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Vibration signatures of a biodiesel fueled CI engine and effect of engine parameters

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Abstract
With increasing emphasis on use of biodiesel in compression ignition engines, the long term effects are yet to be evaluated. Through many studies, the suitability of biodiesel blends upto 20% are well established and are being adopted by many organizations with recommended use of biodiesel. But in all of these studies the combustion and emission evaluations are the main characteristics which received the attention of researchers and the objectives targeted are good performance and low emissions. The long term effects are difficult to be assessed as it requires long time as well as consistent conditions of operation. A short route is suggested in this study using the vibration signatures of the engine cylinder and head vibrations. The comparison between the vibration signatures of an engine fueled with diesel and biodiesel blends under different compression ratio and injection pressures show significant changes in the vibration patterns and the difference can be used to asses the long term effects. The method is based on fundamental relationship between the engines vibration pattern and the relative characteristics of the combustion process under different operating conditions.

Keywords: Vibration; CI engine; Biodiesel; Compression ratio; Injection pressure.

1. Introduction

Biodiesel is considered a promising alternative fuel for the diesel engines. Compared to fossil diesel fuel, biodiesel has several superior combustion characteristics. Its higher oxygen content [1, 2] promote a more complete combustion and effectively reduce the production of unburned hydrocarbons (UHC) [1, 3-6], CO as well as suspended aerosol carbon granules [7-10]. In addition, since biodiesel does not contain carcinogens such as poly-aromatic hydrocarbons and nitrous poly-aromatic hydrocarbons (nPAH), it produces pollutants that are less detrimental to human health when burned. Many researchers have tried the biodiesel and its blends in direct injection compression ignition (DI-CI) engines. The fuel characteristics of biodiesel are approximately the same as those of fossil diesel fuel and thus may be directly used as a fuel for diesel engines without any prior modification of the design upto a blend ratio of 20 with improvement in emissions with a slight loss in thermal efficiency [11-14].
Although biodiesel has many advantages when it comes to fuel properties, it still has several problems that need to be addressed, such as its lower calorific value, higher viscosity leading to poor atomization, lower power output, and its comparatively higher emission of nitrogen oxides. Also, the use of higher blendes is constrained by the improper combustion and detrimental effects on engine life. 100% Biodiesel can be used only after some operating parameter modification like the compression ratio,

injection pressure, injection timing etc. It has been shown that higher blends perform well with higher compression ratio [15-17] and increased injection pressure [18-21].

In most of the studies with biodiesel fuel, the researchers concentrated on the engine performance measured through thermal efficiency, power output, specific fuel consumption, emissions, etc. The long term effects are yet to be studied. Assessment of the impact of these fuels with different operating parameters on engine life is extrapolated from short-term trials without giving any weightage to the maintenance problems arising with these changes. Also the quality of combustion depends on these parameters leading to erratic or smooth running of the engine. The irregular and erratic combustion inside the combustion chamber results in knocking leading to erosion and damage to combustion chamber and piston head. This also sets the engine to vibrate more leading to early failure of structure and parts. Therefore to anticipate the maintenance requirements and quality of combustion in the cylinder of CI engines, vibration signatures may provide a strong diagnostic tool.

The vibration induced in any machine due to its moving parts is only of lower frequency. But some high frequency vibrations are also present in IC engine due to abnormal combustion of charge (fuel-air mixture). Vibrations produced in diesel engine are mainly in two directions:

- Vibrations in lateral direction.
- Vibrations in longitudinal (axial) direction.

The piston impact on the cylinder liner is known as piston slap. This piston slap causes the vibrations in lateral direction. Lateral vibrations leads to greater wear of piston and liner surface and structural failure and the wear due to this is more as compared to axial vibrations. During abnormal combustion, multi point ignition occurs. This ignition causes rise in in-cylinder pressure. The rise in in-cylinder pressure forces on piston, and due to this parting force some high frequency vibrations are generated in longitudinal direction.

Vibration as a diagnostic tool for combustion anomalies has been studied by many. Azzoni et al. [22] used an indicator based on the crankshaft velocity fluctuations and proved that this indicator is able to distinguish with sufficient precision the occurrence of misfire. Ball et al. [23] tested a diagnostic system based on the measurement of environmental noise.

Among the diagnostic techniques applied to internal combustion engines, those based on the analysis of accelerometer data have earned a greater success. Chun and Kim [24] measured oscillations at the upper part of the cylinder block center for knock in SI (spark ignition) engines. Zurita et al. [25] rebuilt the in-cylinder pressure history through the signal provided by an accelerometer placed externally. Othman [26] placed the accelerometer horizontally on the side wall of a SI engine to monitor the combustion anomalies like misfiring. Antoni et al. [27] used vibrations to indicate malfunctioning. Blunsdon and Dent [28] showed that varying the injection profile strongly affect the bulk motion settling inside the combustion chamber. The maximum amplitude of the vibration provides information about combustion intensity, high amplitude may indicate early ignition or presence of a large amount of fuel in the cylinder prior to ignition, lower amplitude may indicate late ignition, injection malfunction or engine compression malfunction. It has been proved by Carlucci et al. [29] that injection pressure and injected quantities, over an energy release threshold, really affect the vibration signals in a peculiar way; injection timing affects the engine block vibration in a less evident way. Gideon et al. [30] used vibration measurement to identify malfunctioning in a multi cylinder engine.

This study is therefore targeted on finding the effect of varying the compression ratio and injection pressures on vibration signatures of a direct injection compression ignition engine and also the effects of biodiesel fueling.

2. Materials and methods

The study was done with an objective of studying the effects of the engine operating parameters viz. compression ratio and injection pressure on the vibrations of the engine, when the engine is run with pure diesel and biodiesel blends. In the study, a small engine was used and vibrations of the engine were recorded at two places i.e. (1) on the head of the cylinder placed vertically and (2) on the cylinder block placed horizontally in perpendicular direction to crank axis (Figure 1). The sensors were attached to the engine by a magnet without an intrusive approach.

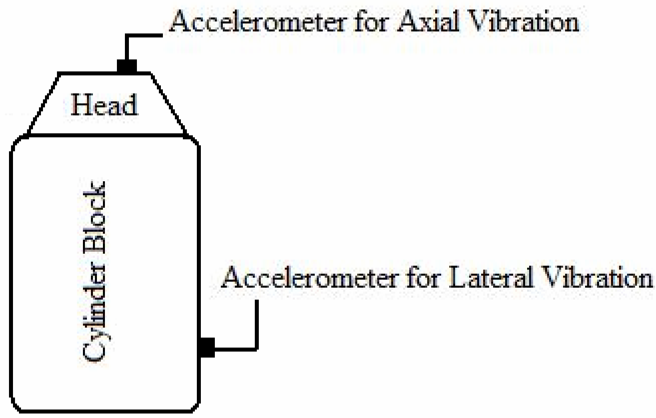

Figure 1. Positions of accelerometer

2.1 Fuels used and their properties

Standard Diesel fuel was acquired from nationalised distribution network from a local outlet where as the biodiesel fuel was prepared in laboratory from the Deccan Hemp (local name: ambari) seed vegetable oil. The blends were prepared by mixing biodiesel and diesel in required proportions on volume basis.

2.2 Experimental set-up

The study was carried out in the laboratory on an advanced fully computerised experimental engine test rig comprising of a single cylinder, water cooled, four stroke, VCR (Variable Compression Ratio) Diesel engine connected to eddy current type dynamometer for loading (Figure 2). The specifications of the engine used for study are given in Table 1.

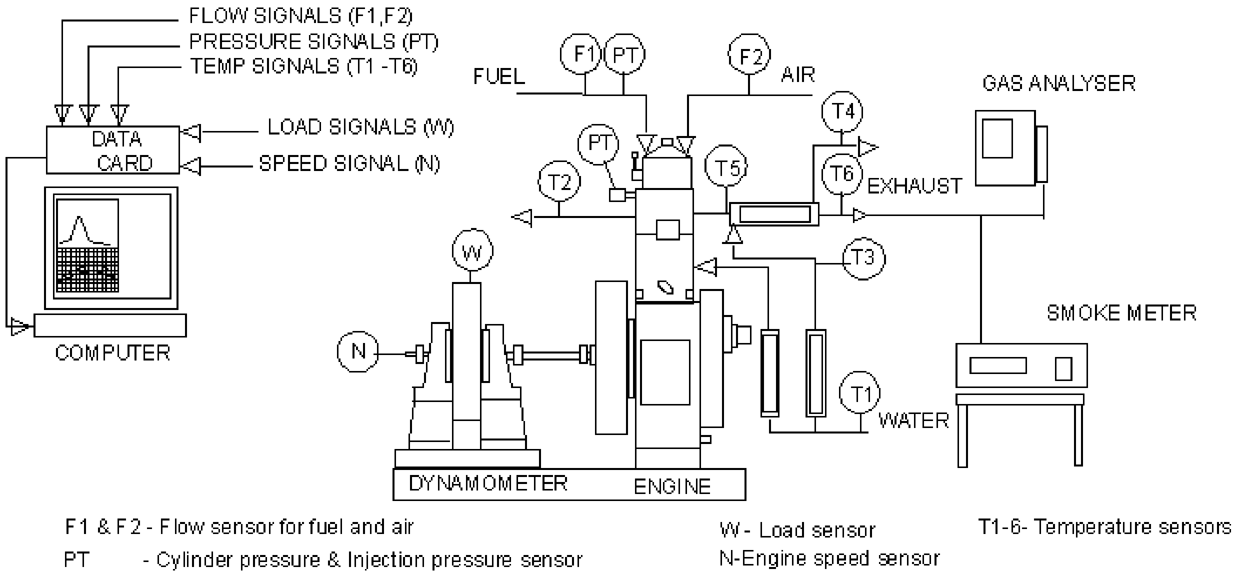

Figure 2. Engine test setup

2.3 Vibration measurement

A dual channel, portable hand held vibration monitoring instrument was used with piezoelectric accelerometers for monitoring the engine vibrations (Make- Pruftechnik; Model- VIBXPERT Data collector and FFT analyzer). It is a high performance, full-featured FFT data collector and signal analyzer and collects field data including vibration information, etc. and integrates with Pruftechnik's OMNITREND maintenance information platform.

Table 1. Test engine details

Make	Kirloskar
Model	TV1
Type	Single cylinder, DI, Four stroke
Cooled	Water
Bore and stroke	87.5 mm × 110 mm
Cubic capacity	0.661 liters
Compression ratio	17.5:1
Rated power	3.5 kW at 1500 rpm
Load at rated power	12 kg
Injector opening pressure	210 bar
Peak pressure	77.5 kg/cm²
Injection timing	23 ° BTDC static (diesel)
Modified compression ratio range	12 to 18

2.4 Experimental procedure

For diesel, the test were conducted at rated condition of 17.5 compression ratio and injection pressure of 210 kg/cm² at rated speed of 1500 rpm under different brake loads. Then tests were carried out at five different compression ratios (16, 16.5, 17, 17.5 and 18) and four injection pressures (100, 150, 200, 250 bar) at full load conditions. For all settings, the vibration velocity signals were recorded in axial and lateral directions for Peak to peak (P-P), Zero to Peak (O-P) and mean (RMS) values. FFT analysis was done using 'Omnitrend' software for velocity amplitude with frequency. For studying the effect of blend, seven blends were used (B0, B10, B20, B30, B40, B50, B75 and B100) for engine tests at full brake load.

3. Results and discussion

The effects of engine operating parameters on the vibration were evaluated with different settings and are presented as correlation curves in the figures to follow. Figures 3 and 4 represents the correlation between vibration velocity and brake load with diesel as fuel. The correlation between vibration velocity and compression ratio are shown in Figures 5 and 6 and between vibration velocity and injection pressure are shown in Figures 7 and 8. The effects of blending ratio on engine vibration at rated values of compression ratio and injection pressure with full brake load are shown in Figures 9 and 10. Figures 11 and 12 represents the frequency spectrum in peak amplitude range.

3.1 Effect of varying brake load

It is found that the lateral vibrations are decreasing continuously with increase in load from no load to over load (Figure 3). Vibrations velocity is recorded highest at no load (P-P 137.09 mm/sec) and lowest at overload conditions (P-P 96.79 mm/sec). The possible reason for which may be that at no load condition there is torque imbalance in the engine, but as load is increased the torque gets balanced resulting in decrease in engine vibrations in lateral direction.

The axial vibrations (Figure 4) increases with increase in load from 0% to 75% load, and after that it decreases. Maximum vibrations occur at 75% load (P-P 101.84 mm/sec) and minimum at 0% load (P-P 67.79 mm/sec). The reason for this are associated with cylinder pressure and temperature. As the load increases, the peak pressure also increases upto 75% load after which it drops marginally. Also, high operating temperatures corresponding to higher load reduces the ignition delay resulting in a decrease in knocking.

3.2 Effect of varying compression ratio

The vibration velocity in the lateral direction (Figure 5) is found to decrease with increase in compression ratio from 16 to 17.5 (130.09 to 114.39 mm/sec) after which it increases sharply (146.74). Thus the lowest vibrations are observed at a compression ratio of 17.5, which is also the prescribed compression ratio by the manufacturer.

Axial vibrations are found to be decreasing continuously (Figure 6) with increase in compression ratio from 16 to 18. Vibrations are maximum at 16.5 (169.08 mm/sec) and minimum at 18 (101.24 mm/sec). As compression ratio is increased, the delay period reduces causing decrease in knocking. The reason for decrease in knocking at higher compression ratio is that air pressure and temperature increases and auto ignition temperature reduces at higher compression ratio.

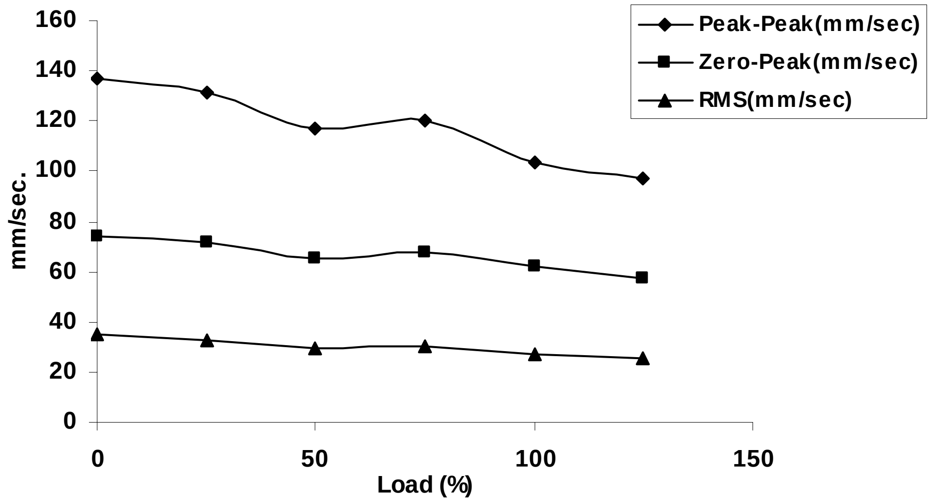

Figure 3. Effect of brake load on vibrations (lateral)

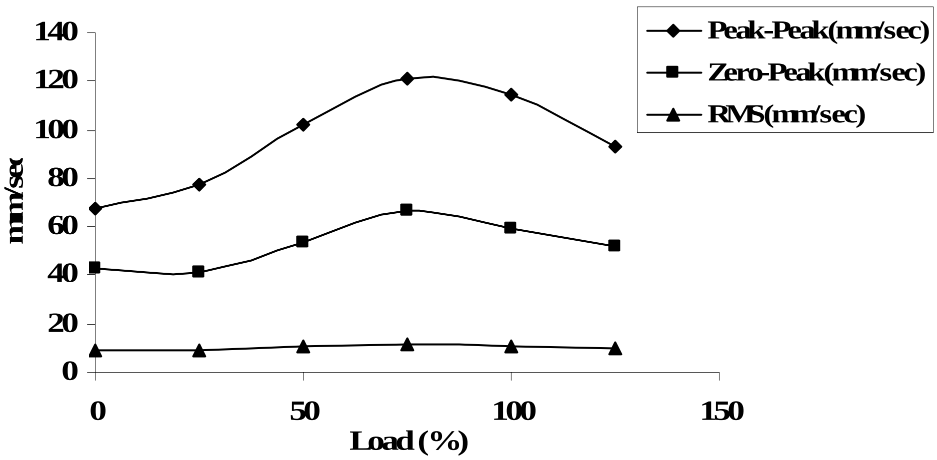

Figure 4. Effect of brake load on vibrations (axial)

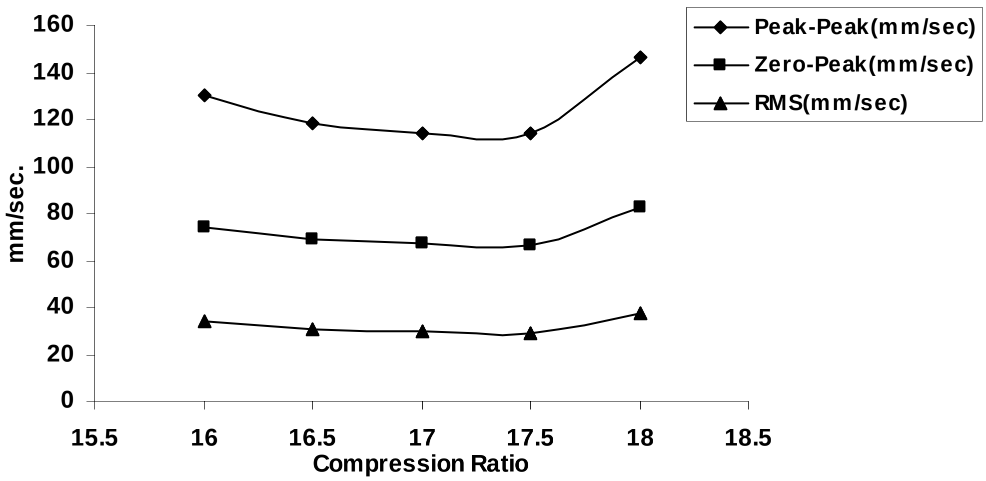

Figure 5. Effect of compression ratio on vibrations (lateral)

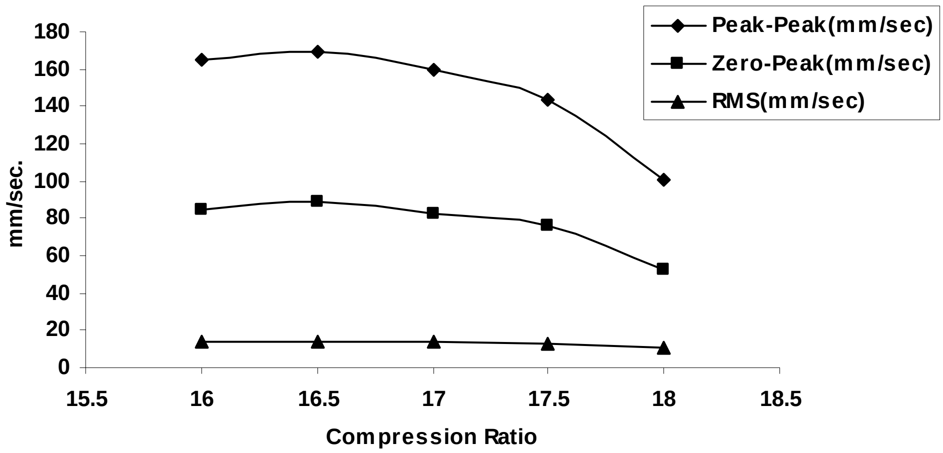

Figure 6. Effect of compression ratio on vibrations (axial)

3.3 Effect of varying injection pressure

Vibrations velocity in both orientations, lateral (Figure 7) and axial (Figure 8), decreases with increase in injection pressure from 100 to 250 bar. Both lateral and axial vibrations were highest at 100 bar (162.14 & 139.47 mm/sec respectively) and lowest at 250 bar (102.39 & 118.39 mm/sec respectively) injection pressure. With increase in injection pressure, sharp reduction in vibrations were observed By increasing injection pressure, better atomization of diesel is obtained and it provides better mixing of air and diesel. Homogeneous charge so obtained results in proper and complete combustion. Thus the delay period is minimized and engine vibrations in both the directions are decreased.

Also, by increasing the injection pressure level, fuel droplets speed and, as a result, mass flow injected increase. At the highest injection pressure, the fuel spray penetrates more deeply in the combustion chamber before reaching the ignition conditions, causing wall impingement in small chambers. An increase of the injection pressure reduces the fuel droplets average diameter and then improves the spray formation promoting droplet vaporization [31].

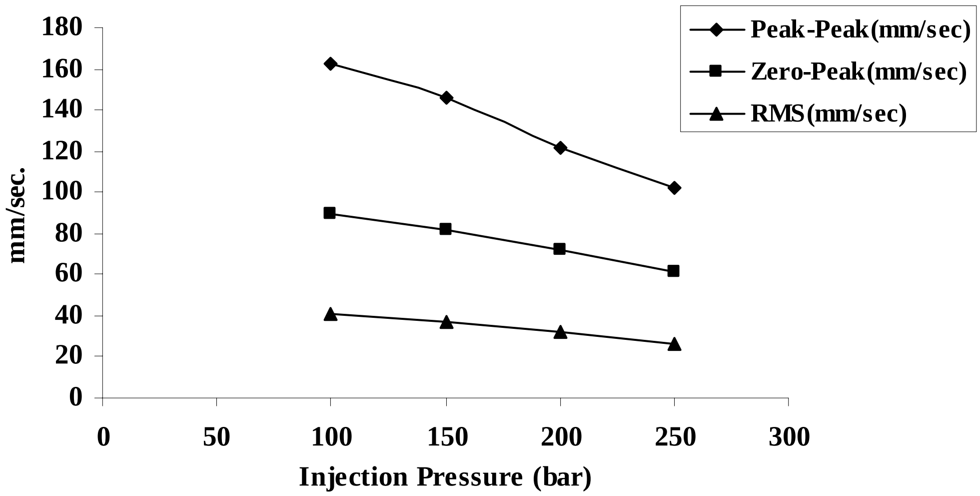

Figure 7. Effect of Injection pressure on vibrations (lateral)

3.4 Effect of blend ratio

While testing the engine with different blends of biodiesel and diesel, the lateral vibrations are found to vary in a pattern which seems to be erratic (Figure 9), but repeated trials revealed similar behaviour. Interestingly, it is found that the most preferred blend (B20) is associated with high vibrations (114.47 mm/sec) whereas B50 with lowest (94.49 mm/sec). With biodiesel in diesel, the combustion seems to be erratic but its higher lubricity tends to decrease vibration with higher concentration upto a certain level beyond which lubricity benefits are offset by poor combustibility.

Almost same pattern is obtained for axial vibrations also (Figure 10). In this direction also, lowest vibrations are evident at B50 blend (108.7 mm/sec). The B0 blend (pure diesel) develops highest vibrations in axial direction (144.03 mm/sec). This may be due to slower burning of fuel in cylinder due to higher flash point of biodiesel as compared to diesel with which rate of pressure rise is higher creating explosion like effects.

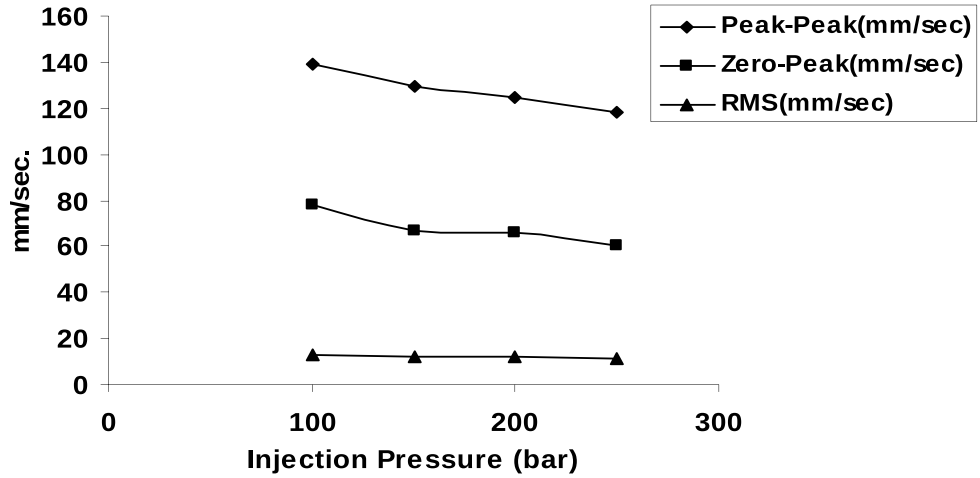

Figure 8. Effect of Injection pressure on vibrations (axial)

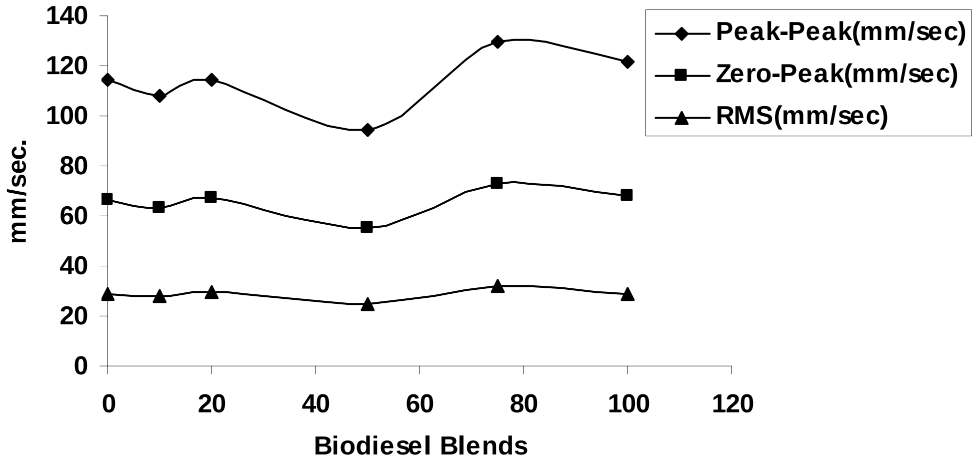

Figure 9. Effect of blend ratio on vibrations (lateral)

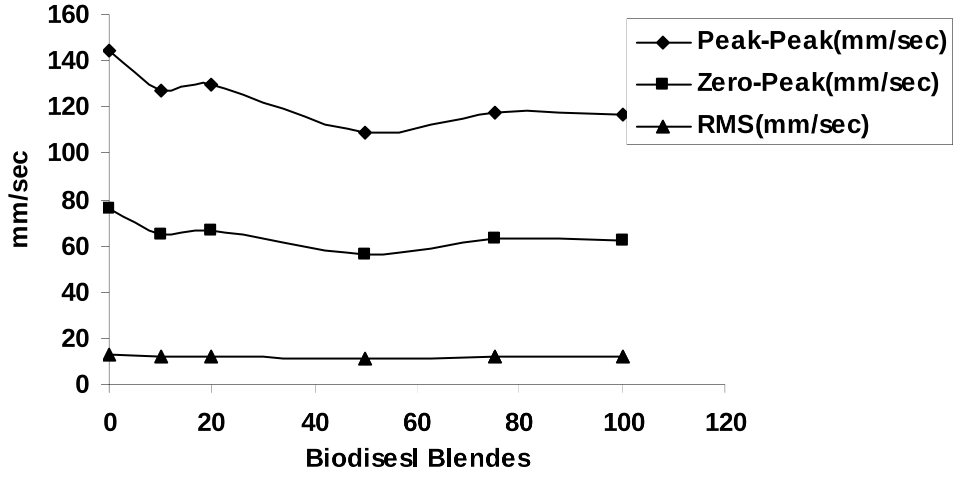

Figure 10. Effect of blend ratio on vibrations (axial)

3.5 Frequency distribution

Mechanical spectrum has been generated by the instrument VIBXPERT itself, which shows velocity amplitude (0-P velocity in mm/sec) of engine vibration at different frequencies. The frequency distribution is recorded at standard values of engine parameters and it represents the Fast Fourier Transformations (FFT). It is found that in lateral direction maximum vibrations occur between frequency range from 20 to 40 Hz (Figure 11). The highest value of amplitude 27.91 is found at 24.5 Hz whereas in axial direction maximum vibrations occur between frequency range from 20 to 50 Hz with the peak value of amplitude 5.96 at 49 Hz (Figure 12).

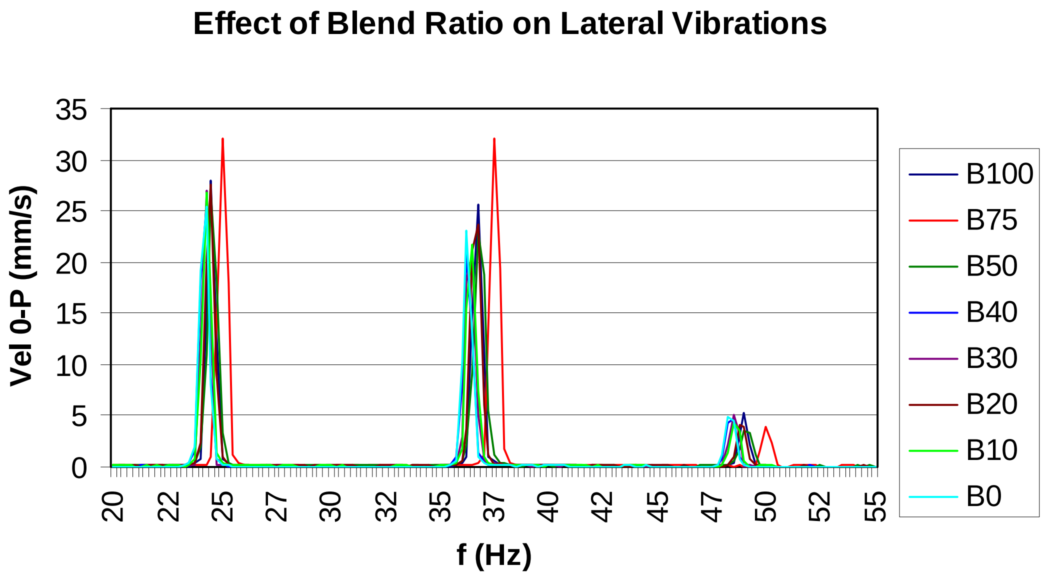

Figure 11. Mechanical spectrum for different blend ratio (lateral)

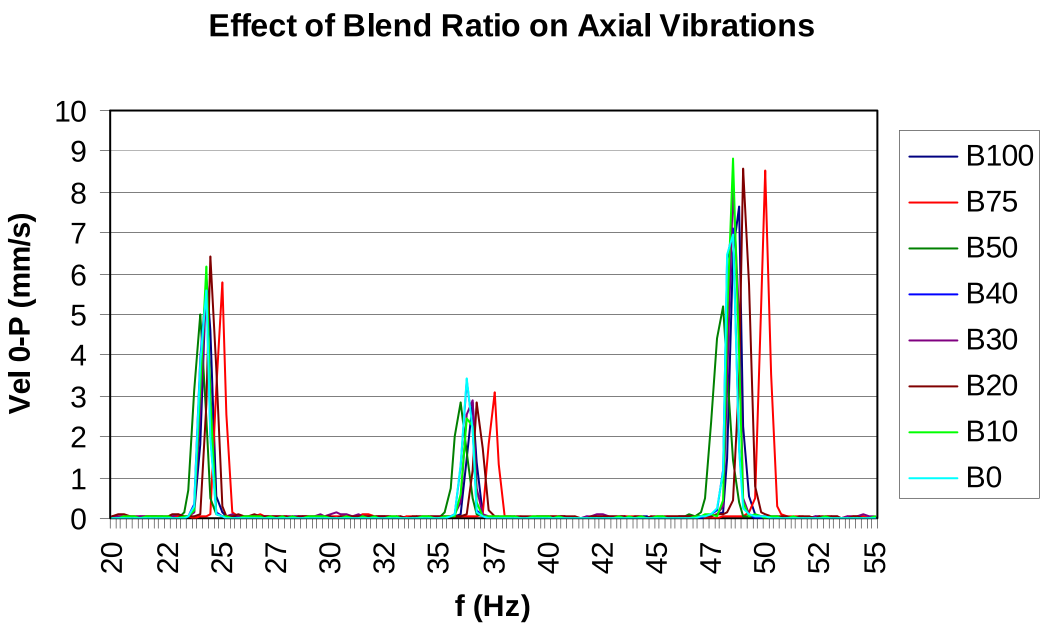

Figure 12. Mechanical spectrum for different blend ratio (axial)

4. Conclusions

The research in the area of biodiesel and vegetable oil based fuels suggested that a 20 percent blend of biodiesel works well in the CI engines without any modifications. Beyond this, engine needs some modifications in design and operating parameters. Commonly effects of varying compression ratio and injection pressures have been studied for better performance and emissions. Changes in these parameters may affect the engine life and the maintenance requirements. To assess these effects, measurement technique based on vibration signature analysis was chosen. The purpose of this research was to investigate dependence relationships between the engine vibrations and engine parameters (compression ratio and injection pressure) and the effect of different blends of biodiesel on vibrations in a small diesel engine.

The results show that the engine parameters affect the vibrations of the engine significantly. The engine runs more smoothly at near full load conditions. The compression ratio needs to be on higher side (but not more than design compression ratio) for smoother running and higher injection pressure always help in reducing the vibrations. With regard to biodiesel blends, a fifty percent blend (B50) is better than mostly recommended B20 blend from vibration point of view. From this connection between engine parameters and vibration signatures it is also possible to assess the quality of the combustion.

The maximum vibration amplitude is related to the rate of pressure rise and the maximum pressure in the cylinder during ignition. When the rate of pressure rise increases the vibration amplitude also increases. We may infer ignition smoothness through vibration amplitude i.e. when the vibration amplitude is smaller the ignition is smoother and the engine noise is moderate.

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