Elamin, Fathi, Fan, Yibo, Gu, Fengshou and Ball, Andrew

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DETECTION OF DIESEL ENGINE VALVE CLEARANCE BY ACOUSTIC EMISSION

Fathi-Elamin, Y.Fan, F.Gu and A. Ball
[1] University of Huddersfield, Queensgate, Huddersfield HD1 3DH, UK

ABSTRACT

This paper investigated, using experimental method, the suitability of acoustic emission (AE) technique for the condition monitoring of diesel engine valve faults. The clearance fault was adjusted experimentally in an exhaust valve and successfully detected and diagnosed in a Ford FSD 425 four-cylinder, four-stroke, in-line OHV, direct injection diesel engine. The effect of faulty exhaust valve clearance on engine performance was monitored and the difference between the healthy and faulty engine was observed from the recorded AE signals. The measured results from this technique show that using only time domain and frequency domain analysis of acoustic emission signals can give a superior measure of engine condition. This concludes that acoustic emission is a powerful and reliable method of detection and diagnosis of the faults in diesel engines and this is considered to be a unique approach to condition monitoring of valve performance.

Keywords Condition monitoring, Diesel Engine Valve clearance, Acoustic Emission, Fault Detection, Signal Processing

INTRODUCTION

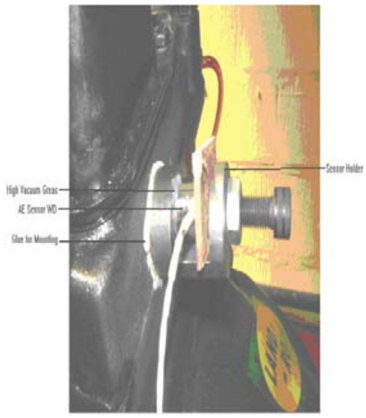
Faults in diesel engines are sometimes difficult to diagnose using conventional techniques such as vibration and acoustics measurements. Vibration monitoring gives only limited information about engine conditions. It often requires many accelerometers and different measurement positions to achieve a general estimation of the engine condition. Another disadvantage is that the vibration signals are contaminated by noise and need effective signal processing to get useful information [1].Problems are also encountered due to the non-stationary characteristics of the vibration signals encountered in the engine [2]. The advantages of airborne acoustic signals can give more information about the engine. However, since acoustic signals are easily contaminated by noise, it is often more difficult to extract useful condition monitoring information [3].
Therefore, to find more effective and reliable monitoring methods, this paper investigates the potential of AE technique to monitor the condition of diesel engines. AE signals encountered on diesel engines are the stress waves travelling on the surface of the engine. Mechanical events that generate AE include impacts and crack formation; in addition, fluid and gas flows also generated AE. [4].

The higher SNR of AE signal is because of the fact that the distance damping of the stress waves increases with frequency. Since AE frequency is much higher than vibrations, AE signals are unlikely influenced by the noises from longer distance. Thus, for AE measurement, the distance between sensor and source should be reduced as much as possible. This will mean that the AE signals are far more localised, e.g., appearing virtually only from the source where they are generated. It also means, however, that differential damping of different sources is crucial in sensor location considerations due to material interfaces along the signal path [5]. Of course, it is necessary to ensure good signal conductivity from the surface to the sensor and high vacuum grease should be used as a coupling.

The AE wave propagation in a real structure attenuates along its transmission path. Previous studies [6] have shown that AE source characteristic which may already be quite complex, can become even more complicated by factors which affect AE wave transmission and attenuation. These include internal damping, reflection, refraction, conversion mode and diffraction. Some of an engine's AE sources and their effects on the overall noise levels show that AE signal generated by engine involves different sources and mechanisms that make the AE signals very complicated. These AE signals contain not only stationary waveforms but also non-stationary transients, pulses and embedded noise.

EXPERIMENT

This paper used a 2.5-litre, Ford FSD 425, four-cylinder, four-stroke in-line OHV, direct injection compression ignition diesel engine as the source of acoustic emission data as seen in Fig. 3.



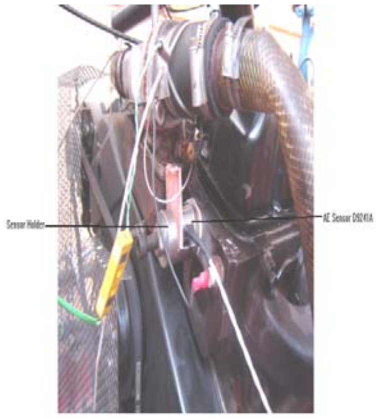


Fig. 3 Photograph of test rig in situ. **Fig. 4** WD AE Sensor (Sensor1) **Fig. 5** D9241A AE Sensor (Sensor2)

Two types of AE sensors are mounted on the sensor holder which fixed on the engine cylinder by glue as shown in Figs. 4 and 5 and these are made by Physical Acoustics Corporation. One wideband sensor, WD, with an operating frequency range from 100kHz to 1MHz was connected to channel one as seen in Fig. 4 This type of sensor has a differential output to decrease the influence of noise. The second sensor is a differential sensor D9241 A, with operating frequency range from 20kHz to 180kHz, and this sensor was connected to channel two as seen in Fig. 5. These two sensors, with overlapping frequency ranges, were chosen for this study to determine the most suitable AE frequency for the condition monitoring of diesel engines.

High vacuum grease was applied between the sensor and the holder surface to get good signal conductivity. The two sensors were mounted in an appropriate places (both on the cylinder head of the engine) to collect the signals from all possible sources. The preamplifiers connected with these sensors are 2/4/6 preamplifiers and from the same company as made the sensors.

RESULTS AND DISCUSSIONS

The first fault introduced was to increase the valve clearance in the exhaust valve of cylinder one by 0.5 mm (positive), and the second fault was to increase the clearance to 0.8 mm (positive). Data was collected for both faults, but this description is limited to the consequences of introducing the second fault (0.8 mm) because the first fault has no significant effect.

The measured AE signal from the engine was displayed in the time domain. The analysis in the time domain was expected to reveal the overall signal amplitude, and cyclic features.

Fig. 7 shows the raw AE waveform recorded from a healthy engine running at 1000 rpm and zero load in a laboratory environment without any special consideration or precautions. It presents the AE signal acquired from one working cycle of the running engine versus crank angle from the two sensors mounted on the cylinder head of the engine (see Figs. 4 and 5). The mechanical events corresponding to crank angle are shown along the bottom of Fig. 7. The main feature extracted from the AE waveform shown in Fig. 7 is that it exhibits four peaks equivalent to the engine firing sequences and each peak is caused by combustion in one of the cylinders of the engine, from left to right, cylinders 1, 2, 4, and 3. There is obvious difference in amplitude between sensors one and two, because of the different frequency ranges of each sensor, and the different sensor's mounting positions.

Thin vertical lines indicate TDC for each cylinder in their fire order: 1/ 2/ 4/ 3. On the figure, INJ is injector; EVO is exhaust valve opening; EVC is exhaust valve closing; IVO is intake valve opening; IVC is intake valve closing; and the numbers 1 to 4 represent the number of the cylinder.

As can be seen from Fig. 7, the largest AE signals, observed at both sensor positions are associated with injection events and occur around TDC for each cylinder. The highest AE amplitudes are, as would be expected, observed at the sensor close to the source, since the magnitude of the signal will decrease with distance from source. Smaller amplitude events are also associated with exhaust valves opening.

The major mechanical events in the engine cylinder head are injection, fluid excitation, exhaust valve opening and mechanical impacts. It can be seen from the AE waveform shown in Fig. 7 that there were four large AE events equivalent to the engine firing sequences and each event was caused by the combustion in one of the cylinders of the engine.

The AE peaks, observed from both AE sensors were associated with injection events and occurred around TDC for each cylinder. Smaller AE events associated with exhaust valves opening can also be observed. The highest amplitude signal detected by sensor one was due to the events occurring in cylinder four. This is because sensor one was mounted closest to cylinder four. The highest amplitude at sensor two is due to events occurring in cylinder one. Numerous authors have confirmed that the highest amplitude AE signals are detected by those sensors placed closest to the source [7].

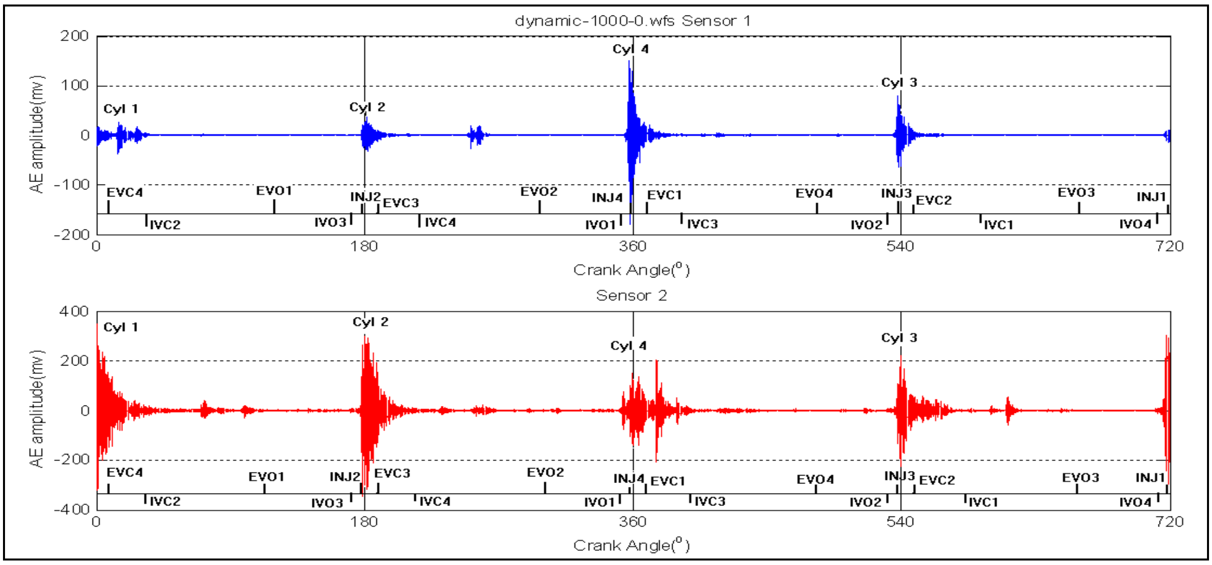


Fig. 7 Raw AE signal from a running engine at zero Nm with 1000 rpm

For a given sensor the figures show that the dominant event follows the fuel injection; that exhaust valve opening is the most significant of valve events that events associated with the engine exhaust valve differ from those associated with the intake valves. The intake valve movement involves lower kinetic energies and the pressure differences across it might be expected to show lower inherent signal energy, and this almost certainly explains the non-appearance of clear exhaust valve closing events.

The injector events for each cylinder occur at crank angles of around 0^0, 180^0, 360^0 and 540^0 after TDC for cylinder-1, consistent with the firing order of 1, 2, 4, 3. However, it is possible that the valves events include a number of related events associated with impacts of the rocker arm with the push rod or valve stem. This is also evident in the AE data that the actual timing of the events can be slightly different. The difference in energy between cycles - e.g. as the kinetic energy between the two potential impact points at push rod and valve stem - is relatively random, depending on exactly the position of the rocker from the previous cycle. There are apparent inconsistencies between cycles, e.g. the exhaust valve opening events show differences between the various running conditions. This is due to the exhaust valve opening energy changing with the force the hot products of combustion exert on the face of the valve, an effect whose magnitude will depend on running conditions.

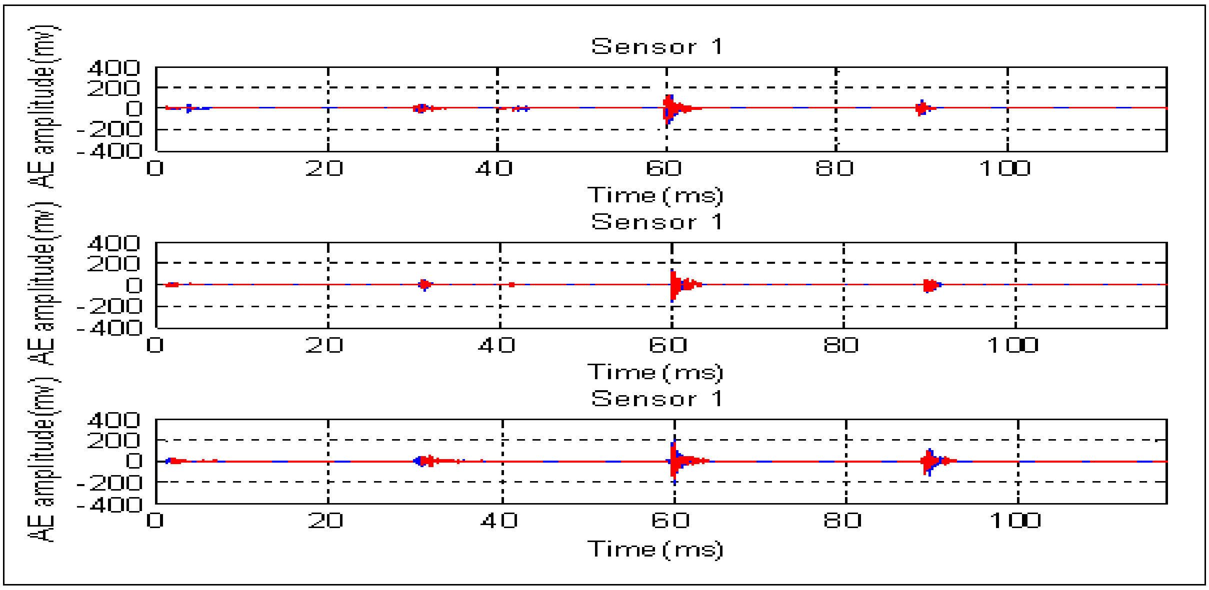


Fig. 8 **Time domain AE signal from sensor one for healthy (blue) and faulty (red) exhaust valve, speed 1000 rpm and different loads**

After investigated the AE activities from healthy engine, fault was introduced to the exhaust valve of cylinder 1 to see the response of AE. Fig. 8 shows the AE waveforms from sensor 1 when the engine ran at 1000 rpm with three different loads (0 Nm, 30 Nm and 60 Nm) under the healthy and faulty conditions. No significant change can be seen because sensor one had a higher frequency response and it was positioned relatively far from the faulty cylinder. There is obvious difference in amplitude between sensors one and two. This is mainly because of the different frequency ranges of the sensors. The different mounting positions also contributed to the variance of measurement. Furthermore, this seeded fault has no influence on the other healthy cylinders

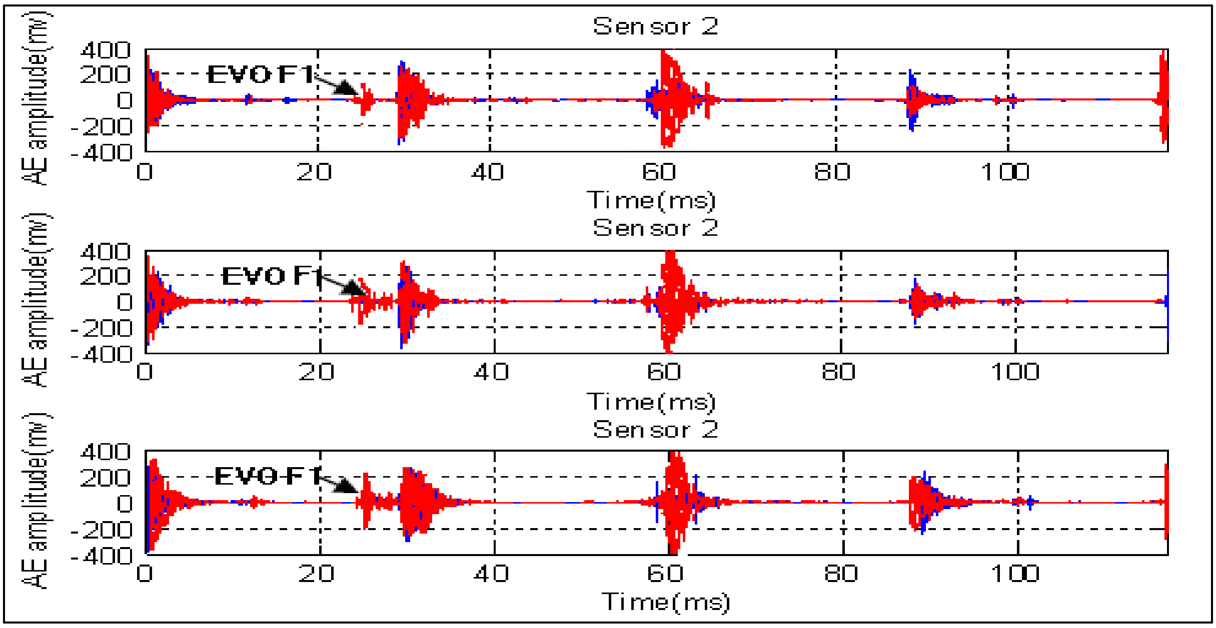


Fig. 9 Time domain AE signal from sensor two for healthy (blue) and faulty (red) exhaust valve, speed 1000 rpm and different loads

Fig. 9 shows that there is no significant difference in the AE signals around TDC for the faulty condition compared with the healthy one. The introduction of the fault appears to have no significant influence on the AE signal from the other cylinders. However, if the AE amplitudes are examined more closely, a relative decrease of amplitude for the faulty condition can be seen. This is because of the AE wave propagation through the engine cylinder head will attenuate a little whilst passing along a transmission path from the AE sources to the position of the sensor and this small increase of attenuation originates from the increase in valve clearance.

The change of AE signal from health to fault was more obvious when the engine speed was increased from 1000 rpm to 2000 rpm with different loads. It can be observed from the response of sensor one, shown in Fig.10, that the AE level under the faulty condition was lower than that under the healthy condition although the AE events were more or less the same.

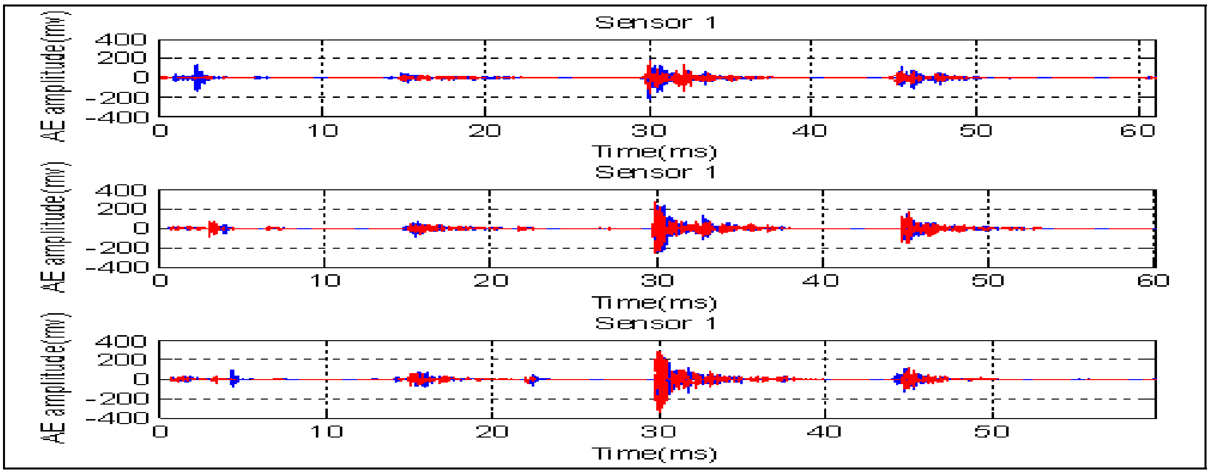


Fig. 10 **Time domain AE signal from sensor one for healthy (blue) and faulty (red) exhaust valve, speed 2000 rpm and different loads**

In Fig. 11 the AE signal for sensor two shows a significant difference in the peak levels for the healthy and faulty conditions. This is because the position of sensor two is close to the faulty first cylinder, and the exhaust valve opening event is clear for both healthy and faulty conditions. The figure shows a difference in the AE signal amplitudes for the exhaust valve opening event with and without the fault, it also shows a clear difference in the time of occurrence at which the exhaust valve opens due to exhaust valve timing differences. Opening occurs later, and closing occurs earlier, for the faulty exhaust valve. The faulty valve opens at 5^0 before BDC (46^0 later than for the healthy condition) and closes at 12^0 before TDC (25^0 earlier than for healthy condition),

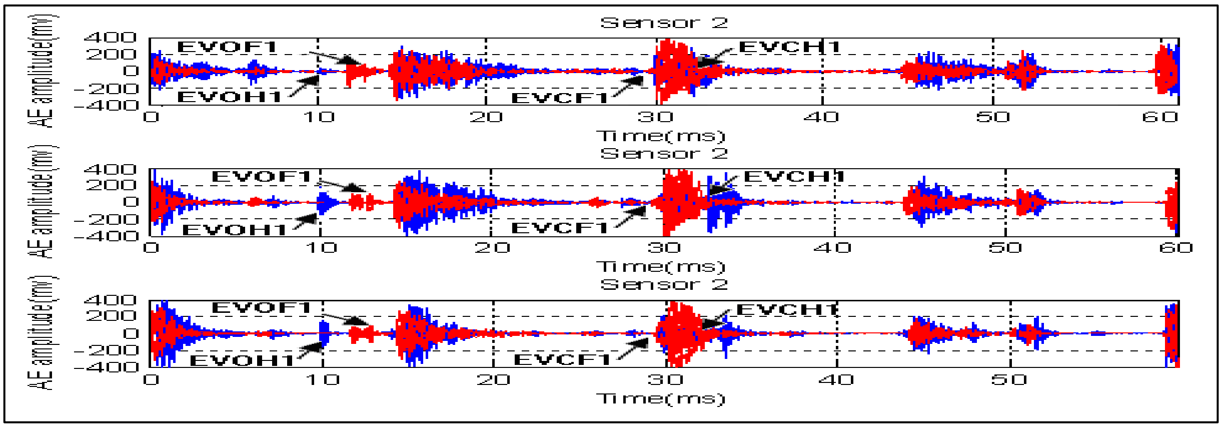


Fig. 11 Time domain AE signal from sensor two for healthy (blue) and faulty (red) exhaust valve, speed 2000 rpm and different loads

A later open of exhaust valve reduces power output because of the increased volume of exhaust gases that must be discharged from the cylinder. This means that there are greater pumping losses while evacuating the exhaust gases from the cylinder. These pumping losses occur before the piston reverses at the end of exhaust stroke.

Early close of exhaust valve leads to a shorter valve overlap period and also reduces the engine volumetric efficiency significantly because the exhaust gas occupies the space that could be used for fresh mixture. Again this results in reduced engine power output. This is why the cylinder pressure with a faulty exhaust valve is higher than that with a healthy valve.

In Fig. 11 if the AE amplitudes are examined closely the decrease in amplitude in the faulty condition in comparison with the healthy condition, is more distinct than in Fig. 10. This means that the power output of the engine is reduced, especially in the faulty cylinder, and the other cylinders will try to compensate for this power reduction by increasing their power output because the engine is working as one system; for this reason the AE signal is slightly decreased under faulty conditions.

CONCLUSIONS

AE is an extremely powerful condition monitoring tool and the change of AE signal can clearly indicate the presence of fault in engine. In this research the AE events associated with exhaust valve opening was clearly observed and the difference between healthy and faulty valves was shown.
The dominant AE events in the four-stroke diesel engine cylinder head are associated with the injector and fluid excitation. Valve events (exhaust valve opening), mechanical impacts and gas flow excitation over the valve face are thought to be the main sources in the AE signal.

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