

Analysis of noise emitted from 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 noise has been investigated by mean of data obtained from cylinder pressure measurements using piezo electric transducers and microphones on a dual cylinder diesel engine test rig. The engine was run under various operating conditions varying various injection parameters to investigate the effects of noise emissions under various testing conditions.

1. Introduction

To meet emissions norms new technologies are being developed all over the world. Many clean engine technologies are being used in diesel engines including EGR, Electronic fuel injection systems etc[1]. However there is a trade off between the exhaust emissions reduction and noise generated from diesel engines [2]. Modern EGR methods allow reductions of particulate matter as well as NOx at a time [3]. Variation in injection processes cause effectiveness of combustion processes which can reduce noise. Pilot injection also causes reduction in emissions from engine. This work is focusses on optimizing parameters of injection without change in structure to reduce the noise levels emitted from engine. Diesel engine combustion process begins when the atomized fuel enters from the injection nozzle orifice into combustion chamber where it gets mixed up with compressed air forming air-fuel mixture. Hence there is ignition delay between actual start of combustion process and fuel injected inside diesel engine [4]. A typical heat release curve of a diesel engine is shown here in figure 1. There is rapid change in pressure of engine cylinder during the phase of pre- mixed combustion which causes oscillation of whole engine structure [5]. The amplitude of these vibrations depends upon injection delay period as well as on rate of injection of fuel. Cylinder pressure can be transformed from time domain to frequency domain to correlate it with engine noise.

2. Background

Due to high efficiency, diesel engines have been a favourite choice for heavy duty applications including trucks . However they suffer from drawbacks of high noise, weight and vibrations. These engines are of two types: 1. Direct Injection(D.I.) Engines and 2. In direct injection engines. In the D.I. engines , the fuel is directly injected inside combustion chamber and due to lesser time for mixing, a heterogamous mixture consisting of both rich and lean parts is formed in the chamber.

Modern diesel injection systems use multiple injection process to control emissions like soot and Nitrous oxide (NOx) formation. These generally use three phases of injection namely pre-



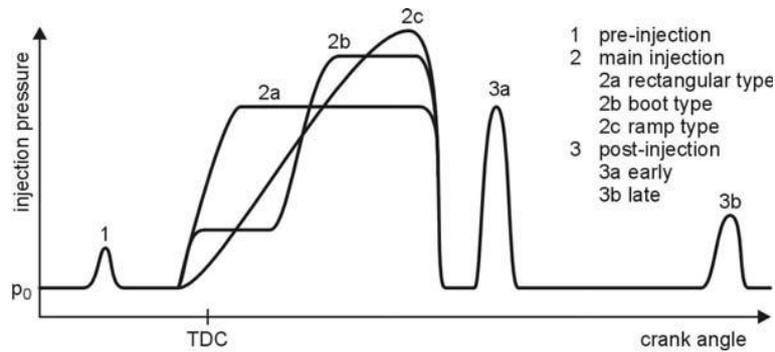


Figure 1. Multiple injection process in diesel engines.

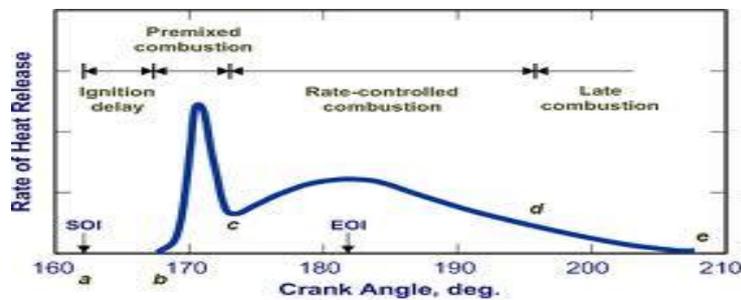


Figure 2. Ideal heat release curve in engine.

injection period, main -injection period and post injection period as seen from figure 1. There is delay period between the start of ignition process and fuel injected inside diesel engine. More this ignition delay, more is the temperature during combustion and hence better condition for NO_x formation. To shorten the delay period, small amount of fuel is pre-injection before main injection during the phase pre-mixed combustion phase. The torque and power produced in engine depends upon main injection period. It is advantageous to vary injected fuel mass with time to reduce the specific fuel consumption. This method is known as rate shaping as depicted in figure 1. Rate shaping may be rectangular, step or boot in shape. Post-injection of fuel is done to reduce soot emissions and in some cases may be useful for exhaust gas recirculation treatment of gases [6]. It has been reported that post injection reduces soot by about 70% without increasing the fuel consumption [7].

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 1. This engine test rig has a piezo electric 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 given system can do maximum of 2 injections per cycle. The injection strategy for the engine is shown in figure 2. Dual injection strategy was used to take emissions and consideration's discussed in previous section. The engine was run at 2000 RPM and the signals were obtained at both motored and 100% load condition. The data obtained is shown in Table 2.

Table 1. Engine specifications.

Type	Direct Injection
Bore	60.6mm
Stroke	68mm
Displacement	440cc
Compression ration	20:1
Maximum Power	8.5kW@4400RPM
Maximum Torgue	25Nm2000 RPM

Table 2. Testing cases.

Case	Prail	Qpre	Qmain	SOIpre	SOImain
B3	700	1	14.1	13.2°	6°
BASE	720	1	14.6	16.2°	6°
B1	700	2	14.1	17.1°	6°
B2	700	1	14.1	20.1°	6°

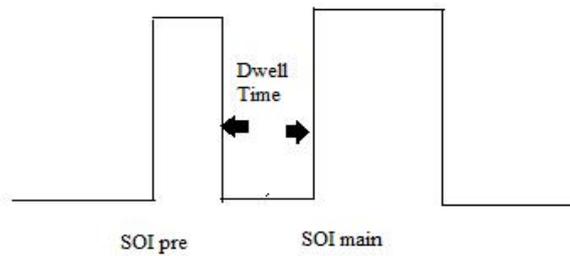


Figure 3. Injection process.

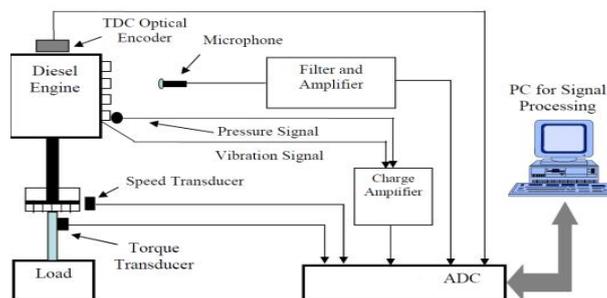


Figure 4. Engine rig showing microphone.

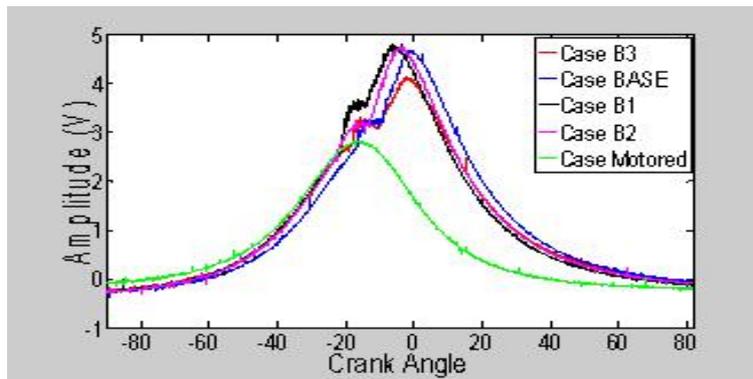


Figure 5. In cylinder pressure.

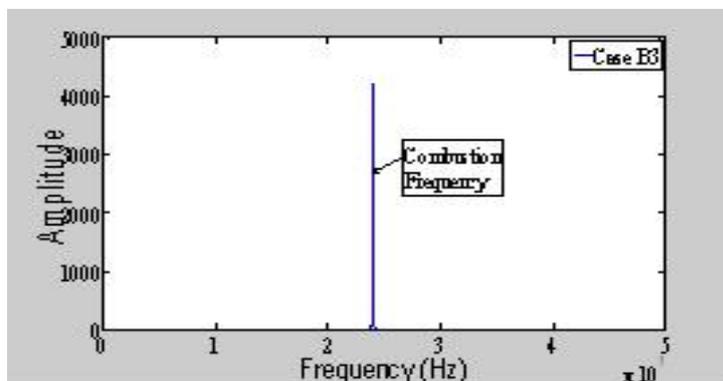


Figure 6. Acoustic emission spectrum(Case B3).

4. Results and discussions

As seen from figure 5, an increase in pre-injection timings causes increase in the injection delay which in turn leads to more fuel being injected inside the combustion chamber, hence more cylinder pressure rise. The frequency of combustion oscillations can be evaluated from relationship[8].

$$F_c = \frac{Zn}{120}, \quad (1)$$

where, n -Engine RPM and Z -number of cylinders.

Acoustic emissions spectrums for the test conditions have been plotted in figures 6-9 using FFT transformations. An increase in pre injection timing causes increase in pressure and energy increase in acoustic spectrum. This is due to increase in energy released. In order to take into account the energy content, rate of heat release equation is considered next for the test conditions. For combustion engines ideal rate of heat release equation is given by relationship[9].

$$ROHR = \left(\frac{du}{d\theta} * V * \frac{1}{r-1} + \frac{r}{r-1} * P * \frac{du}{d\theta} \right), \quad (2)$$

here p , v represent the specific heat ratio, pressure, volume corresponding to crank angle. Figures 10 and 11 show the traces of ROHR and Cumulative ROHR for the test conditions. As evident from these plots high ignition delay causes impulsive combustion which increases the

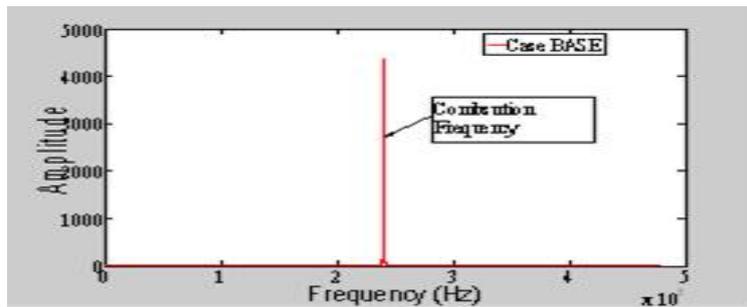


Figure 7. Acoustic emission spectrum(BASE).

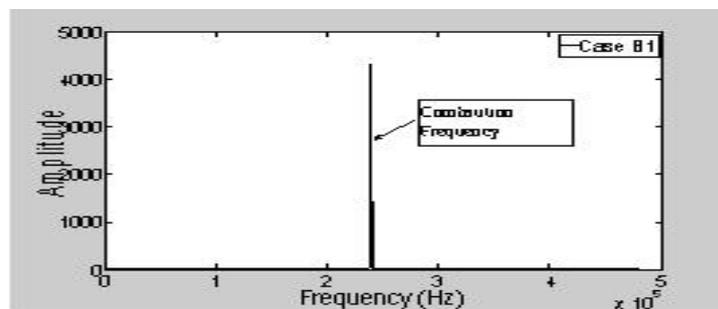


Figure 8. Acoustic emission spectrum(Case B1).

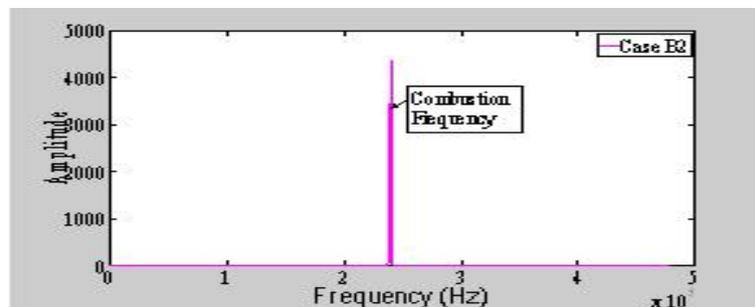


Figure 9. Acoustic emission spectrum(Case B2).

amplitude of audio spectrum from engine. The vibrations from the structure cause oscillations of engine rig which have been investigated in figures 12-15.

Table 3. Difference in injection parameters.

Case	Parameter
C	BASE
D	Q_{pre} increased by $1 \text{ mm}^3 / \text{stroke}$
A	Injection angle retarded by 3°
B	Injection Pressure Increased by 20 Bars

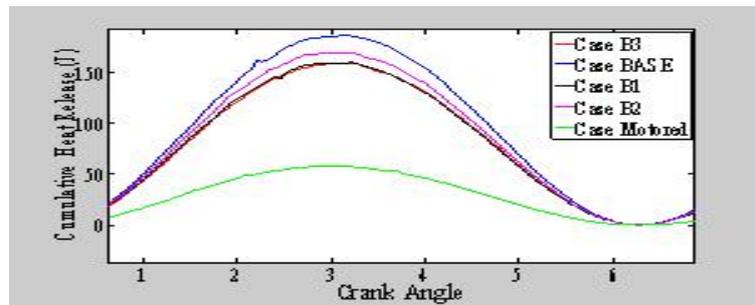


Figure 10. Rate of heat release(J/Degree).

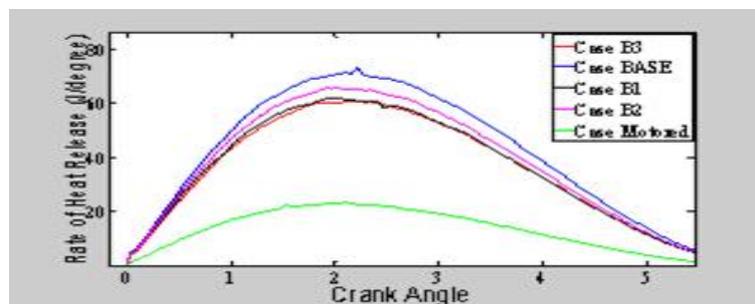


Figure 11. Cumulative heat release(J).

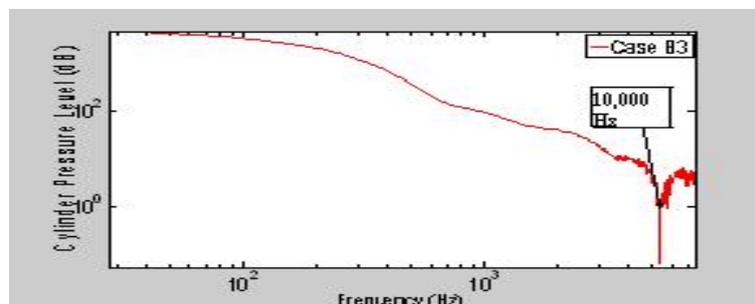


Figure 12. Cylinder pressure spectrum(Case B3).

In general spectrum plot of in cylinder pressure can be divided into three regions[6]:

- Region of low frequency-in this region the maximum pressure depends upon integration of cylinder pressure curve.
- Second one is that of medium frequency range in which cylinder pressure falls linearly in logarithmic scale.
- Third region of high frequency zone is the beginning of combustion phenomenon where resonance of engine structure takes places which depends upon gas temperature and geometry of cylinder.

Due to changing temperatures of gas, resonance is unsteady process. As seen from these curves, the region 3 begins around a frequency of 3000Hz. In order to find the range corresponding to region 1, change in the fuel injection parameters were again varied for the given test conditions [10]. The parameters can be seen in Table 3.

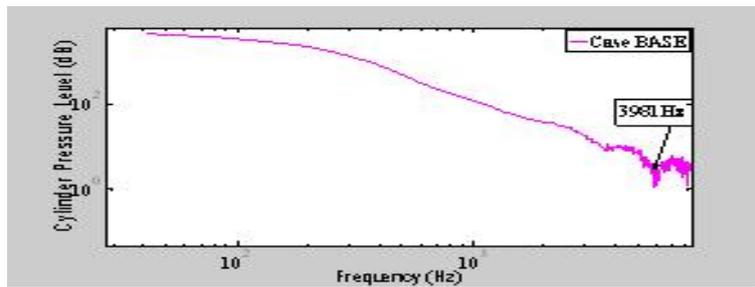


Figure 13. Cylinder pressure spectrum (Case BASE).

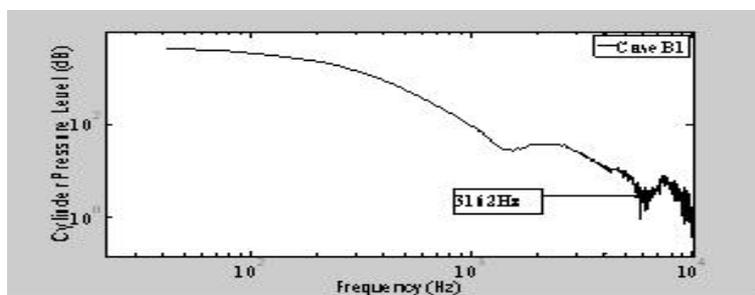


Figure 14. Cylinder pressure spectrum (Case B1).

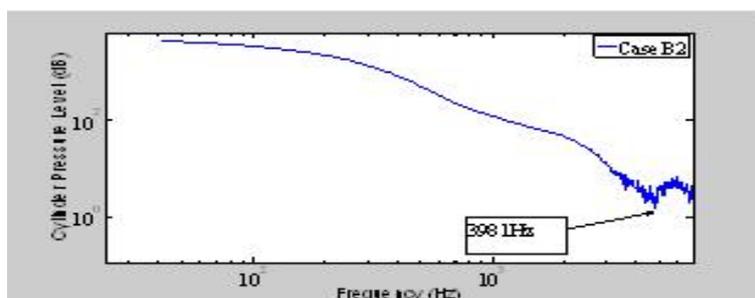


Figure 15. Cylinder pressure spectrum (Case B2).

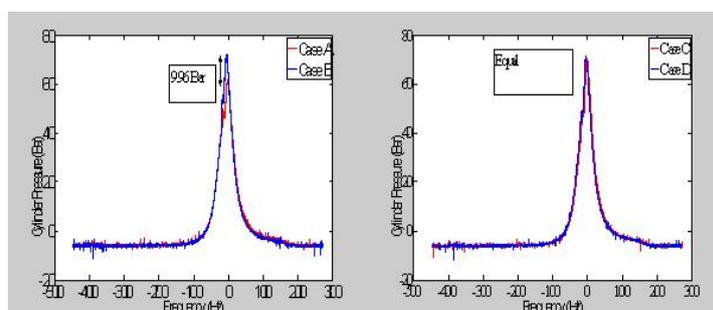


Figure 16. Cylinder pressure after change of parameters.

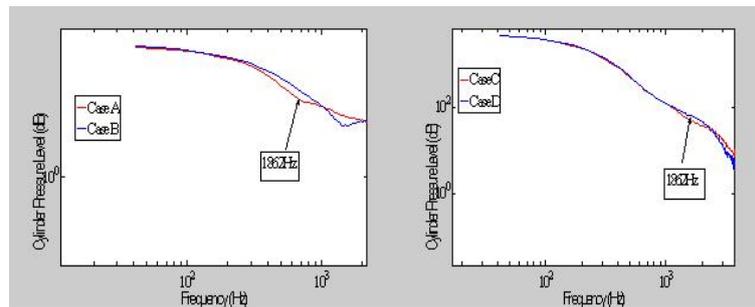


Figure 17. Cylinder pressure ppectrum after change of parametres.

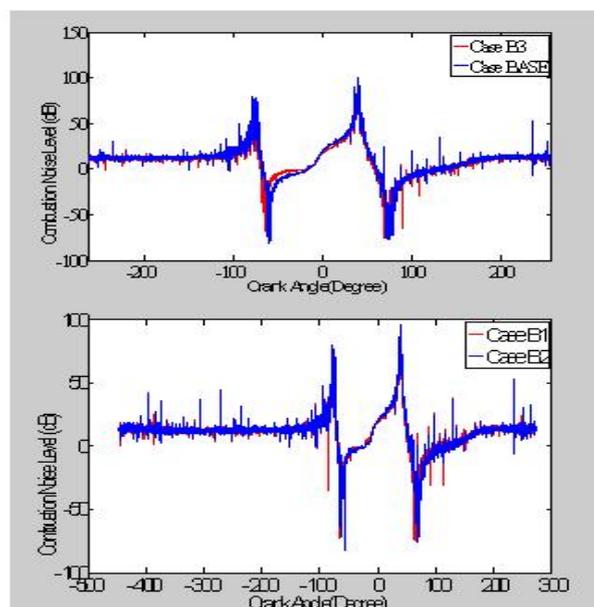


Figure 18. Combustion noise levels for given test conditions.

As seen from figure 15 and 16, differences in maximum pressures for conditions A, B and C, D is 9.96 bar and none respectively. Region 1 of pressure spectrum falls below 1800Hz band. In order to further evaluate the combustion noise, the engine was fired under motored condition. It has been assumed that total air borne noise (ON) is sum of combustion noise(CN) and motored engine noise (MN) as reported in [11]. i.e.

$$ON = MN + CN,$$

where MN-engine noise under motored condition, CN-Combustion noise as elaborated in works [12]. Peak values of both combustion as well as mechanical noise occurs at near TDC position, hence it is difficult to separate both of these components. Bearing these conditions in mind, combustion noise for given test conditions was evaluated and results are plotted as seen in figure 17. As seen from these plots, there are two peaks corresponding to double injection events during engine cycle.

5. Conclusion

It is evident from plots that increase in pre-injection causes an increase in combustion noise levels. In order to reduce emissions from engine combustion control should be optimized. This work presented here allows comparison of noise emitted from engines by varying various testing parameters. The combustion noise was seen to be function of rate of heat release and load on engine. Based on both parameters a loop system can be developed for control of the centre of combustion. The correlation thus obtained can be used to stop or start the pre injection system for optimizing combustion noise keeping pollution emissions at minimum levels.

Nomenclature

SOI-Start of injection

TDC-Top dead centre

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

EGR-Exhaust gas recirculation

ROHR-Rate of heat release

FFT-fast Fourier transformations

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