Detection of Diesel Engine Injector Faults Using Acoustic Emissions

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ABSTACT

This study investigated the method of identifying injector faults in a JCB 444T2 diesel engine using acoustic emission (AE) technique. Different kinds of injector faults were seeded in the four-cylinder, four-stroke, and turbo-engine. The AE signals recorded from the tests were processed in the angular domain, frequency and joint angular-frequency domain. The results showed that AE could clearly monitor the combustion process of diesel engine because high frequency AE signal measured from engine cylinder head has very high signal-to-noise ratio. Using features in the AE signal, faults of injector can be identified during the operation of the engine.

Keywords: diesel engine, injector faults, fault detection, acoustic emission.

1. INTRODUCTION

Early detection of diesel engine faults is essential in order to take early correction actions and avoid costly repair. Injection faults due to defects in a fuel pump, fuel lines and injectors affect the power of engine, increase polluting particle emission and reduce the life cycle of engine. Higher injection pressure increases the pollutants in the emission and fuel consumption. A lower pressure, however, reduces the engine power and efficiency [1]. Blocked injector results in misfire, increase in noise and reduction in engine power and efficiency.

Acoustic emission (AE) can be used as a non-intrusive method to monitor the mechanical events and processes in diesel engines and diagnose faults during their operation. AE measurement on the cylinder head has been used successfully for monitoring diesel engines [2-6]. The technology was also employed to detect exhaust valve leakage [7], fuel injection behaviour [8] and various aspects of the combustion process [9, 10]. One major advantage of using AE monitoring and diagnosis is that the signal has a very high signal-to-noise ratio because the signal frequency is very high, usually in the range from 100 kHz to 1 MHz

There are a number of AE sources in engine operation such as combustion, piston slap and fluid flow/injection etc. During the combustion a significant and quick increase of the pressure in the engine cylinders occurs. The impact of the combustion pressure applies a direct excitation on the engine head and generates stress waves in a wide range of frequencies [11]. Piston slap is another important source of acoustic emission in diesel engines. It is caused by the inversion of the inertia forces of the piston in the neighbourhood of the TDC. Piston slap results from the succession of two strong impacts. One impact is applied by the upper part of the piston while the other impact is applied by the lower part of the piston. The piston slap impacts cover a large range of frequencies. The injection of diesel fuel under a high pressure (healthy condition) (270 bar for the engine used in this study) during a very short time (some micro-seconds) creates a mechanical impact. Furthermore, the spring of the needle of each fuel injector is also a source of secondary importance contributing to cylinder head acoustic emission [12].

In the present work, the potential of AE for early detection of injection defaults was investigated. A four-stroke, four-cylinder diesel engine was employed in the experimental study and three injection faults were tested. First, the injection pressure of the Cylinder one was reduced from its nominal value (270 bar) to 235 bar and then the pressure was increased to 325 bar. At last the injector was completely blocked. Acoustic emission signals recorded from these tests were analysed in the angular, frequency and joint angular-frequency domain to identify the symptoms of the seeded faults.

2. EXPERIMENTAL STUDY

2.1 Test Rig

The experimental study employed JCB engine test rig available in the Automotive Laboratory at the University of Huddersfield, as shown in Figure 3. It is a four-cylinder, four-stroke, turbocharged direct injection engine with a displacement of 4.4 litres. The fuel is injected directly into the combustion chambers at a pressure of 270 bars in the firing order of 1-3-4-2. Full operating parameters and characteristics of the JCB engine are given in Table1.

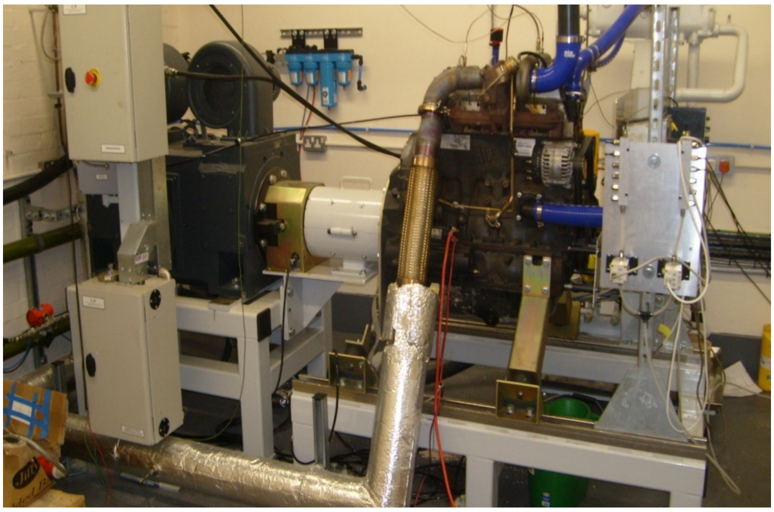

Figure 1 JCB Engine Test Rig

Table 1 Description of JCB Engine

Type of engine	Turbocharged diesel engine
Number of cylinders	4
Bore	103mm
Stroke	132mm
Inlet valve diameter	36.5mm
Exhaust valve diameter	33.2mm
Compressor inlet diameter	60mm
Compressor outlet diameter	60mm
Turbine inlet diameter	100mm
Turbine outlet diameter	80mm
Compression ratio	18.3
Number of valves	16
Injection system	Direct injection
Displacement	4.399 litre
Cooling system	Water
Speed range	850 – 2200 rpm
Recommended speed	850 rpm
Compressor speed	60,000 – 220,000 rpm
Maximum power	74.2 kw @ 2200 rpm

2.2 Measurements Setup

The experiment employed the PAC WD2030 sensor with a frequency range from 100-1000 kHz. The output of AE sensor was amplified using PAC 2/4/5 preamplifier and sampled using PAC PCI 2 data acquisition board. The filter of PAC PCI 2 was set from 100 kHz to 1 MHz and the sampling frequency was 2 MHz for each test AE raw signal was recorded continuously for 3 seconds.
Acoustic emission sensor has been used for the acquisition of the acoustic emission signal.
The AE sensor was mounted on the front side of the cylinder head of the engine to collect the AE signals generated during the operation of engine. To get good signal conductivity, vacuum grease was used to couple the AE sensor with the measurement surface.

3. RESULTS AND DISCUSSIONS

3.1 Analysis in the Angular Domain

In the angular domain, the analysis can clearly correlate AE transient events to the operation of engine. Figure 2 presents the AE waveforms corresponding to the three seeded faults when the engine was tested at 1000 rpm with no torque. Figure 2A gives the AE signal when the injection pressure of Cylinder one was increase by 55 bar to 325 bar; Figure 2B shows the AE signal when the injection pressure of Cylinder one was reduce by 35 bar to 235 bar and Figure 3C presents the AE signal when the injector of Cylinder one was completely blocked. In addition, the reference AE signal corresponding to the healthy condition on the cylinder head is shown in figure 2A, 2B and 2C in blue colour in order to compare with the faulty AE signals presented in red colour. Every signal contains 40000 samples covering one cycle (2 crankshaft rotations).

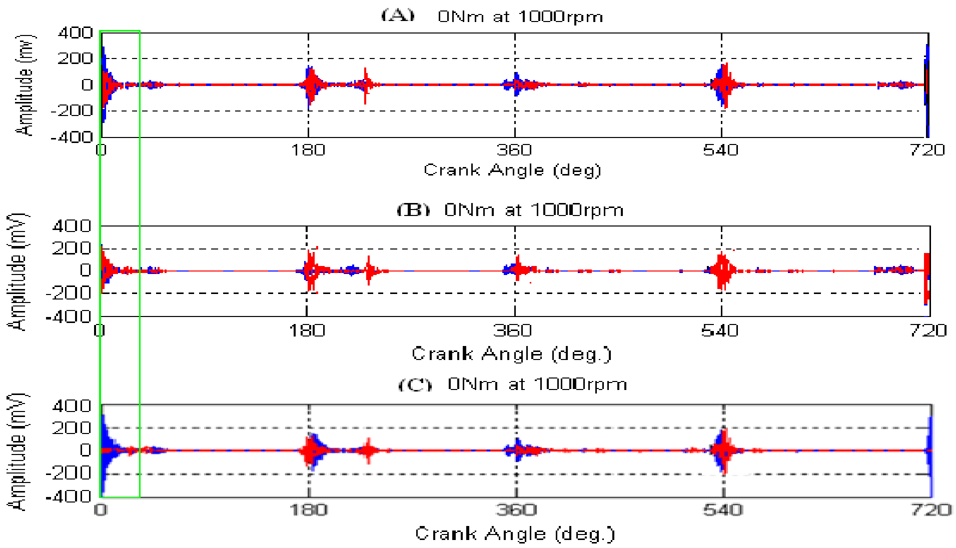

Figure 2 AE signals in the angular domain.

It can observed seed from Figure 2 that clear AE bursting transients were excited when a crank angle rotation was about 15 ° after one of the pistons reached its top dead centre. These AE transients, occurring four times per cycle, are essentially caused by the combustion of fuel in cylinders. Since the AE sensor was mounted in the front side of the cylinder head close to Cylinder one, the AE transient caused by fuel injection and combustion in this chamber was the highest at an angle 0 ° and 720 °.

When injection pressured was increased, less fuel was injected into the cylinder and less energy was generated. Hence the AE transient related to Cylinder one, shown in Figure 2A, became weaker that the healthy condition. When the injection pressure was decreased, more fuel was injected into the cylinder and a stronger AE transient was observed in Figure 2B. When the injector was completed blocked, misfire occurred in Cylinder one and the AE transient could not be observed, as shown in Figure 2C. Therefore the condition of the injector of Cylinder one can be monitored by analysing the AE transients at angle 0 °.

3.2 Analysis in the Frequency Domain

The acoustic emission signals in the frequency domain are obtained using the Fast Fourier Transformation (FFT). Figure 3 shows the spectrum of the healthy condition (blue colour) and the spectra of each of the three faulty conditions (red colour). Figures 3A, 3B and 3C present the results of higher injection pressure, lower injection pressure and blocked injector respectively.

It can be seen from Figure 3 that high acoustic emission energy can be observed between 100 and 140 KHz. But on clear change could be observed in the spectra even when the injector was completely blocked. It is not possible to determine which cylinder has a faulty injector from the spectrum.

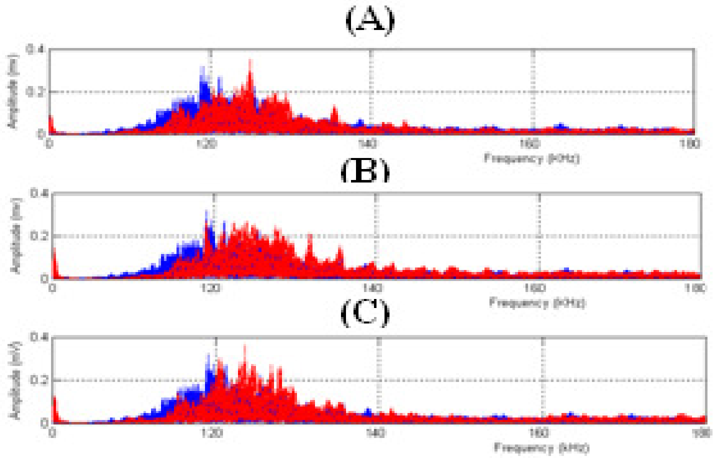

Figure 3 Frequency spectra of the AE signals

3.3 Analysis in the Angular-Frequency Domain

For stationary signals, frequency analysis is a useful and the most frequently used signal processing tool. The frequency content of non stationary signals, however, varies with time and therefore time frequency analysis tools should be used for a more in depth analysis. This research employed the short time Fourier transformation (STFT) to process the AE signals recorded from engine cylinder head. Gaussian window was used and 50% overlap was applied in the analysis in order to reduce information loss due the window function.

Time-frequency analysis methods are used to determine the frequency content at each time [2, 3, 4, 6, 13]. For the fault diagnosis of engines, angular-frequency analysis in which time is replaced by the crank angle is more useful and has been used in this research work. Figures 4-7 gives the result of angular-frequency analysis of the AE signal given in Figure 2. Large AE events occur at crank angles integer-multiple of 180°, when the piston of each cylinder reaches the top dead position and immediately afterward during combustion. The acoustic emission signals at these angles are significantly larger in the 100 kHz to 140 kHz frequency domain and last about 15 degrees especially for cylinders 3 and 4. This proved that the AE transients observed in Figure 2 were mainly caused by the combustion in each cylinder. The higher frequency components relating to Cylinder 1 increased when more fuel was injected due to the reduction in injection pressure, as shown in Figures 6A and 6B. This indicated that AE signals with higher frequency were generated when the combustion became stronger. No signal components in the frequency range from 150 kHz to 200 kHz could be clearly observed from Figure 7 when the injector was completed blocked. Therefore, the motions of the pistons and other moving parts did not were not main AE sources within this frequency band. An injection fault is expected to be diagnosed by observing its influence on combustion.

4. CONCLOUSION AND FUTURE WORKS

The acoustic emission signal measured on the cylinder head are shown to be effective for the detection of injector faults. The analysis in the angular domain provides a straightforward method to identify the malfunction of the injectors. Analysis in the angular-frequency domain has the potential of separating several AE sources occurring at the same time but having different frequency content. It was found that the main AE transients were generated by the combustion in each cylinder and the faults of injection can be reflected in these main AE transients through their influence on the combustions.

Further research work will be conducted to extract more features from the angular and angular-frequency results. The engine faults may then be identified using these features.

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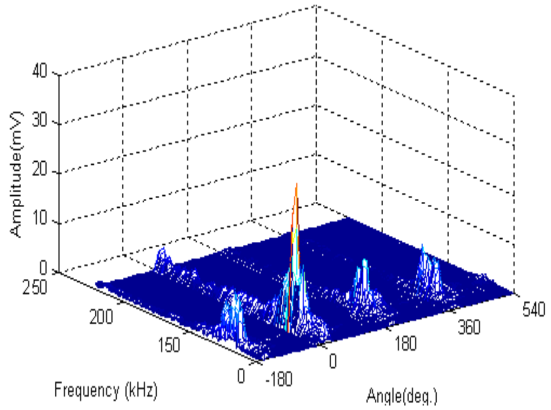

Figure 4a Angular-frequency representation of healthy injector

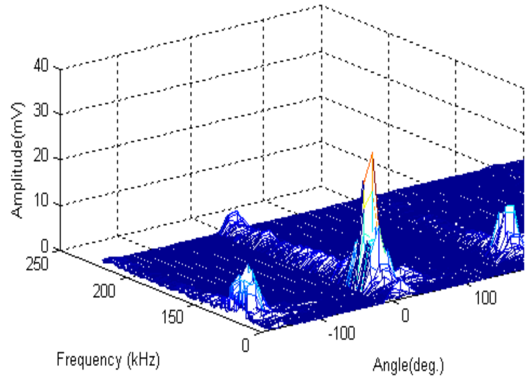

Figure 4b Zoom around 0 ° angle of figure 4a

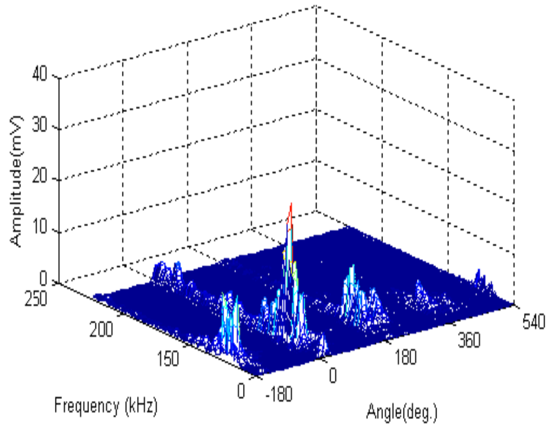

Figure 5a Angular-frequency representation of the injector with 55 bar pressure increase

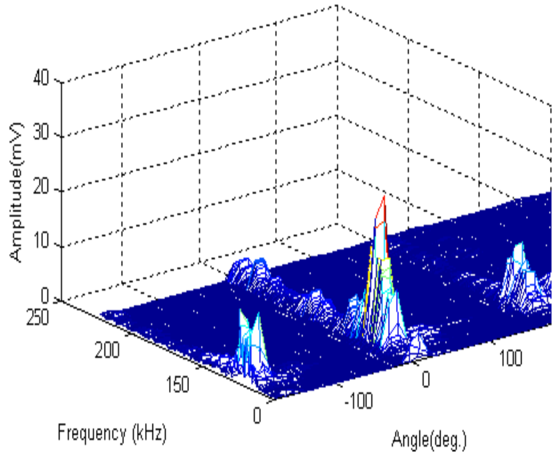

Figure 5b Zoom around 0 ° angle of Figure 5a

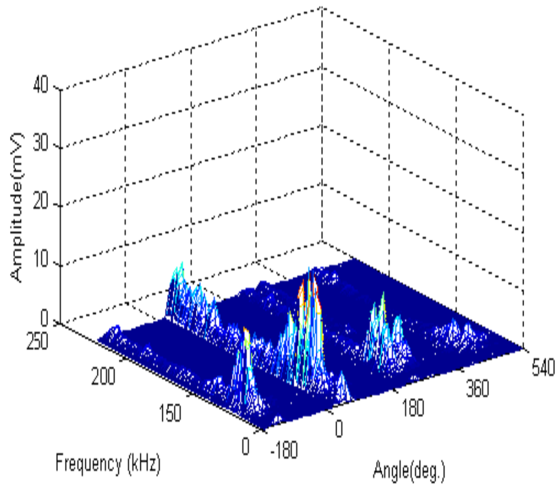

Figure 6a Angular-frequency representation of the injector with 35 bar pressure reduction,

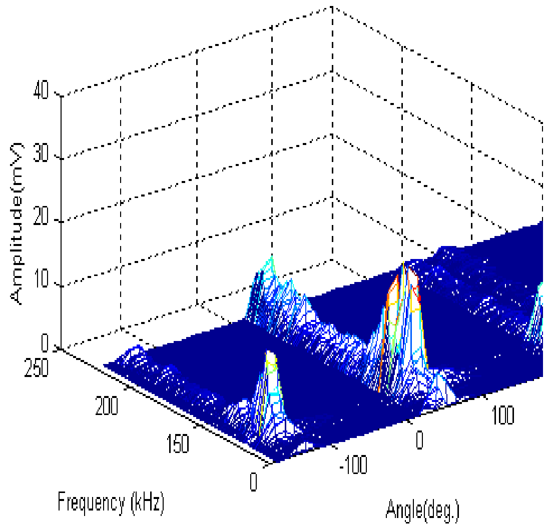

Figure 6b Zoom around 0 ° angle of Figure 6a

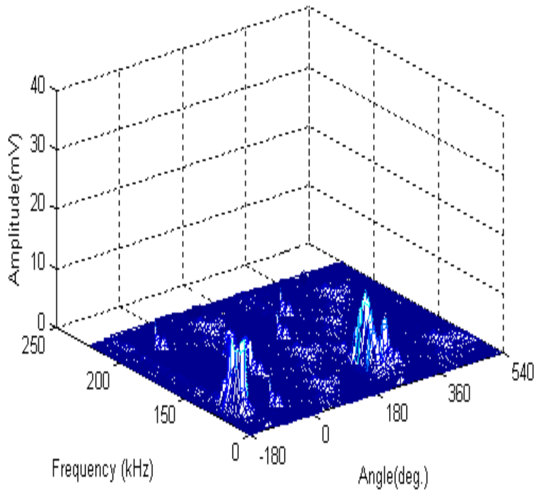

Figure 7a: Angular-frequency representation of the blocked injector

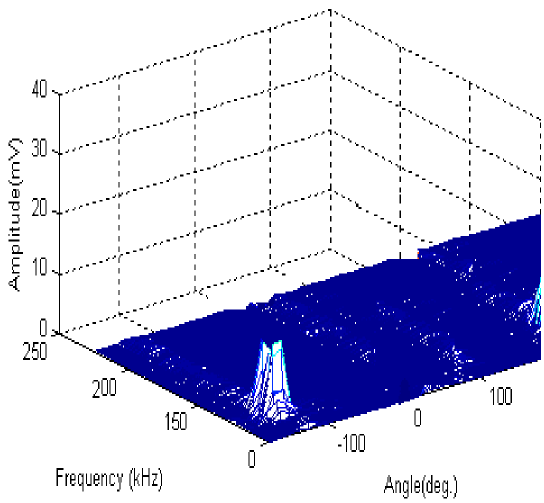

Figure 7b Zoom around 0 ° angle of Figure 7a