Combustion Noise Reduction of a Compression Ignition Direct Injection Engine by Optimizing the Fuel Injection Equipment

Rajath Mallya P¹, Rajath Alva K², N Seshaprakash³, M Vijayakumara⁴, N S Srikanth⁵, N V Raghavendra⁶

¹²UGscholars,, Mechanical Engineering, The National Institute Of Engineering, Mysuru, INDIA
³Visiting Professor, Dept of Mechanical Engineering,The National Institute of Engineering, Mysuru - 570008
⁴Assistant Professor, Dept of Mechanical Engineering,The National Institute of Engineering, Mysuru - 570008
⁵Assistant Professor, Dept of Mechanical Engineering,The National Institute of Engineering, Mysuru – 570008
⁶Professor, Dept of Mechanical Engineering,The National Institute of Engineering, Mysuru – 570008

Abstract- Automobiles have played a major role in the development of modern civilization. There has always been an increased demand for safer, sophisticated and environment friendly engines. It has been the concentrated efforts of the researchers around the globe that has helped in achieving these goals. Aiming at the comforts, the ‘Combustion Noise Reduction’ poses a challenge. The Open Chamber Compression Ignition (CI) Engine is characterized by higher noise levels given the Higher Rates of Injection and the Higher Injection Opening Pressures. The open chamber CI engines are the leaders when it comes to lower Fuel consumption and lower Exhaust Emission Levels. This paper deals with the experiments conducted on an Open Chamber CI engine with Mechanical Fuel Injection Equipment to reduce the Combustion Noise in idling conditions. Concerning the reduction of combustion noise, various experiments have been carried out / are being carried out as listed below: Study the effect of change of nozzle projection into the combustion chamber and the effect of change of the injection pressure. All these experiments are carried out without other hardware changes. Experiments have been confined to Idling characteristics such as Noise level and Fuel Consumption.

Keywords- Direct injection CI engines, Combustion noise, Fuel Injection Equipment (FIE), Nozzle projection, Rate of pressure rise, Peak combustion pressure, Injection Timing, Nozzle Sealing Washer.

I. Introduction: Diesel powered vehicles have increased demand in India especially due to subsidised diesel rates and because of their attractive features like fuel efficiency and reduced CO emissions. However, from the noise point of view, diesel engines remain deplorable to the gasoline engines, as they have fiddly systems comprising various dynamic forces acting on an equally complex structure of varying stiffness, damping and response characteristics. Direct injection engines have an edge over their indirect injection counterparts because of less fuel consumption and emissions.

The main sources of noise generation are: gas-flow, mechanical processes, and combustion [1-2]. Low frequency controlled, gas-flow noise, is associated with the intake and exhaust processes, including turbo charging and the cooling fan. The various reciprocating and rotating parts in the engine components impart mechanical noise; originating because of inertia forces causing piston slap, from gears, tappets, valve trains, timing drives, fuel injection equipment and bearings. The third and most widely studied and researched is the combustion noise. The reason behind its source is the high rate of pressure rise dp/dθ, mainly after the ignition delay period, which causes discontinuity in the cylinder pressure frequency spectrum and increase in the level of the high-frequency region, resulting in vibration of the engine block and ultimately, in combustion noise radiation.

Fig. 1 Combustion chamber of a CI engine
Combustion chamber design and injection parameters, e.g., Injection timing, amount and rate of fuel injected play a vital role in combustion noise emission. The typical injection pressures today are around 1500 bar (1 bar = 1 atmosphere = 14.6 psi), heading toward 2000 bar, with experimental installations running at 3000 bar in Fig. 2 Pressure Vs Crank Angle for a CI engine Common Rail Direct injection and around 800 bar in Mechanical injection. At such pressures, the fuel spray becomes quickly well atomized into tiny droplets that first vaporize on their surfaces in the hot air and then ignite. Rate of combustion pressure rise is around 10 bar°Crank angle.

The electronic fuel injection system is easily the most expensive item going into a new CI engine. For comparison, gasoline electronic fuel injection systems are much simpler and less expensive: pressures are only 4-5 bar (portinjection) using solenoid injectors, and around 200 bars for direct injection (which is rising in popularity). Accordingly, a diesel engine will cost much more than a gasoline engine of the same power level.

In the first stage of combustion in a CIEngine (Fig. 2) some fuel that has been admitted is not ignited instantaneously. This delay period, exerts a great influence on engine design as well as its performance.

Delay period in CI combustion affects the rate of pressure rise leading to the combustion noise. It also affects the engine start-ability. Hence, in-order to study the effects of this rate of pressure rise, various changes in the Fuel Injection Equipment and Injection timings have been made.

Initially, the effects of change of injection timing have to be studied (Fig. 3). There is an increase in delay period with advance in injection timing because the pressures and temperatures are lower when injection begins. As the injection advance angles are small delay period reduces and operation of the engine is smoother [3].

Optimization of FIE leads to various changes in the combustion process. The injection nozzles, high pressure pipes and their respective nozzle holders are vitally important components situated between the in-line injection pump and the diesel engine; its functions are as metering the injection of fuel, management of the fuel, sealing-off against the combustion chamber. Various injection parameters that affect the performance and noise are:

- **Start of Injection**
  - **Static**: It is the time at which the fuel comes out of the fuel pump.
  - **Dynamic**: This is more relevant and the actual time of injection into the cylinder with a delay as against static injection timing.

- **Duration of Injection**
  It is the duration of injection from start of injection till the end of injection in terms of crank angle or time.

- **Injection law**
  This represents the distribution of fuel inside the combustion chamber for the defined duration of injection.

- **Atomization**
  It is the pulverisation of fuel to increase the area of fuel coming in contact with the hot air in the cylinder.

- **Penetration and spread of the fuel**
  It is the fuel distribution into the combustion chamber for best air utilization.

All the above are exclusive to different conditions such as Power, Speed, Ambient Temperature, Cold Start, Hot Start, Acceleration, Deceleration, Shape of combustion chamber and different types of engines.

II. Scope of the project
Reducing the Combustion noise in idling by altering the nozzle projection into the combustion chamber for different injection timings.

III. Description of the experimental setup and procedure
A general layout of the test bed installation, the instrumentation used and the data acquisition system is illustrated in Fig. 5. A brief description of the engine specifications and the
The experimental procedure followed is provided in the following subsections.

A. Engine specifications -
The engine under study is a 4 cylinder, naturally aspirated, water cooled, vertical, CI engine with mechanical fuel injection system.

B. Combustion noise measurement -
Engine is run and brought to operating temperature. The first sets of readings are recorded with the base nozzle projection. Combustion noise at eight different positions and at four different planes at each position is recorded using a noise level indicator (Fig. 5). Then the nozzle is withdrawn by 0.5mm by adding Nozzle Sealing Washer (Fig. 4) and the same procedure is followed. Finally the nozzle is projected by 0.5mm, as against the base nozzle by reducing the thickness of the nozzle sealing washer, into the combustion chamber and the noise is recorded. Fuel consumed for each trial is noted. These sets of experiments are conducted for three different injection timings (5.5° BTDC+ 7.5° BTDC+ 9.5° BTDC).

![Fig. 4](image4)

**Fig. 4** Different nozzle projections into the combustion chamber

![Fig. 5](image5)

**Fig. 5** Layout of the experimental setup of the diesel engine apparatus

![Fig. 6](image6)

**Fig. 6** Ground level noise data for 9.5 deg BTDC

![Fig. 7](image7)

**Fig. 7** Noise data for 1m height above ground for 9.5 deg BTDC

![Fig. 8](image8)

**Fig. 8** Noise data for 1.5m height above ground for 9.5 deg BTDC

![Fig. 9](image9)

**Fig. 9** Ground level noise data for 7.5 deg BTDC

![Ground level noise data for 9.5 deg BTDC](image10)

**Ground level noise data for 9.5 deg BTDC**

![Noise data for 1.5m height above ground for 9.5 deg BTDC](image11)

**Noise data for 1.5m height above ground for 9.5 deg BTDC**

![Noise data for 1m height above ground for 9.5 deg BTDC](image12)

**Noise data for 1m height above ground for 9.5 deg BTDC**

![Ground level noise data for 7.5 deg BTDC](image13)

**Ground level noise data for 7.5 deg BTDC**
IV. Results and discussion-

From the graphs (Fig. 6 to 15) obtained it can be inferred that:

i. Table I – Noise level comparison

<table>
<thead>
<tr>
<th>Injection timing</th>
<th>Noise level in decreasing order (nozzle projection)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5° BTDC</td>
<td>Projected &gt; Base &gt; Withdrawn</td>
</tr>
<tr>
<td>7.5° BTDC</td>
<td>Base &gt; Withdrawn &gt; Projected</td>
</tr>
<tr>
<td>5.5° BTDC</td>
<td>Base &gt; Withdrawn &gt; Projected</td>
</tr>
</tbody>
</table>

- 9.5°BTDC has 6.1% more noise (2 dB) than 7.5°BTDC base nozzle which has 1.4% more noise (1.6 dB) than 5.5° BTDC.
- Nozzle withdrawn has 2.9% lesser noise (2.5 dB) than the base nozzle for 9.5°BTDC.
- Nozzle projected has 0.5% lesser noise (0.5 dB) than the base nozzle for 7.5°BTDC.
- Nozzle projected has 2% lesser noise (1.6 dB) than the base nozzle for 5.5°BTDC.
ii. Table II – Fuel consumed for different injection timing

<table>
<thead>
<tr>
<th>Injection timing</th>
<th>Fuel consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>For 9.5° BTDC</td>
<td>Nozzle withdrawn &gt; 14.8% Base nozzle.</td>
</tr>
<tr>
<td>For 7.5° BTDC</td>
<td>Nozzle projected &gt; 8% Base nozzle.</td>
</tr>
<tr>
<td>For 5.5° BTDC</td>
<td>Base nozzle &gt; 8.6% Nozzle projected.</td>
</tr>
</tbody>
</table>

V. Summary of results-

- Injection timing of 5.5° BTDC with 0.5mm nozzle projection into the cylinder is favourable for noise and fuel consumption.
- Since 5.5°BTDC reduced noise with favourable fuel consumption, 3.5°BTDC could be tried.
- Retardation reduces noise in idling without any compromise in fuel consumption. In fact fuel consumption also reduces. Further retardation could help to be ascertained by experiments.
- If retardation has adverse effect on performance at other loads and speeds, inclusion of Injection timer or upper helix, retardation groove on plunger can obviate the negative effect.

REFERENCES

[1] Evangelos G. Giakoumis, M Athanasios Dimaratos and D Constantine; Experimental study of combustion noise radiation during transient turbocharged diesel engine operation; Classifications: 2.040 Diesel Engines; 2.070 Combustion
[8] CFD Analysis of combustion characteristics of Jatropha in compression ignition engine- Irwin Osmond Toppo; October – 2013; International