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Wavelet Analysis of Diesel Engine Noise

Sunny Narayan
Department of Mechanical Engineering,
University of Roma Tre, Via Della Vasca Navele, Roma, Italy

Abstract: Combustion engines is main type of noise radiated from diesel engines, so that methods can be devised to reduce the noise levels. Fourier tranformation methods along with block attenuation curves have been used to study the correlation between cylinder pressure and noise radiated from engines. In this research, wavelet method has been used to study noise emitted from a dual injection diesel engine. The results show high variation in cylinder pressure levels and noise emitted which indicate non stationary nature of combustion process.

Key words: Diesel engine noise, wavelets, cylinder pressure, attenuation, noise radiated

INTRODUCTION

The noise emitted from engines has been studied long time back. Signal processing is an important technique to separated various noise sources. FFT transformations have been used as an effective method of signal analysis (Zheng and Leung, 2002). These transformations have many transient parts, hence are unsuitable (Chui, 1992). In recent years, linear and bi linear time frequency distributions have been used as an alternatives (Cohen, 1989). Both of these methods have their own advantages and short comings. The former one has low resolutions while the latter one has low processing speed and is complex (Zheng and McFadden, 1996). In this research, time-frequency analysis have been done on signals acquired from a diesel engine test rig.

Noise in an engine consists of several components like flow based noise, combustion noise, mechanical noise, etc. (Anderton, 1979). Combustion noise is produced due to rapid change in pressure which causes vibrations and resonance of combustion chamber. As the piston moves from TDC to BDC, the gap between liner and piston causes impact of piston with walls of cylinder which is known as piston slap (Zheng and Leung, 2002). Motion of rotary parts adds low frequency components to overall noise levels. Gears, injectors and valve motion also contribute towards transient components of noise. Injector noise depends upon stiffness of spring which holds needle tight to its seat (Zheng and Leung, 2002). Low spring stiffness may cause failure of needle to return back to seat (Zheng and Leung, 2002). This may cause needle to remain open even after injection events. Any faults in valves seats, cams, tappets or valve springs may cause irregularity in valve operations.

Flow induced inlet and exhaust noise also contribute high frequencies components towards overall noise levels (Zheng and Leung, 2002). Figure 1 shows a typical plot of noise signals obtained from a diesel engines. A noise signal from diesel engine can be expressed in form of Eq. 1 (Desantes *et al.*, 2001):

$$x(t) = \sum A_i \text{Cos}(\omega_i t + \theta_i) + \sum B_k \text{Cos}(\omega_k t + \theta_k) u(t - t_k) \quad (1)$$

This relationship both transient, as well as harmonic components. The major harmonic content can be removed by fourier transformations and the results are seen in Fig. 2.

In diesel engines, the mixing of fuel with air produces a sudden pressure rise known as knock (Desantes *et al.*, 2001). Hence, noise radiated is both due to combustion events, as well as motion of parts is shown in Fig. 3.

High oscillations causes resonance of whole engine structure frequency of which is, also dependent on temperature of gas inside.

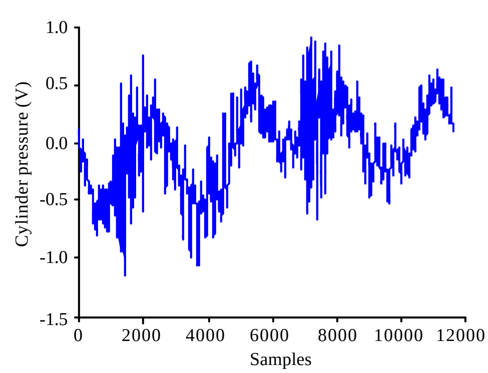

Fig. 1: Diesel engine noise signals

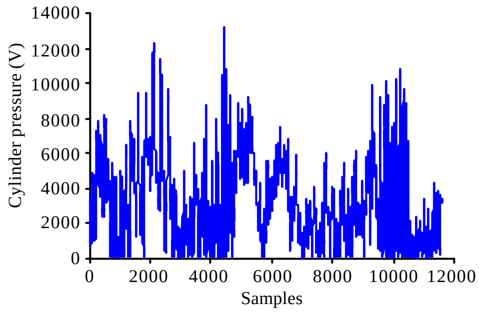

Fig. 2: Residual noise signals

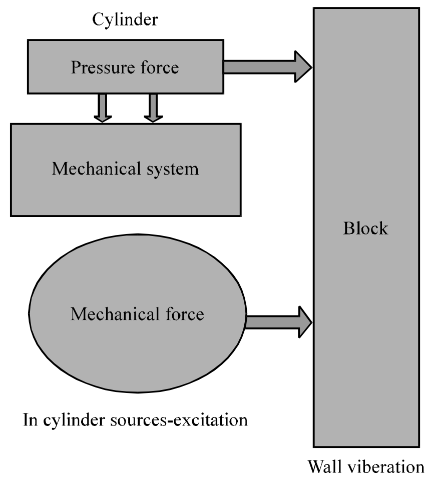

Fig. 3: Noise process

Due to increase in restrictions in limits of noise radiated from vehicles study has been focused on block attenuation and transfer function between noise radiated and cylinder pressure. With use of modern injection systems, it has been possible to optimize the injection parameters, e.g., engine speed, injection pressure, etc.

TESTING RIG

A lombardini LDW442CRS common rail double direct injection engine system was used to conduct tests. This engine has specifications as given by Table 1. This engine test rig has a piezo electric type Kistler 6056A make pressure transducer for in cylinder pressure measurements and a optical crank angle encoder for detection of TDC position, as well as engine speed (Fig. 4).

The signals data obtained from the tests was processed using B&K Nexus device which amplifies and filters data at 22.4 kHz.

Experiments were carried out by varying the dwell time between pre and main injections keeping other parameters fixed. The data presented in Table 2, was obtained at a speed of 2700 RPM and 100% load condition.

Fig. 4: Test rig showing micro phone

Table 1: Engine features

Types	Direct injection
No. of cylinders	2
Bore	68 mm
Stroke	60.6 mm
Displaced volume	440 cm^3
Compression ratio	20:1
Maximum power	8.5 kw@4400 RPM
Maximum torque	25 N-m@2000 RPM

Table 2: Experimental data obtained

Conditions	P_{rail} (bar)	Q_{pre} (mm^3/c)	SOI_{pre} (°BTDC)	SOI_{main} (°BTDC)
B3	700	1	13.2	6
Base	720	1	16.2	6
B1	700	2	17.1	6
B2	700	1	20.1	6
Motored	-	-	-	-

In order to observe complex non-stationary phenomenon in diesel engines, time-frequency methods have been used to surpass limitations of classical time or frequency domains. In this research, mathematical models have been used to find the correlation between radiated noise and excitation forces. Spectrogram which is an extension of FFT is not an effective method to analyze the combustion process due to non stationary effects. These signals are best analyzed by Wigner distribution, however this distribution has cross terms (Stankovic and Bohme, 1999). In contrast, the wavelet method frequency information is obtained by widow dilation. This method is useful for assessment of phenomenon where there are sharp peaks in signals as in case of radiated noise and in cylinder pressure (Graps, 1995).

In this research, following approach has been used for analysis study of in cylinder pressure to identify various sources and contributions. Estimation of attenuation of engine block to check validity of method. Time-frequency analysis of noise radiated from engine and determining any correlation between in cylinder pressure and noise radiated.

The test cell used is large enough with noise absorbing walls to measure radiated noise at low frequency.

FREQUENCY ANALYSIS

The spectrum analysis is carried out by Discrete Fourier Transformation (DFT) which gives energy distribution among frequency associated with any variable.

In this study, DFT of in cylinder pressure with and without motoring condition has been carried out. As seen from Fig. 5, there is difference between energy levels at these conditions. At higher frequency low energy distribution can be observed in motored condition as compared to combustion condition.

A peak can be clearly seen at a frequency of 240 kHz which denoted the resonant frequency related to combustion chamber.

Further in this study, time frequency analysis has been done to obtain spectral energy distribution of combustion noise. This type of information is not available in DFT, hence spectrogram plots of engine noise and in cylinder pressure derivatives was plotted (Fig. 6).

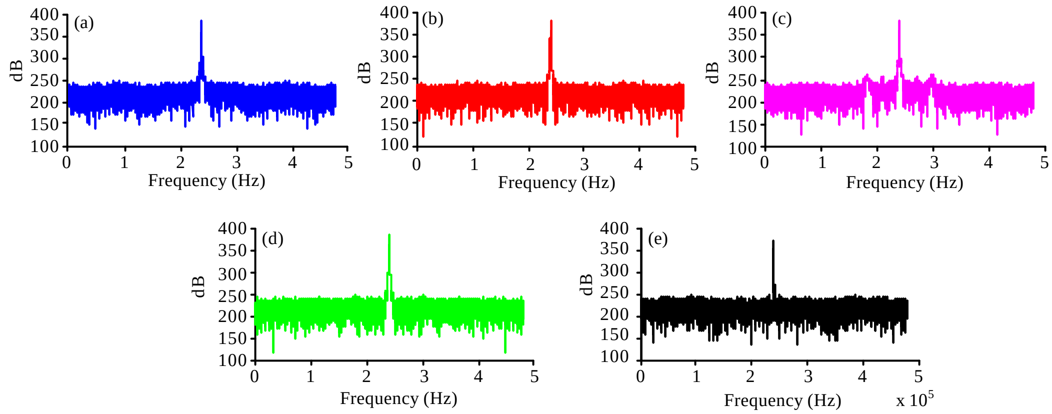

Fig. 5: Cylinder pressure spectrum: a) Case B3; b) Case base; c) Case B1; d) Case B2; e) Case motored

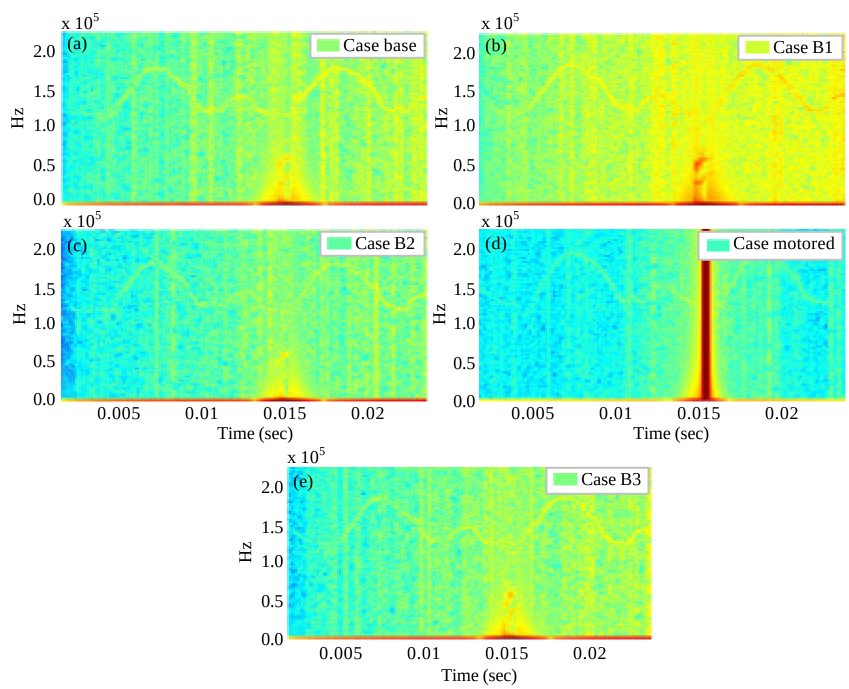

Fig. 6: Spectrogram plots of in cylinder pressure levels

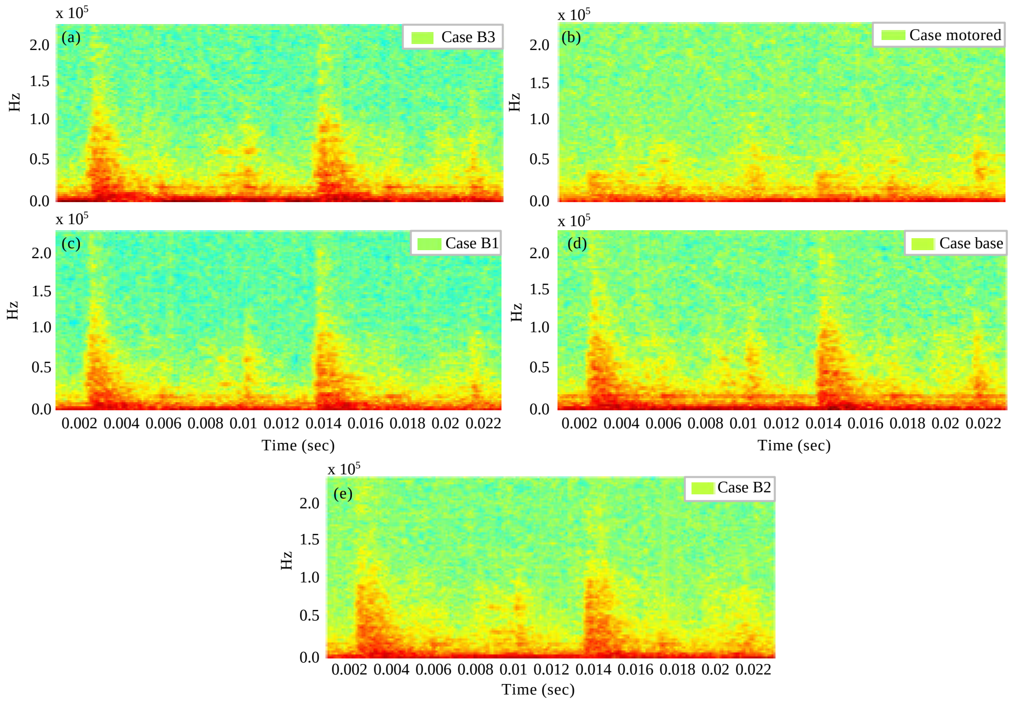

Fig. 7: Spectrogram plots of cylinder noise levels

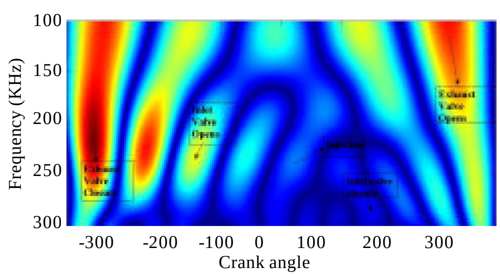

Fig. 8: Diesel engine noise contour plots

In these plots, the fluctuation of cylinder pressure of combustion chamber can be seen. Also, resonant frequency of chamber can be noticed with its amplitude dominant over all other frequency ranges. The spectrogram plot of in cylinder pressure derivative of motored condition shows a different distribution along time that can be distinguished. In this range, the energy is distributed in lower frequency range of where radiated sound is concentrated. Stankovic and Bohme (1999) have proposed a time variant transfer function of block attenuation (Tichy and Gautschi, 1980). From these observations, it can be concluded that mechanical noise is concentrated in this range whereas sound power levels greater than Hz are associated with noise caused due to pressure forces. This is coincident with observations made by Usami *et al.* (1975) during study of piston slap. Figure 7 shows plots of spectrogram of noise radiated from diesel engine. As evident from these plots a reduction in energy level is observed in case of motored condition in range where mechanical noise is dominant.

Further, using with time-frequency contour plots various mechanical events can be studied as evident from Fig. 8.

CONCLUSION

As engine noise signals needs time, frequency or time-frequency parameters for complete disciption. With help of time-frequency plots contribution of various sources can be studied. An important application of such plots is in condition monitoring of engines where problems in parts of engines can be detected. This method, also provides a more reliable method to correlate.

NOMENCLATURE

SOI = Start of Injection
BTDC = Before Top Dead Center
P_{rail} = Rail injection pressure
Q_{pre} = Amount of fuel injected per stroke
db = decibel level
ATDC = After Top Dead Center
BBDC = Before Bottom Dead Center
ABDC = After Bottom Dead Center

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