Acta Mechanica Slovaca
ISSN 1335-2393
www.actamechanica.sk

Pressure Waveform Modelling in Diesel Engines

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Abstract: In this work combustion noise produced in diesel engines has been investigated. In order to reduce the exhaust emissions various injection parameters need to be studied and optimized. The combustion noise has been investigated by means on in cylinder pressure measurements using piezo electric transducers. The noise has been evaluated for a 440 cc diesel engine mounted on test rig. The engine was run under various operating conditions varying various injection parameters.

Keywords: Engine Acoustics, Noise.

1. Introduction

A number of non-intrusive methods have been used to reconstruct the cylinder pressure. Tohyama et al. [1],Agren [2] & Randall [3] have studied pressure identification methods based on processing of engine surface vibrations. The frequency response function computed for both acceleration and engine noise levels can be used for this purpose. Gao have used time domain techniques to reconstruct cylinder pressure from accelerometer signals [4].Combined with signal mapping methods developed in [4],the capability of acoustic emissions increases significantly.

2. Signal Processing

The frequency response function $H(\omega)$ expresses relationship between forcing function $P(\omega)$ & response function $F(\omega)$.

Mathematically: $F(\omega) = P(\omega)H(\omega)$ (1)

Which leads to: $P(\omega) = F(\omega)H^{-1}(\omega)$ (2)

Cepstrum analysis is a useful technique used in signal and image processing [5]. The complex Cepstrum of a time signal $w(t)$ can be **mathematically defined as**:

$$\hat{W}(t) = F^{-1}[\log(F(w(t)))] \quad (3)$$

Where F is Fourier transformation of function.

From equation 1 we have:

$$\log(F) = \log(P) + \log(H) \quad (4)$$

Taking inverse Fourier on both sides we have

$$F^{-1}[\log F] = F^{-1}[\log P] + F^{-1}[\log H]$$

Hence it can be written:

$$\hat{F}(t) = \hat{P}(t) + \hat{H}(t) \text{ [6].}$$

3. Experimental Test Rig

Experiments were conducted on a dual cylinder lombardini LDW442CRS common rail direct injection test rig having specifications as presented in table no 1.This engine test rig has a piezo electric type Kistler 6056A make pressure transducer for

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in cylinder pressure measurements and an optical crank angle encoder for detection of TDC position as well as engine speed. The given system can do maximum of 2 injections per cycle. The injection strategy for the engine is shown in figure no 1.

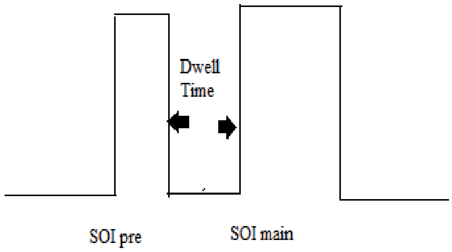

Fig. 1: *Injection Process.*

Table 1: *Engine Specifications.*

Type	Direct Injection
Number of cylinders	2
Bore	68 mm
Stroke	60.6 mm
Displaced Volume	440cm^3
Compression Ratio	20:1
Maximum Power	8.5kw@4400 RPM
Maximum Torque	25N-m @2000 RPM

The engine was run at 1600RPM & 50%load condition. The data obtained is shown in table no 2.

Table 2: *Data Acquired.*

4. Results and Discussions

Figure no 2 shows the comparison of acquired acoustic signal and cylinder pressure as a function of frequency for data obtained . The raw emission signals has information about combustion as well as mechanical events in the engine. From these plots it is clear that both signals are correlated particularly in section where combustion events occur.

Figure no 3 shows the close view of signals as a function of crank angle for one cycle of operation for the same condition. There is an increase in acosutic emissons signals just after injection of fuel at 20° & 6° before TDC positions inside cylinder, although the pressure did not reach its peak value until 10°after TDC.This phenomenon has been explained by Shiozaki et at who suggested that heat release rate rose somewhat before the pressure reached its peak inside cylinders [6].

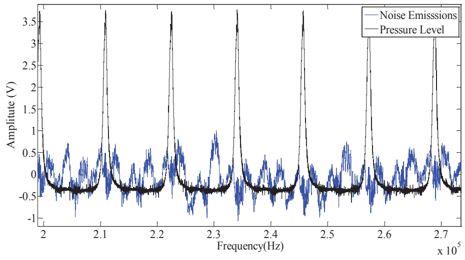

Fig. 2: *Acquired Signals.*

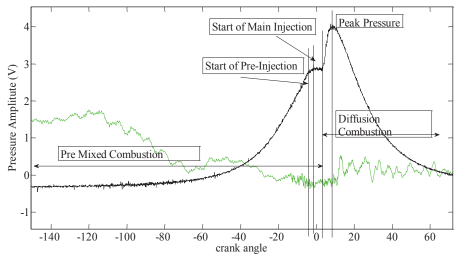

Fig. 3: *PressureTrace for a Cycle.*

The frequency content of pressure signals was found to be below 153KHz.In order to improve signal to noise ratio a low pass filter was applied to remove all frequency contents which are not related to combustion events.The results can be seen from figure no 4.As evident from this figure there is a high degree of non correaltion between signals,hence it can conculded that raw acoustic signlas are unsuitbale for direct frequency modeling. A more accurate method is by use of envelope functions.Time modelling of pressure trace can be done by dividing into two parts.First part which represents the time till end of compresion stroke can be modelled using polynomial fitting function aplied to cylinder pressure trace data for various load and speed conditions. Second part which includes time from start of injection till end of expansion stroke can be modelled using ARMA technique[6].

Complex ceptrum can also be used to model the pressure signals using acosutic emission signals. The advantage of this method is that it does not need complex curve fitting.The complex pressure ceptrum H^(t) of Frequency response function was evaluated for the test case and ressure signal was reconstructed.The resultscan be seen in figure no 5.

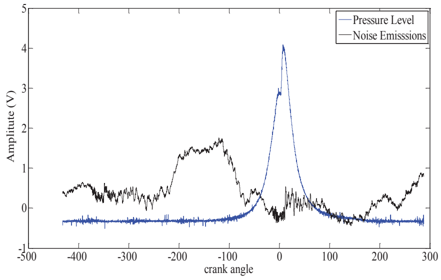

Fig. 4: *Data Acquired for a Cycle.*

The reconstruction error percentage (REP) can be evaluated for each signal as follows:

$$\text{REP} = \frac{\sum_{1}^{\pi} Pi - Ci}{Pi}$$

Where Pi is pressure signal & Ci is reconstructed pressure signal.

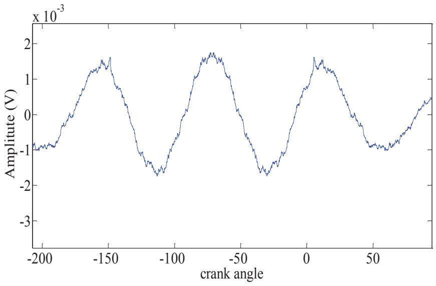

Fig. 5: *Reconstructed Pressure Signal.*

5. Conclusion

Acoustic emission signals are useful in determining the cylinder pressure signals and has proven useful in fuel/air mixture monitoring of engines. El-Ghamry et al [6]have shown use of acoustic emissions techniques to monitor engines of various sizes and types. Operating parameters can also be monitored including combustion phenomenon. The capability of these emissions may lead to new methods of engine management in order to meet various environmental legislations.

6. References

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Nomenclature:

- SOI - Start of Injection
- TDC - Top dead Center
- QMain - Amount of fuel injected per stroke in pilot(pre)injection
- Prail - Common rail injection pressure
- QPre - Amount of fuel injected per stroke in pilot(pre)injection.