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Acoustic Monitoring of Diesel Engine

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Abstract: *The sound generated from a diesel engine can be modelled by suitable time-frequency analysis techniques. These methods show that there is a widening of frequency bands around top dead centre positions. As anticipated, the sound emitted from engine increases with an increase in speed and load. Condition monitoring of engines by Winger Ville functions and complex wavelet transformations allow studying the recognition of combustion events. This work deals with the tests carried out on a common rail direct diesel engine test rig. The acquired data was processed by signal processing techniques and results obtained are analyzed.*

Keywords: *Noise, vibrations, acoustic*

1. Introduction

Condition monitoring in diesel engine is accomplished by several means e.g., acoustics, wear, speed & cylinder pressure measurements. However, acoustic measurements provide a non-intrusive information about the signals originating from the engine. Acoustic monitoring of diesel engines has provided rich haul of information based on vibration measurements [1]. Acoustic contamination is perceived to be a problem for signal processing of diesel engine acoustics. Acoustic measurements can be carried by means of microphones placed at a distance that eliminates the need of high temperature resistant monitoring equipment. Initial step in acoustic monitoring is to consider factors like load, speed. Injection parameters etc. Austen and Priede have considered these factors in their work [2]. Yuichi and Yashiro have considered frequency components of noise radiated from camshaft and crankshafts [3].

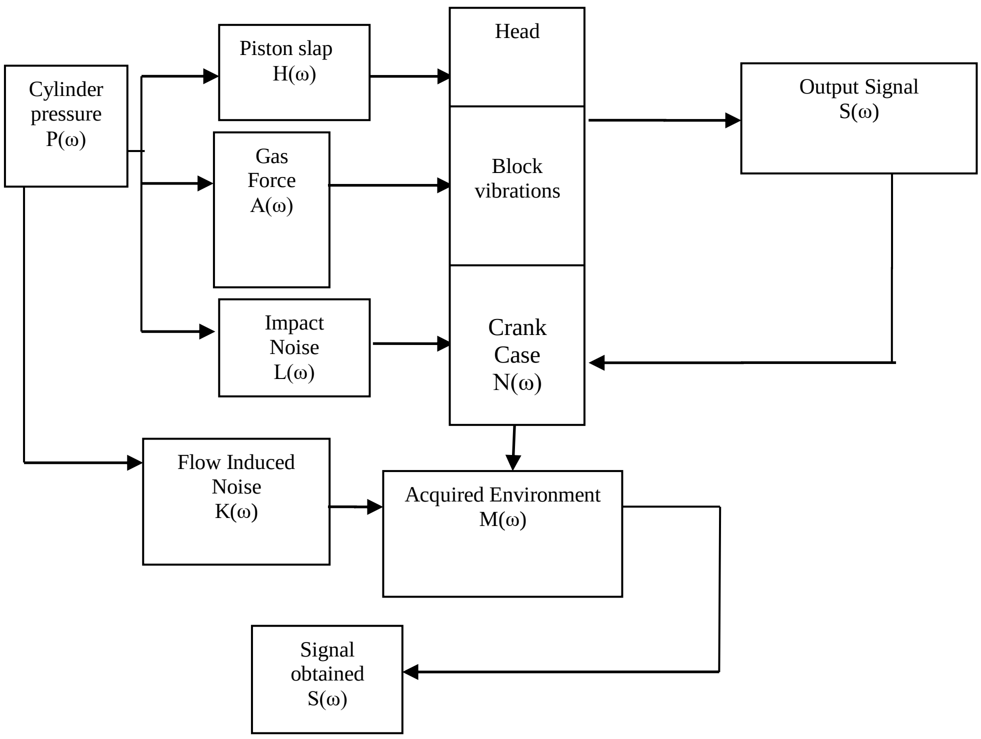

Fig. 1. Flow Chart of Engine Noise

Apart from these motion-based noise, combustion-based noise has been studied extensively [4]. Combustion based noise is affected by misfires, pressure rise rate, injection angles and amount of fuel injected. Li et al has used advanced signal processing techniques to detect injection faults, misfires etc. [5]. Gu and Ball have used fuzzy logic techniques to monitor noise spectra for condition monitoring of engines [6].
Several research works have been done to reduce the noise radiated from engines. Combustion noise is most important noise, which induces other kinds of noises like piston slap, bearing noise etc.
The overall noise emissions can be summarized as given in the figure 1 presented herein [7-20].

The sound signal in frequency domain can be expressed as:

$$S(\omega) = P(\omega)\,K(\omega)\,M(\omega)+[\,H(\omega)\,A(\omega)\,L(\omega)]\,P(\omega)\,N(\omega)\,M(\omega) \qquad [1]$$

$$S(\omega) = \{[K(\omega) +[\,H(\omega)\,A(\omega)\,L(\omega)]\ \ N(\omega)\,\}\,P(\omega)\,M(\omega) \qquad [2]$$

Which further yields

$$S(\omega) = J(\omega)P(\omega)\,M(\omega) \qquad [3]$$

If we neglect the resonance phenomenon and take into consideration only combustion excitation this relationship can be written in time domain as:

$$S(t) = J(t)*P(t)*\,M(t) \qquad [4]$$

All the types of noises except flow noise depend upon the combustion excitation force, which is dominant near TDC, hence sound emitted from the engine can be considered to vary linearly with combustion pressure in form of:

$$S(\theta) = k\,p(\theta) \qquad [5]$$

Hence, it can be referred that combustion process is the key source of noise in engines. Figure 2 shows the plot of wave forms of in cylinder pressure for a complete revolution of 720° crank angle.

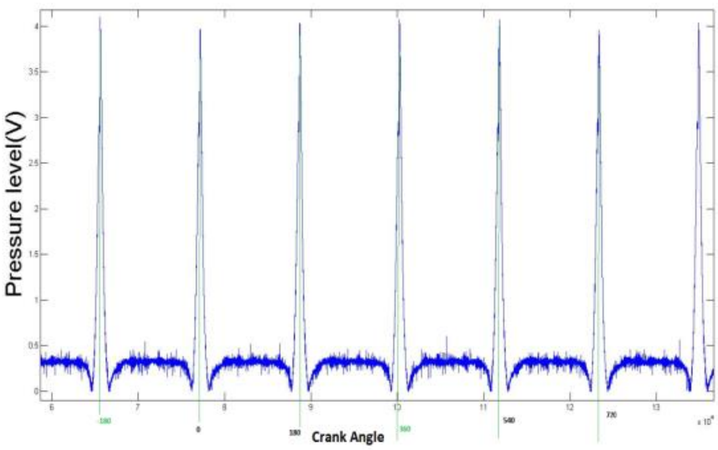

Fig. 2. Cylinder Pressure

Peaks in this figure correspond to combustion events taking place in the cylinder around TDC. These events can be more understood by time-frequency representation of graphs as shown in figure 3, which denotes that acoustic frequency at TDC positions is very high.

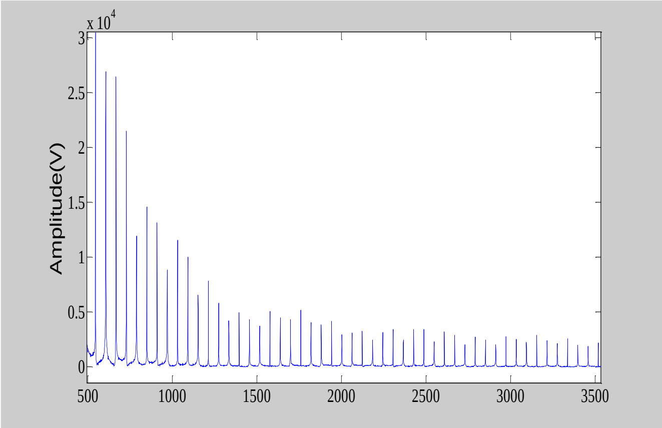

Fig. 3. Spectrum of Pressure Signals

2. Time-Frequency analysis

Cyclic averaging is the most efficient method to cancel the random noise. RMS value of sound can be calculated using relationship:

$$\mathrm{RMS} = \frac{1}{n}\sum_{1}^{n}\sqrt{\frac{[s]^2}{T}} \quad [6]$$

Where: s is windowed engine cycle signal, n is number of cycles & T is time period of cycle.
The average SPWVD function is defined by relationship:

$$(\mathrm{SPWVD}) = \frac{1}{n}\sum_{\mathrm{I}=1}^{n}(SPWVD)_{\mathrm{I}} \quad [7]$$

3. Experimental setup

Tests were done on a single cylinder HARTZ engine having specifications as presented in Table no 1.

Table 1: Engine Specifications

Type	Diesel Engine
Make	HARTZ
No of cylinder	**1**
Bore	69 mm
Stroke	65 mm
Displacement	0.243 liter
Compression	22:1
Maximum Power	3.5kW@4400RPM
Maximum Torque	10N-m @2000RPM

Table 2: Pressure Transducer Specifications

Range	0-250Bar
Sensitivity	20pC/Bar
Resonance Frequency	160kHz

The in-cylinder pressure was monitored by an AVL transducer having specifications shown in Table 2. Block vibrations were measured by means of a Endveco7240C type Mono axial accelerometer having features accelerometer are presented in Table no 3. The data recorded during each test was under steady state conditions as seen in Table no 4.

Table 3: Accelerometer Transducer Specifications

Range	1000g
Sensitivity	3pC/g
Resonance Frequency	90kHz

Table 4: Test Data Collected

Case	Load	Speed	Q (pre)	Q (main)	SOI (pre)	SOI (main)	P_{rail}
B3	50%	1600	1	6.3	19.9	5.09	508
BASE	100%	1600	1	13.8	14.8	6.29	714
B1	0%	1600	-	-	-	-	-
B2	50%	2000	1	6.6	22.5	5.68	515

4. Results and discussions

Figure no 4 shows the acoustic signals obtained from the testing conditions. The signals obtained may be contaminated by room resonance conditions. This distortion is maximum when the wavelength of sound waves matches with room dimensions. The resonance modes of rectangular room of length L, width W& height H is given by relationship:

$$f = \frac{c}{2}\sqrt{\frac{p^2}{L^2} + \frac{Q^2}{W^2} + \frac{R^2}{H^2}} \quad [8]$$

Where c is velocity of sound in air & P,Q,R=0,1,2,3……

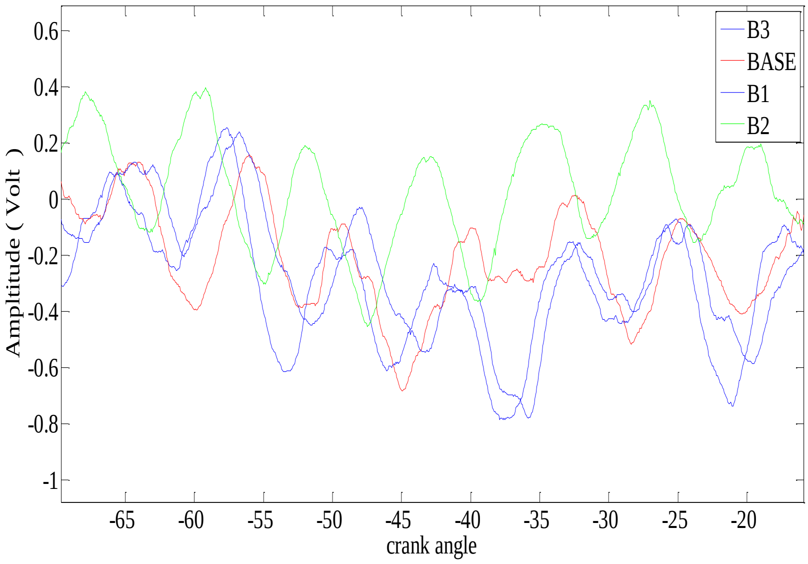

Fig. 4. Sound Data Acquired

Figure no 5-7 shows the time-frequency plots using Winger Ville function. Combustion events are evident by broadening of frequency bands around TDC positions. The onset of combustion events is evident by a sharp increase, which slowly decays with advanced crank angles. The even contribution of each cylinder is evident from the similar shape.

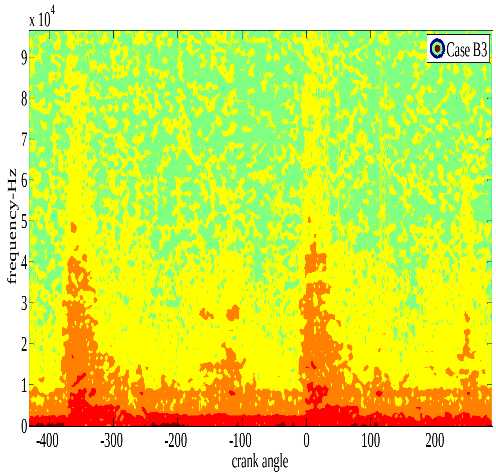

Fig. 5. Time-Frequency plot(B3)

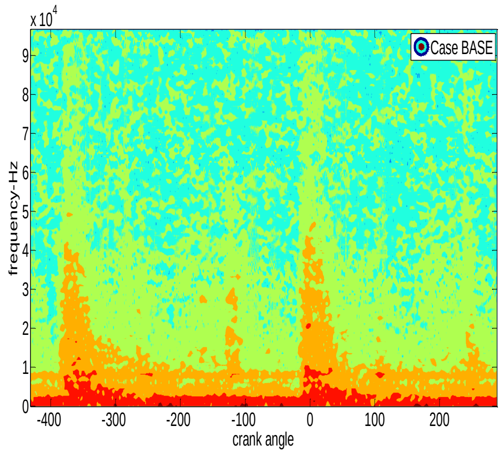

Fig. 6. Time-Frequency plot(BASE)

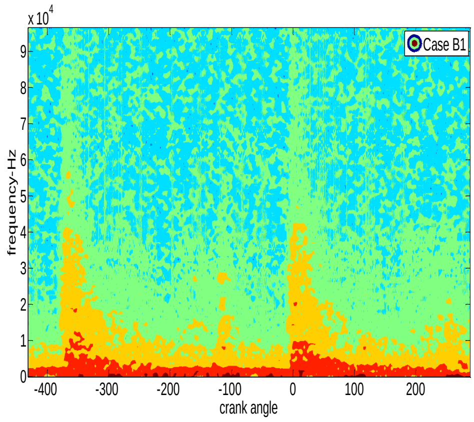

Fig. 7. Time-Frequency plot(B1)

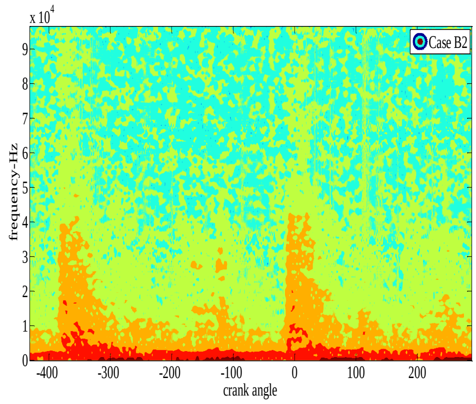

Fig. 8. Time-Frequency plot(B2)

These plots show that the dominant frequencies are below 100KHz & the fluctuations in amplitude of these frequencies below 1KHz does not correspond closely to combustion events. These observations endorse the anticipated resonance effects. Two persistent bands are visible around 10KHz& 40KHz which corresponds to resonances in pre amplifier and microphone respectively. Figure 9-12 show the CWT contour plots for the given testing conditions. It is clear that CWT plots do not provide detailed information in low frequency range as Winger Ville plots, however they highlight combustion features better at higher frequency ranges [9-26].

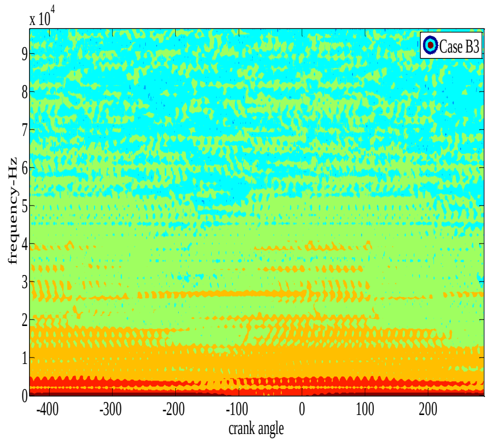

Fig. 9. CWT Time-Frequency plot(B3)

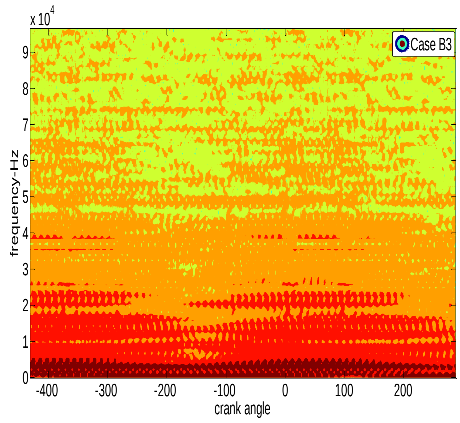

Fig. 10. CWT Time-Frequency plot(BASE)

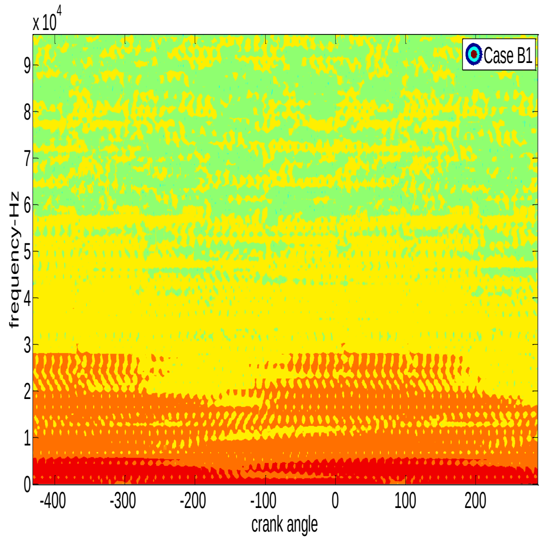

Fig. 11. CWT Time-Frequency plot(B1)

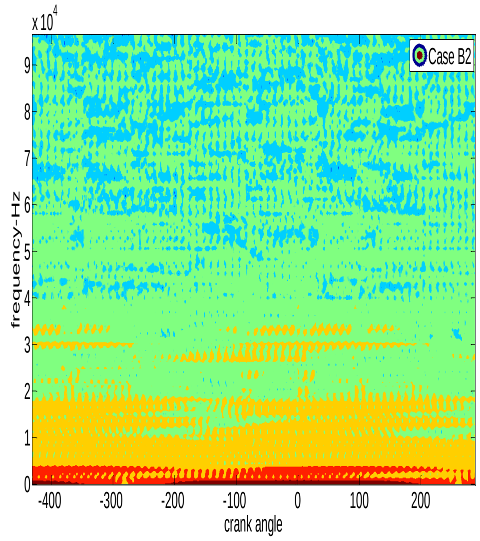

Fig. 12. CWT Time-Frequency plot(B2)

5. Conclusion

The sound models can be generated based upon the measurements of in cylinder pressures. Time frequency models show that at lower frequency ranges sound is distorted by external noise whereas at higher frequency ranges combustion events dominate. Use of Complex wavelet transformation and Pseudo Winger Ville distribution provides effective ways for condition monitoring of diesel engines.

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