ACTA TEHNICA CORVINIENSIS – Bulletin of Engineering
Tome VII [2014] Fascicule 3 [July – September]
ISSN: 2067 – 3809

1. Sunny NARAYAN

TIME-FREQUENCY ANALYSIS OF DIESEL ENGINE NOISE

1. Mechanical Engineering Department, University of Roma Tre, ITALY

Abstract: *Combustion is the main type of noise radiated from diesel engines. Several methods have been 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 work wavelet method has been used to study noisee mitted from a dual injection diesel engine. The results show high variation in cylinder pressure levels and noisee mitted which indicate non stationary nature of combustion process.*
Keywords: *Engine Noise, Vibrations, Condition Monitoring*

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 [1]. These transformations have many transient parts, hence are unsuitable [2].

In recent years linear and bi linear time frequency distributions have been used as an alternatives[3]. 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 [4]. In this work 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 [5]. 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 [1]. 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[1]. Low spring stiffness may cause failure of needle to return back to seat[1]. This may cause needle to remain open even after injection events. Any faults in valves seats, cams, tappets orvalve springs may cause irregularity in valve operations. Flow induced inlet and exhaust noise also contribute high frequencies components towards overall noise levels [1].

Figure 1 shows a typical plot of noise signals obtained from a diesel engines. In diesel engines the mixing of fuel with air produces a sudden pressure rise known as knock [6]. Hence noise radiated is both due to combustion events as well as motion of parts is shown in Figure 3.

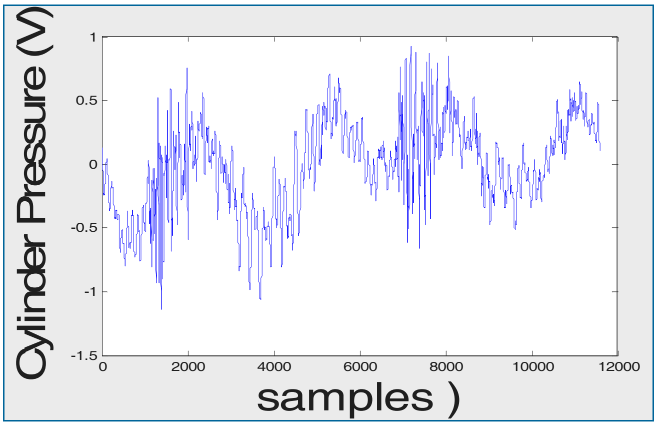

Figure 1 - Diesel engine Noise signal

This relationship both transient as well as harmonic components. The major harmonic content was removed by Fourier transformations and the results are seen in Figure 2.

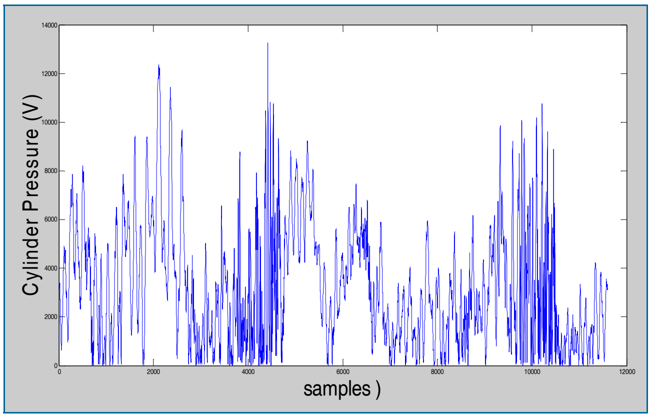

Figure 2 - Residual Noise signals

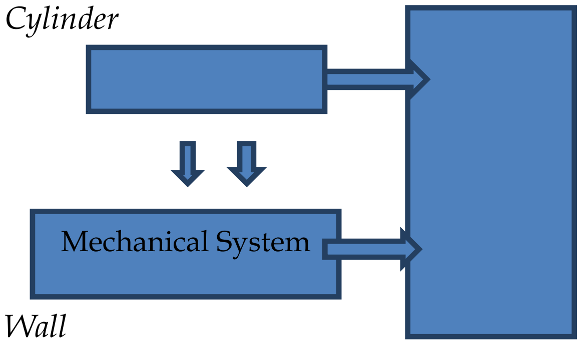

Figure 3 - Noiseprocess

A high oscillation causes resonance of whole engine structure frequency of which is also dependent on temperature of gas inside. 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 SETUP

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 right as a piezoelectric type Kistler 6056A make pressure transducer for in cylinder pressure measurements and an optical crank angle encoder for detection of TDC position as well as engine speed. The signals data obtained from the tests were 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 2000 RPM and at motored & 100% load conditions.

Table 1 - Engine Features

Type	Direct Injection
Number of cylinders	2
Bore	68 mm
Stroke	60.6 mm
Displaced Volume	440cm³
Compression Ratio	20:1
Maximum Power	8.5k w@4400 RPM
Maximum Torque	25N-m @2000 RPM

Table 2 - Injection Features

Condition	P_{rail} (Bar)	Q_{pre} (mm³/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°

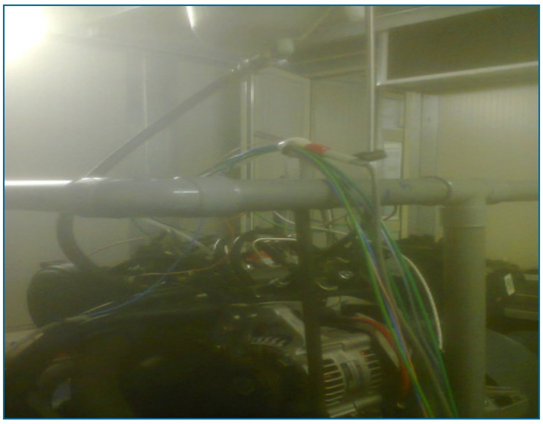

Figure 4 - Engine Test Rig showing Microphone

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 work, 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 [7]. 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 [8]. In this work following approach has been used for analysis study of incylinder 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.*

RESULTS AND DISCUSSIONS

The spectrum analysis is carried out by Discrete Fourier transformation (DFT) which gives energy distribution among frequency associated with any variable.In this section DFT of in cylinder pressure with and without motoring condition has been carried out. As seen from Figure 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 conditions.

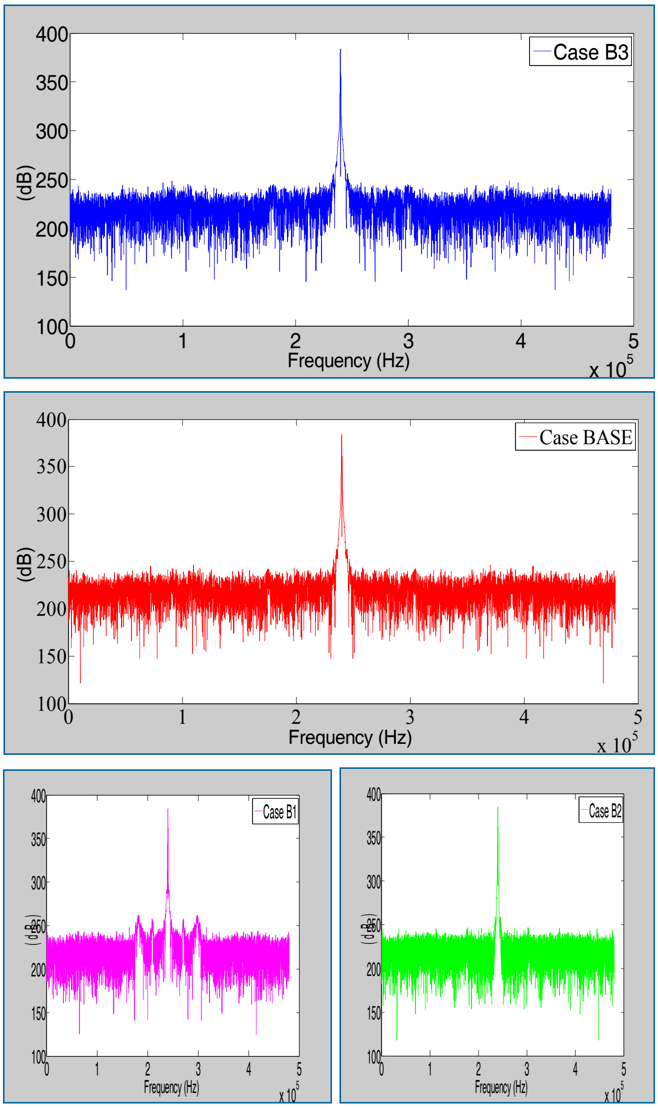

Figure 5 - Cylinder Pressure Spectrum

A peak can be clearly seen at a frequency of 240KHz which denoted the resonant frequency related to combustion chamber. Further time frequency analysis has been done to obtain spectral energy distribution of combustion noise. This type of information is not available in DFT.

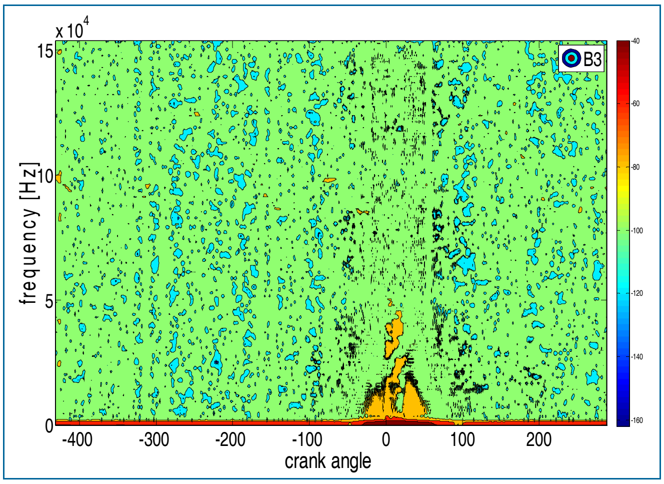

Figure 6 - Cylinder Pressure STFT using Spectrogram –(B3)

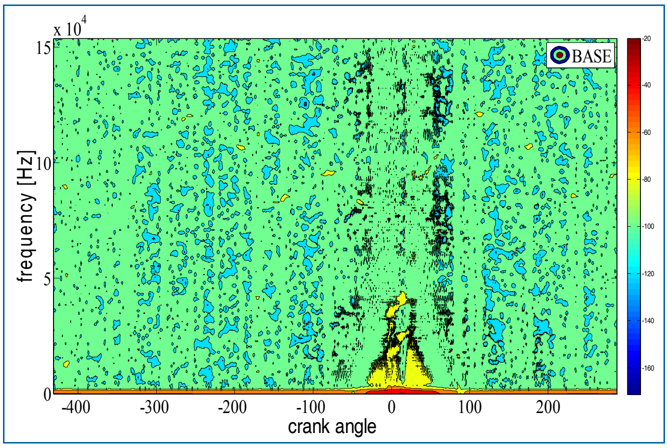

Figure 8 - Cylinder Pressure STFT using Spectrogram –(BASE)

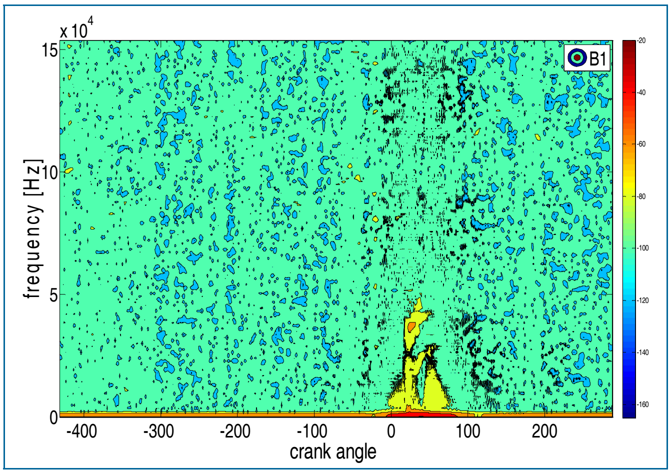

Figure 9 - Cylinder Pressure STFT using Spectrogram –(B1)

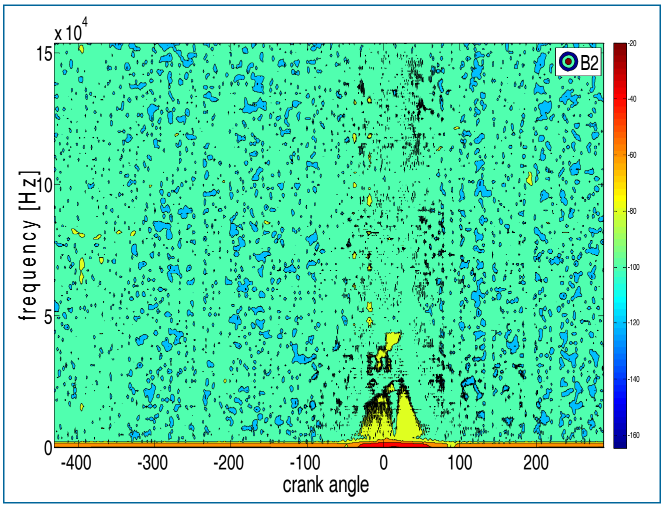

Figure 10 - Cylinder Pressure STFT using Spectrogram –(B2)

In these plots the fluctuation of cylinder pressure of combustion chamber can be seen. A burst of energy havign frequency of around 1500 Hz is visible around TDC position in each case which corresponds to onset of combustion process. Combustion noise is also dependent upon the strutural attenuation of engine. Stankovic and Bhome have proposed a time variant transfer function of block attenuation [9]. 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 during study of piston slap [10].

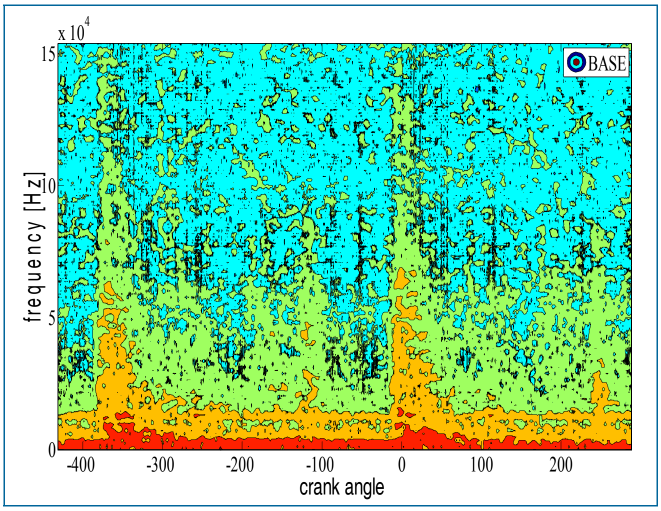

Figure 11 - Cylinder Noise STFT using Spectrogram –(BASE)

Figures 11-14 show plots of spectrogram of noise signals 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. Figure no 15 shows the zoomed contour plots of noise emissions in case of condition BASE in which various mechanical events can be identified.Most of these events are in frequency ranges 10KHz-20KHz.

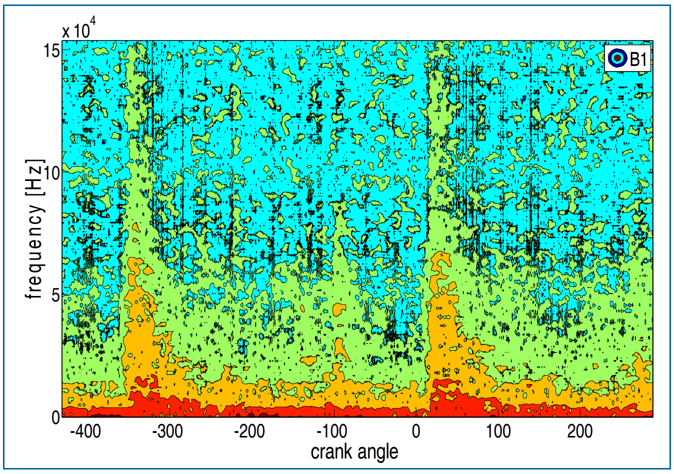

Figure 12- Cylinder Noise STFT using Spectrogram – (B1)

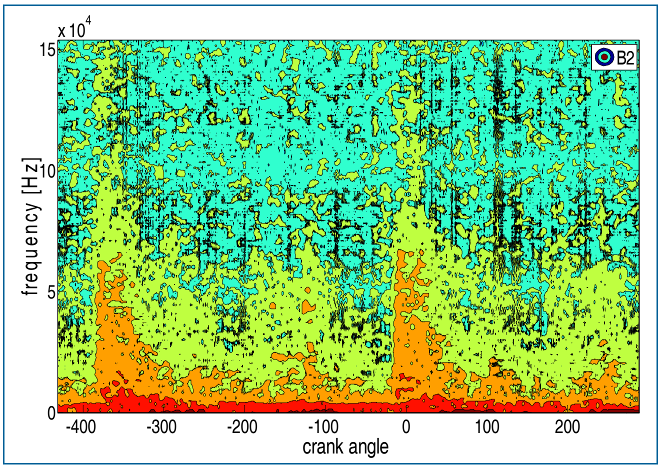

Figure 13 - Cylinder Noise STFT using Spectrogram – (B2)

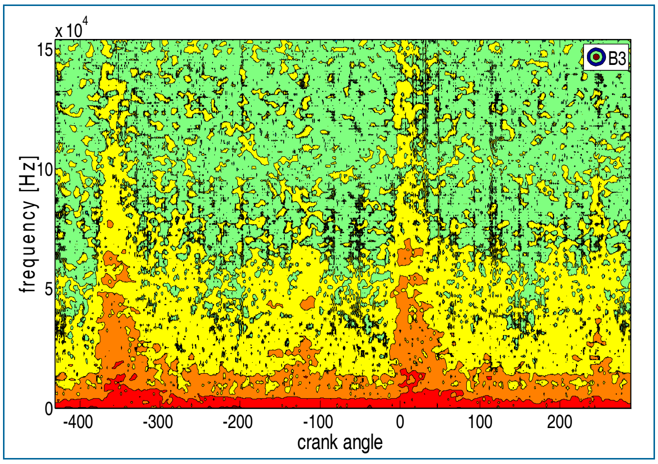

Figure 14 - Cylinder Noise STFT using Spectrogram –(B3)

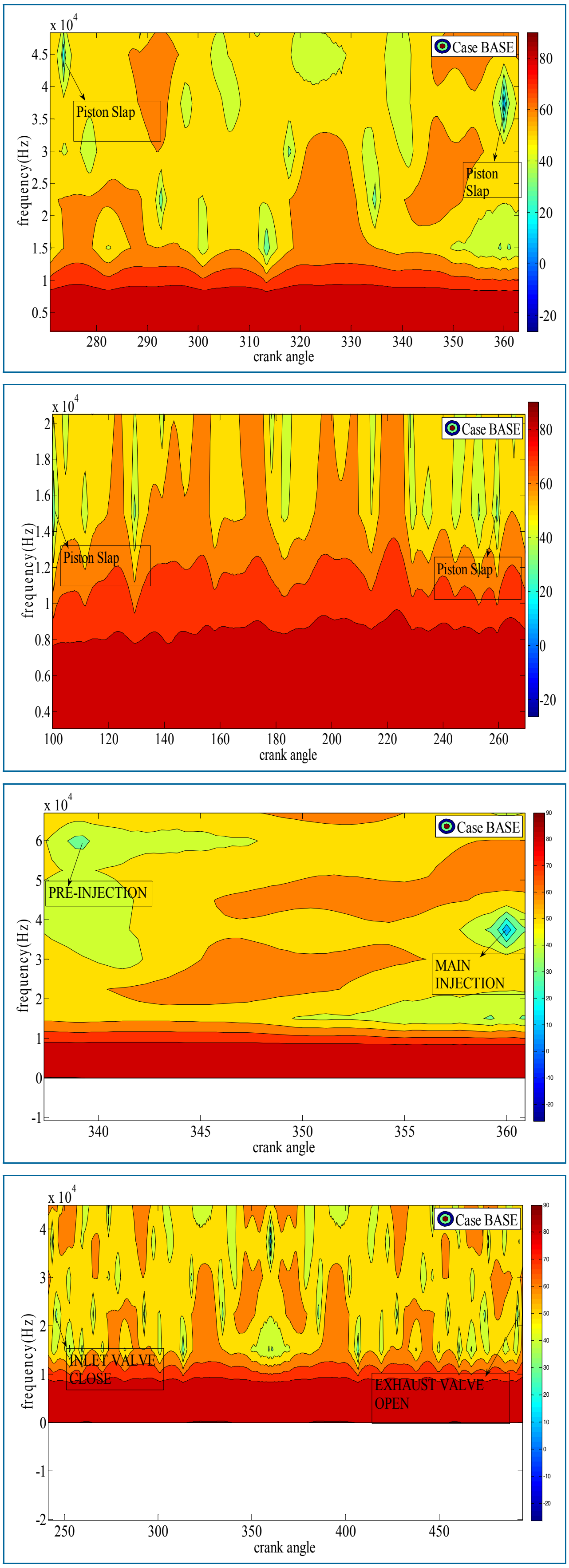

Figure 15 - Mechanical Events from contour plots

CONCLUSION

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 various events occurring in the engine operation process.

NOMENCLATURE

Q_{pre} - Amount of fuel injected during pre-injection Period (mm^3per stoke)
Q_{main} - Amount of fuel injected during main-injection Period (mm^3per stoke)
SOI_{pre} - Angle of start of pre-injection period (degrees before Top Dead Centre)
SOI_{main} - Angle of start of main-injection period (degrees before Top Dead Centre)
P rail - Injection Pressure of fuel inside cylinder
BTDC - Before Top Dead Centre
FFT - Fast Fourier Transformations
dB - Decibel Level
STFT - Short Time-Frequency Fourier Tranformation

REFERENCES

[1.] Zheng, Leung, ''Internal Combustion Engine Noise Analysis With Time-Frequency Distribution'', Transactions of ASME, Vol 124,July 2002.
[2.] Chui, C. K., 1992, An Introduction to Wavelets, Volume 1: Wavelet Analysis and Its Applications, Academic Press, San Diego,CA.
[3.] Cohen, L. 1989, ''Time-Frequency Distributions—A Review,'' Proc. IEEE, 77, No. 7, pp. 941–981.
[4.] Zheng, G. T. and McFadden, P. D., 1996, ''A Time-Frequency Distribution for Analysis of Signals With Transient Components and Its Application to Early Gear Failure Detection,'' Report OUEL 2088/96, Department of Engineering Science, University of Oxford, Oxford, UK.
[5.] Anderton D, ''Relation between Combustion System and Engine Noise'', SAE paper 790270-1979.
[6.] Desantes, Torregrosa, ''Wavelet Transform applied to Combustion Noise Analysis in High

Speed DI Diesel Engine'', SAE paper no 2001-01-1545.

[7.] *Stankovic, Bohme, ''Time Frequency analysis of multiple resonances in combustion engine signals'', signal processing 79, pp 15-28, 1999.*

[8.] *Graps, "An introduction to Wavelets'', IEEE computational science and engineering 2(2), 1995.*

[9.] *Tichy J, Gautschi, Piezo-electrische Mebtechnik Spinger, Berlin, 1980.*

[10.] *Usame, Wada, Sonada, ''Piston slap noise of indirect combustion diesel engine'', SAE paper 750801-1975.*

ACTA Technica CORVINIENSIS
BULLETIN OF ENGINEERING

ISSN:2067-3809