a previously determined wave speed of 2650 m/s [4]. A comparison of the measured wave time of flight with the theoretical shortest path time of flight is shown in Figure 3. As can be seen, the agreement is generally good, although at larger distances, the apparent speed is a little slower than the assumed value of 2650 m/s.

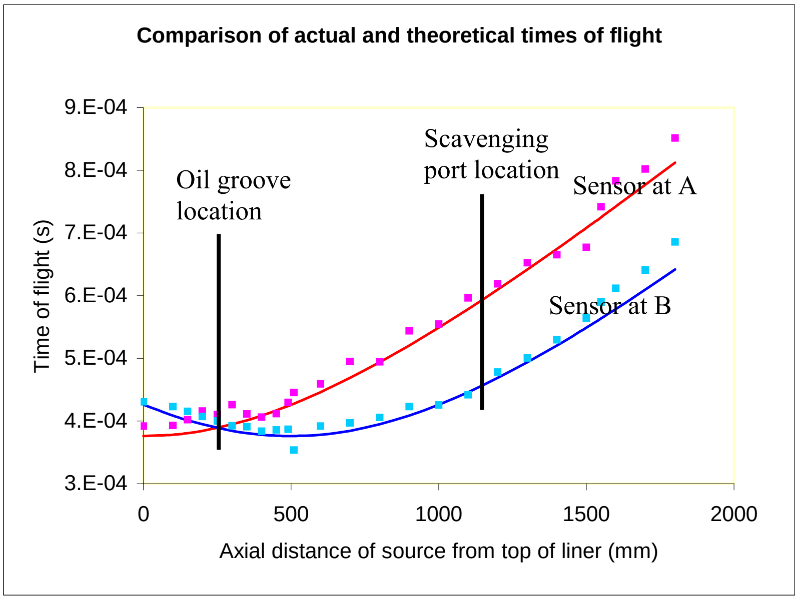

Figure 3: Comparison of calculated and measured times of flight for simulated sources on the cylinder liner

In addition to the results seen in Figure 3, further source characterisation tests were carried out with sources running along the inside of the liner at +60°, -60° and 180° from the sensor array in order to examine the variation in arrival time difference, ΔT, at sensors A and B for circumferential as well as axial location of the source. Figure 4 shows the results of this study and confirms the expected result that sensitivity to circumferential position is greater when the source to sensor axial distance is shorter. It also illustrates that larger circumferential displacements result in smaller arrival time differences in an axial array.

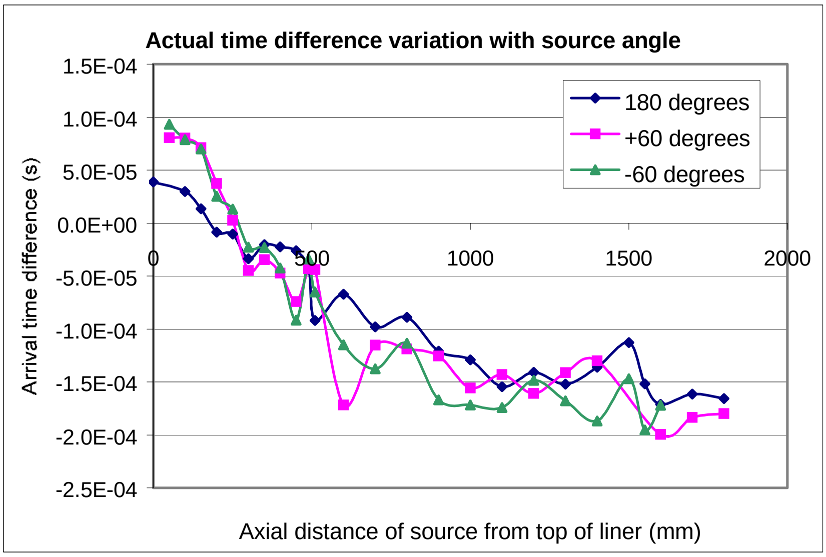

Figure 4: Effect of circumferential location on arrival time as a function of axial position

Figure 5 shows the theoretical time difference resulting from a wave front triggering the two sensors located in an axial array. The sensors are located at 0 and 500 mm from the top of the liner and it can be seen that there is a distinct linear variation in wave arrival time difference for sources located within the extents of the array. With increasing distance, the distance down the liner dominates ΔT and the circumferential path length becomes less significant. For this reason the ΔT value at large distances becomes constant rendering source location non-feasible.

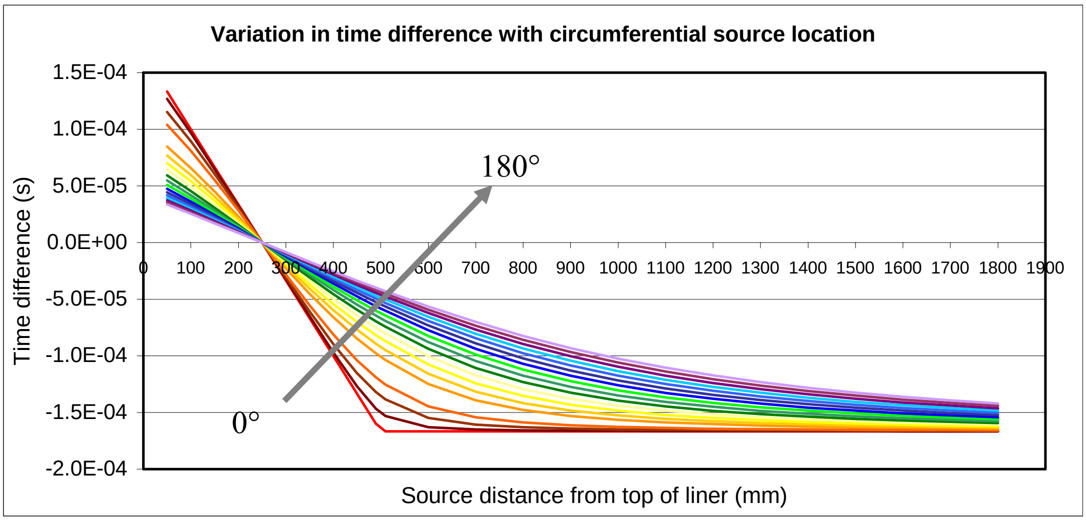

Figure 5: Theoretical ΔT for circumferential source variation 0° – 180°

During the simulated source experiments it was noticed that there could be variations in the AE waveforms recorded if the receiving sensor was moved slightly but the source kept the same. This is most likely attributable to the fact that the liner is not simply a plain cylinder and, in particular, the presence of cooling passages in the upper liner wall would leading to structural filtering of the signal, especially if such passages are close to the sensor.

The grosser changes from cylindrical geometry can be seen to have asymmetric effect on the wave arrival times in Figure 3 where there is an increasing deviation from the calculated time due the effect of the scavenging ports which start at 100mm from the top of the liner. Greater deviation from the predicted arrival time can be observed in the signal recorded at sensor A, which has a longer path length through a larger number of geometry changes than the sensor B signal.

With increasing distance from source to sensor it is more likely that the dispersive nature of the waveform will become significant and the actual trigger point on the waveform will be affected by this [5,6].

ENGINE RUNNING TESTS

Using knowledge of the engine timing and duration of events within the diesel cycle, an event map has been developed which could be used to identify events automatically within a record.

Data was acquired from the running engine using the National Instrument DAQ card and two PAC Micro 80D sensors. The sampling rate was 2.5MHz and the record length was 3 million data points corresponding to 2.7 revolutions of the engine at 136.6rpm.

To allow automatic mapping of the AE signal from the running engine major events within the AE record were identified using a threshold technique. Firstly, to enable subsequent identification of events without knowledge of the Top Dead Centre (TDC) location, a consistent event within the cycle needs to be identified. Such events are most likely to arise from direct mechanical interactions such as the piston rings passing the scavenging ports or over the oil groove inside the liner. Other major events such as injection and the opening and closing of exhaust valves could be independently controlled on some engines and are not therefore reliable indicators of engine crank angle position.

Studies using information from an shaft encoder indicated a strong event at approximately 125 degrees after TDC and it was determined that the cause of this event was likely due to the piston rings passing the scavenging ports near the bottom of the liner. Due to the repeatability and consistency of this event it was used as the datum for automatic mapping of the event cycle.

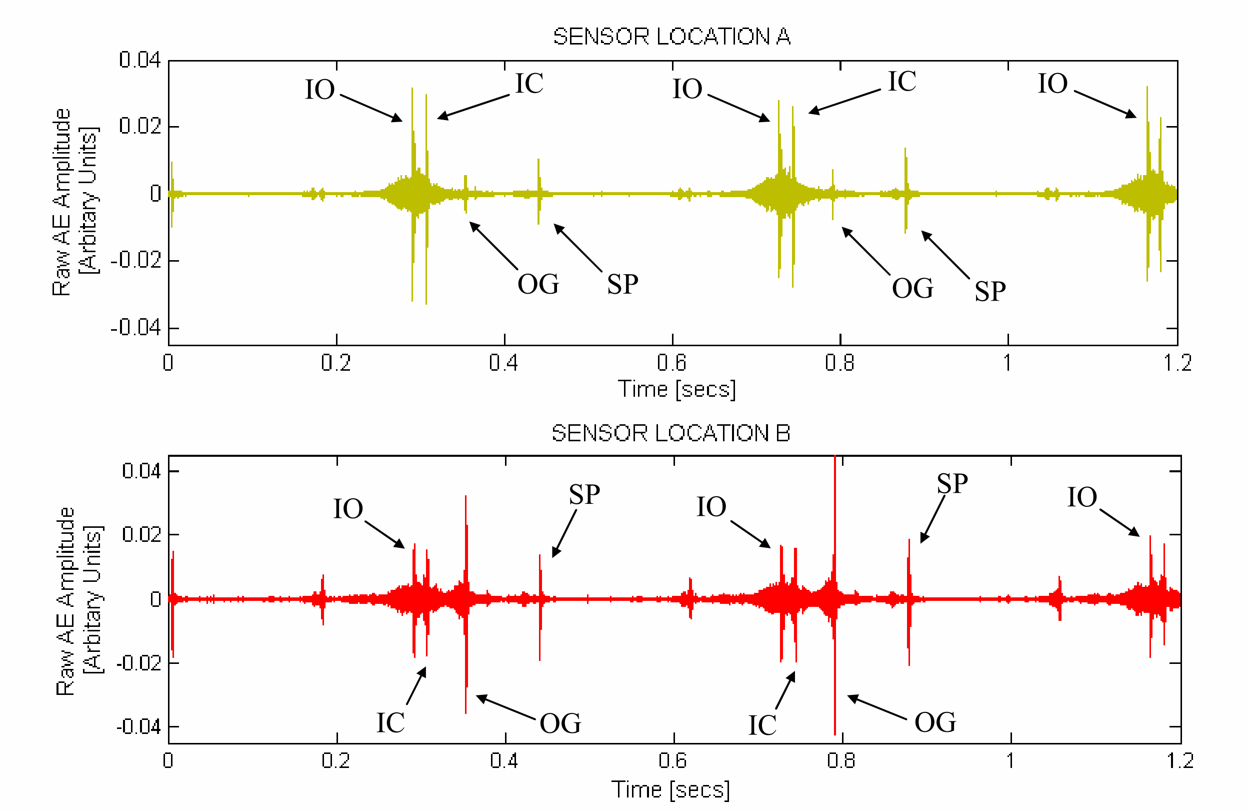

Figure 6: Typical running engine AE from sensor locations A and B with major events indicated;
IO = Injector opening, IC = Injector closing,
OG = Ring pack passing oil groove,
SP = Ring pack passing scavenging ports.

From Figure 6 it can be seen that the scavenging event recorded at sensor location A is attenuated compared to that at location B. This suggests that the event is closer to sensor B than sensor A and, by comparing the arrival time to the event map, the most probable identification of the event can be made. Confirmation of the observation that the recorded signal represents energy propagating past location B towards location A can be obtained by comparing the energy within the time window corresponding to the passage of the ring pack over the scavenging ports at the two positions.

Once the scavenging event is identified it is a simple matter to locate the TDC position in the cycle and from there other events can be mapped out with respect to the engine timing diagram and separately extracted for further analysis.

Due to the large size of the diesel engine under investigation in this paper there was very little signal cross contamination due to transmission between individual cylinders and, as a result, the AE signal was largely free from unwanted external events. This allowed easier identification of cyclical events within the cylinder under examination than may be possible on small block diesel engines.

CONCLUSIONS

True 3-dimensional source location on an entire cylinder liner is not possible using just two sensors mounted at the locations A and B. However, considerations of axial propagation, including arrival time and attenuation, can be useful in informing diagnostic algorithms.

Identification of sources within a signal acquired from the limited array on the liner is achievable without prior knowledge of the TDC location using basic information about the mechanical events that give rise to AE signals. This source identification can be informed and verified by simple propagation characteristics such as time of flight and attenuation.

For many applications, sources on the cylinder liner are circumferentially distributed and so the axial source location is sufficient. In the event that circumferential location is of interest this may be possible by ensuring sensors can be located axially either side of the source.

ACKNOWLEDGEMENTS

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