An Experimental Investigation of the Effects of Diesel-Ethanol Blends on the Noise and Vibrations of a Diesel Engine

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ABSTRACT

This study performed a noise and vibration analysis of a single-cylinder diesel engine with 5, 10, and 15% ethanol concentration in diesel fuel at 20, 40, 60, 80, and 100% load and a constant engine speed of 1500rpm. Vibrations were measured at the cylinder head in the horizontal, vertical, and axial directions. The frequency and octave spectrums were obtained using an FFT analyzer. The results revealed that the E5D95 blend had significantly less vibration and noise than the E10D90 and E15D85 blends. The vibration level was minimum at 20% load and maximum at 100% load in the vertical, horizontal, and axial directions, while the highest noise level was observed for E15D85.

Keywords-engine; ethanol; vibration; noise

I. INTRODUCTION

Biofuels have been developed as an alternative energy source to reduce the dependency on fuel imports and satisfy regulatory emission limits. Internal combustion engines are typically powered by the most prevalent biofuels, such as ethanol and biodiesel. Ethanol fuel is significantly attracting more attention compared to other biofuels because it is made from more environmentally sustainable raw materials. Ethanol can be produced from sugar cane, sugar beets, wood, corn, and other grains and has significant potential as a fuel for both Spark Ignition (SI) and Compression Ignition (CI) engines due to its physicochemical characteristics. The automotive industries compete to improve passenger comfort, efficiency, and environmental friendliness. To reduce vibration, noise, and engine spray characteristics, a thorough analysis is essential to both fuel use and repairs to the combustion engine. Engine noise and vibrations are influenced by engine combustion characteristics in addition to contributions from moving engine components. The combustion characteristics depend on various engine operating parameters such as fuel type, engine load, and speed. Signals from the engine body vibrations contain information regarding an engine's physical characteristics and operating conditions, while both vibration and noise help determine an engine's condition.

Many studies investigated the effects of different blends on engine noise and vibration. In [1], noise, vibration, engine performance characteristics, and emissions of a diesel engine were studied, using diesel and n-butanol blends, reporting the viability of a diesel and n-butanol mixture as an alternative fuel for generators. In [2], engine performance was evaluated using water-diesel emulsions in diesel engines, showing that 2% water emulsions had the optimum engine performance and noise levels. In [3], the noise and vibration of a single-cylinder diesel engine were studied at five different engine speeds at an 80% load condition and three different injection pressures. The results showed an increase in engine vibration when butanol was added to diesel fuel. In [4], the performance, combustion, emission, and vibration characteristics of diesel engines were studied, using rice bran biodiesel and the n-butanol additive. The results indicated vibration levels comparable to diesel fuel, indicating smooth combustion. In [5], a diesel engine investigation was performed by changing engine load, speed, and injection timing, concluding that the maximum rate of heat release was inversely proportional to the level of vibration in the engine block, which was affected by changes in the injection timing. In [6], combustion-induced vibrations of engine reciprocating components were studied, presenting a dynamic model that used Lagrange's equation. In [7], the effects of diesel-biodiesel combinations on noise and vibration were studied, examining engine block displacement, time domain, waveform, side thrust, and in-cylinder force and reporting that the levels of vibration and noise were highest between 1500 and 2500rpm. In [8], Moringa oleifera-diesel mixed fuel samples were tested at various loads, concluding that the B20D80 mixture had minimum vibrations. In [9], the effects of diesel-biodiesel and turpentine blends on the noise and vibration of a diesel engine were investigated, showing that turpentine fuel could reduce noise and vibration levels at increased engine loads compared to pure diesel.

In [10], noise, vibration, and exhaust pollutants of a dual-fuel operative diesel engine were examined, using fuel combinations of diesel and Mustard Oil Biodiesel (MOB), diesel, MOB, and hydrogen gas. The results suggested that engine noise and vibration could be greatly reduced using MOB. In [11], the vibration of a diesel engine was examined using both pure diesel and a fuel blend of 10% recycled lubricating oil with 90% diesel, showing that engine vibrations were reduced for the selected fuel mixture. In [12], a diesel engine noise source identification was performed at various speeds, finding that engine noise increased with engine speed and indicating that engine mounting is another substantial source of vibration resulting in a considerable impact on noise levels. In [13], the emission, vibration, and noise parameters of a single-cylinder DI diesel engine were investigated at varied engine running loads at a constant speed, using diesel and Niger seed oil methyl ester blend for experimental tests. The results showed 26.15% and 45.78% reduction in noise and vibration levels, respectively, for the B20 blends. In [14], nanoparticles were added to the diesel fuel to observe the emission and vibration characteristics of a single-cylinder diesel engine with Variable Compression Ratio (VCR), showing that the addition of nanoparticles reduced both noise levels and engine block vibrations. In [15], 3 different biofuels were used to prepare biodiesel blends, reporting that B50 blends caused minimum engine vibration. In [16], the vibrations of a single-cylinder variable compression ratio diesel engine were studied using a Jatropha biodiesel blend. The frequency domain was obtained using the Fast Fourier Transform (FFT). In [17], an improvement in the RMS and kurtosis values of an engine body vibration was obtained for diesel-ethanol blends.

In [18], the vibration effects of canola (rapeseed), sunflowers, and mixtures were investigated on low-sulfur diesel fuel at various speeds. The lowest vibration was achieved using a 60% biodiesel blend. The engine performance analysis in [19] revealed that the B30 (30% biodiesel and 70% diesel) mix brake-specific fuel consumption was 6.9% higher than that of 100% diesel, while the brake thermal efficiency of B30 was decreased by 4.75%. In [20], the noise and emissions of pure diesel and two biodiesel blends were investigated at variable loads with constant engine speed. In [21], the emissions, performance, and sound pressure levels of diesel and biodiesel blends of cooking oil waste were examined, indicating that the biodiesel blends reduced particle emissions by 7.29%, the fuel consumption of brake-specific biodiesel blend decreased as brake power increased, brake thermal efficiency increased with brake power, while the blend B25 produced less noise than pure diesel. In [22], potassium hydroxide was used as a catalyst and methanol as a co-solvent through the transesterification process. The particulate matter emissions were analyzed on a CI engine with pure diesel fuel, biodiesel-mixed, and clove oil. This study showed a 5.27% reduction in particulate matter in biodiesel-blended fuel, and an 11.61% reduction in particulate matter when clove was added to biodiesel-blended fuel compared to pure diesel. Finally, the engine noise of the biodiesel-mixed and clove oil was lower than pure diesel.

Many studies have investigated the effect of blends on engine noise and vibration, but most of them considered the vibration effect in a single direction without examining them in three directions. This study aimed to investigate the vibration frequency spectrum in three directions at different loads and obtain the noise levels and the octave spectrum of different diesel and ethanol fuel blends. The spectral composition of an engine's vibration signal was analyzed, and the vertical, horizontal, and axial vibration levels of an internal combustion engine block were correlated and examined for different ethanol and diesel blends.

II. MATERIALS AND METHODS

Three diesel-ethanol blends, E5D95, E10D90, and E15D85 were prepared by blending 5, 10, and 15% ethanol with pure diesel. The noise and vibration of the engine were measured using an FFT analyzer at 20, 40, 60, 80%, and 100% load.

A. *Experimental Setup*

This study used a 4-stroke single-cylinder Kirlosker TV1 CI engine. Figure 1 shows the experimental setup. An eddy current water-cooled dynamometer was used. The engine noise and vibration measurements were performed at constant 1500rpm with 20, 40, 60, 80, and 100% loads for each blend. Noise and vibrations were analyzed using a 4-channel vibration analyzer, and three accelerometers were used to measure vibrations in the three directions at the engine's head. Table I shows the maximum uncertainty in measurements.

TABLE I. MAXIMUM UNCERTAINTIES IN MEASUREMENTS

Measuring Parameter	Instrument/Sensor	Uncertainty
Engine vibration	Accelerometer	±80g, peak (Sensitivity: 100mV/g)
Noise	Microphone	± 2dB (Sensitivity: 50 mv/pa)

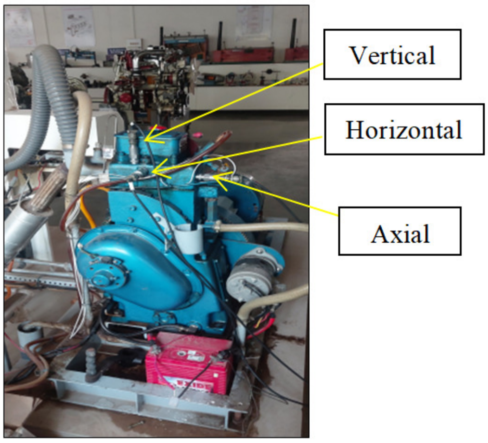

Fig. 1. Test engine.

Fig. 2. The FFT analyzer.

III. RESULTS AND DISCUSSION

The Vertical (V), Horizontal (H), and Axial (A) vibration signals and FFT spectra were analyzed for all tested blends.

A. Vibration Analysis

1) Using 5% Ethanol Blending (E5D95)

Table II shows the velocity-RMS amplitudes of the E5D95 blend in the three directions on the engine head. The vibration level was minimum in the vertical direction and maximum in the horizontal direction. Figures 3 and 4 show the frequency spectra for 20, 40, 60, 80, and 100% engine loads in V, H, and A directions. Velocity in the V direction was found minimum (9.47mm/s) at 20% load and maximum (16.3mm/s) at 100%. Velocity in the H direction was found minimum (48.6 mm/s) at 20% load and maximum (16.3 mm/s) at 100%. Velocity in the A direction was found minimum (23 mm/s) at 20% load and maximum (31.9 mm/s) at 100%.

TABLE II. OVERALL RMS OF AMPLITUDE IN THE THREE DIRECTIONS

Speed (rev/min)	Load	RMS Amplitude (mm/s)			
		Location	Direction		
			Vertical	Horizontal	Axial
1500	20%	Cylinder head	9.47	48.6	23
	40%		11.9	50.4	24.2
	60%		14.1	51.1	26.9
	80%		15.9	53	30.3
	100%		16.3	54	31.9

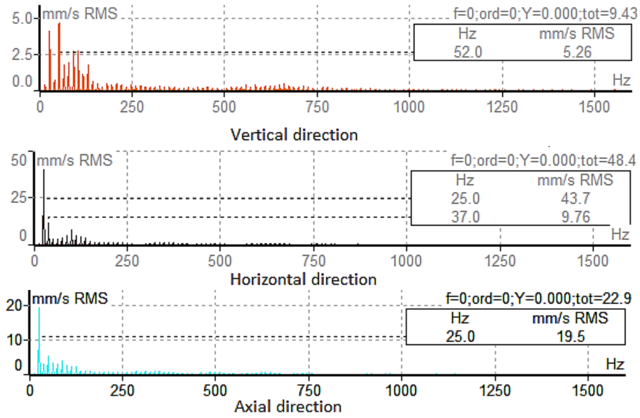

Fig. 3. Frequency spectra at 20% load in the V, H, and A directions.

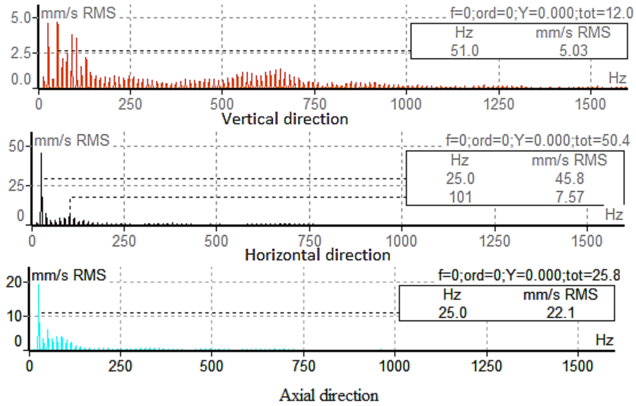

Fig. 4. Frequency spectra at 40% load in the V, H, and A directions.

In the frequency spectrum, harmonics were observed in the vertical direction. At 20% load, the peak amplitude was 43.7mm/s in the H direction and 19.5mm/s in the A direction at 25Hz. For 40% load, the corresponding values for the peak amplitude were 45.8mm/s in the H direction and 23.1mm/s in the A direction at 25Hz. Similar tests were conducted for 60, 80, and 100% loads. At 60% load, the peak amplitude was 43.6mm/s in the H direction and 22.3mm/s in the A direction at 25Hz. At 80% load, the peak amplitude was 45.7mm/s in the H direction and 26.8mm/s in the A direction at 25Hz. The corresponding values at 100% load were 45.2mm/s in the H direction and 30mm/s in the A direction at 26Hz. A reason for this could be the pressure changes within the cylinder during combustion.

2) Using 10 % Ethanol Blending (B10D90)

Table III shows the overall velocity-RMS amplitude of the E10D90 blend in the three directions. Figures 5 and 6 show the frequency spectra for the same engine loads at 1500RPM. Velocity in the V direction was found to be minimum (10mm/s) at 20% load and maximum (16.5mm/s) at 100%. Velocity in the H direction was found to be minimum (50.1mm/s) at 20% load and maximum (54.7mm/s) at 100%. Velocity in the A direction was found to be minimum (26.1mm/s) at 20% load and maximum (32mm/s) at 100%. The minimum velocity was reported at 20% load while the maximum was reported at 100%.

TABLE III. OVERALL RMS VALUES OF AMPLITUDE IN THE THREE DIRECTIONS

Speed (rev/min)	Load	RMS Amplitude (mm/s)			
		Location	Direction		
			Vertical	Horizontal	Axial
1500	20%	Cylinder head	10	50.1	26.1
	40%		12.5	50.8	26.8
	60%		14.3	52.7	29.9
	80%		16.3	53.9	30.3
	100%		16.5	54.7	32

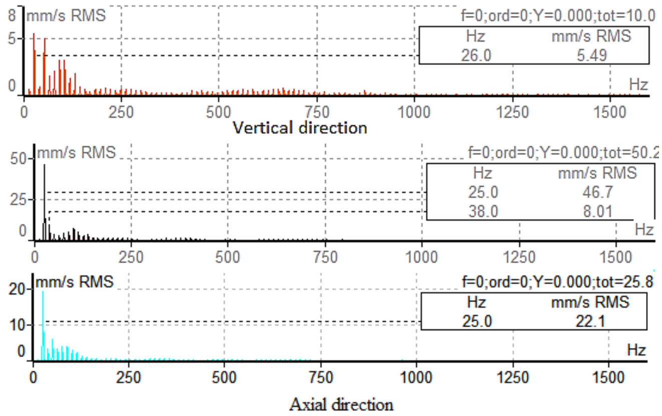

Fig. 5. Frequency spectra at 20% load in the V, H, and A directions.

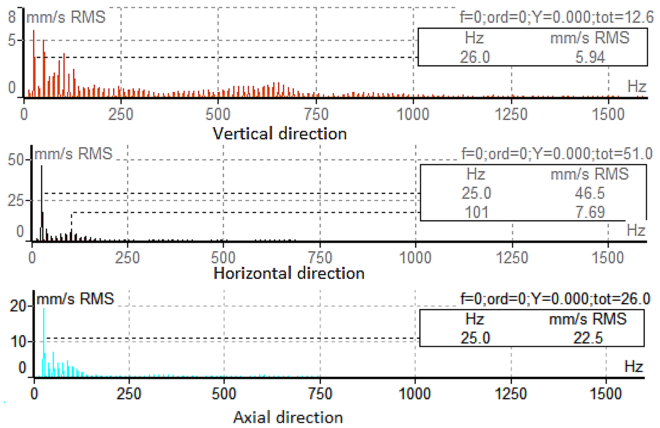

Fig. 6. Frequency spectra at 40% load in the V, H, and A directions.

In the frequency spectrum, harmonics were observed in the V direction. At 20% load, the H peak amplitude was 46.7mm/s and the A peak amplitude was 22.1 mm/s, at 25Hz. At 40% load, the peak amplitude was 22.5mm/s in the A direction and 46.5mm/s in the H direction at 25Hz. Similar trials were conducted for 60, 80, and 100% loads. At 60% load, the peak amplitude was 47mm/s in the H direction and 24.8mm/s in the A direction at 25 Hz. At 80% load, the maximum H amplitude was 34.2mm/s and the maximum A amplitude was 22.1mm/s at 25Hz. At 100% load, the maximum amplitude was 53.3mm/s in the H direction and 28.5mm/s in the A direction at 26Hz. This could also be attributed to the pressure changes within the cylinder during combustion. The V direction had lower vibrational amplitudes than the H and A directions.

3) Using 15% Ethanol Blending (B15P85)

Figures 7 and 8 show the FFT spectra for the same engine loads at 1500 RPM. Table IV shows that the minimum and maximum velocities were recorded at 20% and 100% loads, respectively. Velocity in the V direction was found minimum (10mm/s) at 20% load and maximum (17mm/s) at 100% load. Velocity in the H direction was found minimum (52mm/s) at 20% load and maximum (55.8mm/s) at 100% load. Velocity in the A direction was found minimum (24.2mm/s) at 20% load and maximum (34.3mm/s) at 100% load. The vibration levels of B15D85 were higher than those of B5D95 and B10D90 blends.

TABLE IV. OVERALL RMS VALUES OF AMPLITUDE IN THE V, H, A DIRECTIONS

Speed (rev/min)	Load	RMS Amplitude (mm/s)			
		Location	Direction		
			Vertical	Horizontal	Axial
1500	20 %	Cylinder head	10	52	24.2
	40%		12.2	52	26.1
	60%		14.9	54.7	31
	80%		16	54.8	32
	100%		17	55.8	34.3

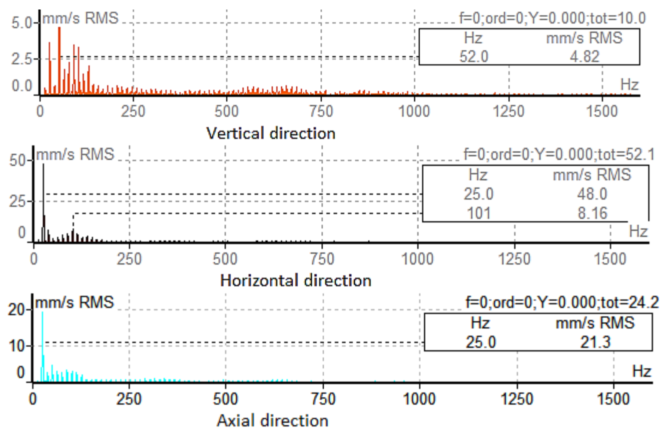

Fig. 7. Frequency spectra at 20% load in the V, H, and A directions.

In the frequency spectrum, harmonics were observed in the V direction. At 20% load, the peak amplitude was 48mm/s in the H direction and 21.3mm/s in the A direction, at 25Hz. At 40% load, the peak was 48mm/s in the H direction and 27.4mm/s in the A direction at 25Hz. At 60% load, the peak amplitude was 49.8mm/s in the H and 27.4 mm/s in the A direction at 26Hz. At 80% load, the peak amplitude was 49.8 mm/s in the H and 28.5mm/s in the A direction at 26Hz. At 100% load, the peak amplitude was 51.5mm/s in the H and 33.2mm/s in the A direction at 26Hz. The high peak amplitude in the H direction may be due to the variation of the cylinder pressure inside the combustion chamber. The vibration amplitude was less in the V direction compared to the others, as the internal components piston, connecting rod, crankshaft, bearings, and camshaft have less degrees of freedom in this direction.

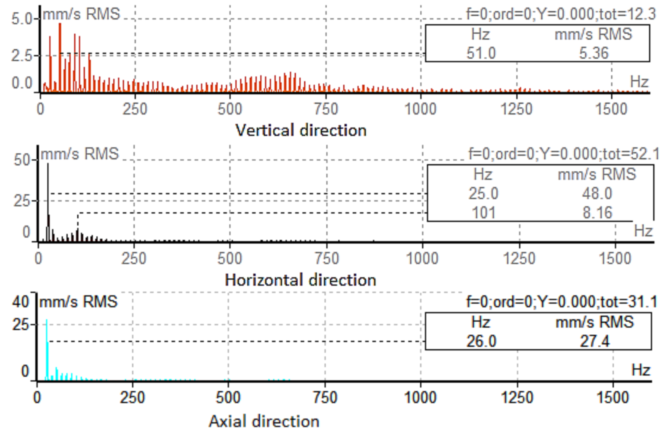

Fig. 8. Frequency spectra at 40% load in the V, H, and A directions.

The three tested blends showed reduced engine vibration in the V direction compared to the H and A directions. The intensity of the vibration was highest in the H direction. Peak velocities were observed in the horizontal plane because of the rapid changes in cylinder pressure that occur during combustion. Vertical vibration was reduced because piston, connecting rod, crankshaft, bearings, and camshaft have less degrees of freedom in this direction. The fuel cetane number and the injection advance may affect the vibration, while a short ignition delay may reduce it.

B. Noise Analysis

The engine noise data were recorded in a similar experimental indoor environment and conditions for the three blends, using an FFT analyzer to capture the engine noise. Noise level was measured with a microphone (Make: K type 40 ph; Sensitivity: 50mv/pa) kept 1.25m off the ground and 1m from the engine centreline. The microphone was connected to the FFT analyzer. Table V shows the noise levels recorded for the three blends. The E5D95 blend produced less noise than the E10D90 and E15D85 blends. Figures 9–14 show the octave spectra of the E5D95, E10D90, and E15D85 blends at 20% and 40% load. Similar trials were conducted for 60, 80, and 100% loads at 1500rpm.

TABLE V. NOISE LEVEL OF FUEL AT DIFFERENT LOAD

Fuel	Load	Noise level (L) dB
E5D95	20	89.7
	40	95.5
	60	97.7
	80	98.2
	100	99.9
E10D90	20	92.6
	40	94.7
	60	98.6
	80	99.3
	100	102
E15D85	20	93.9
	40	95.6
	60	98.6
	80	101
	100	102

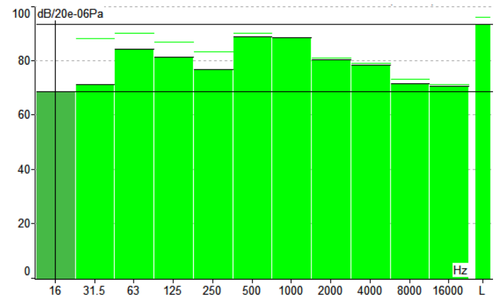

Fig. 9. Octave spectrum of the E5D95 blend at 20% load.

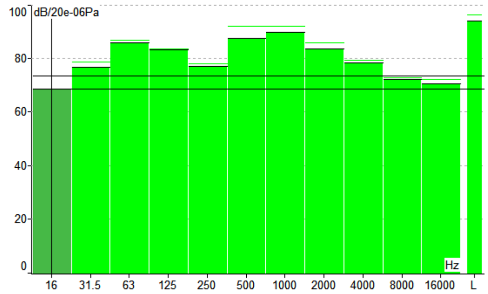

Fig. 10. Octave spectrum of the E5D95 blend at 40% load.

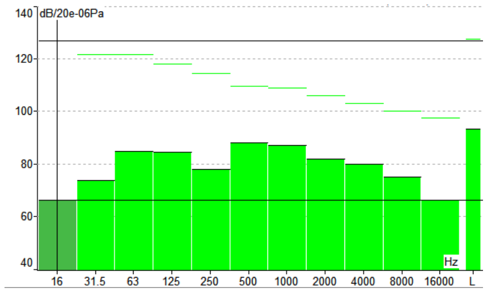

Fig. 11. Octave spectrum of the E10D90 blend at 20% load.

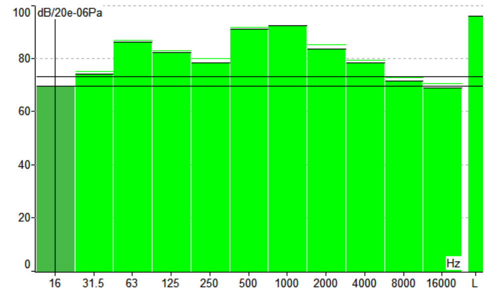

Fig. 12. Octave spectrum of the E10D90 blend at 40% load.

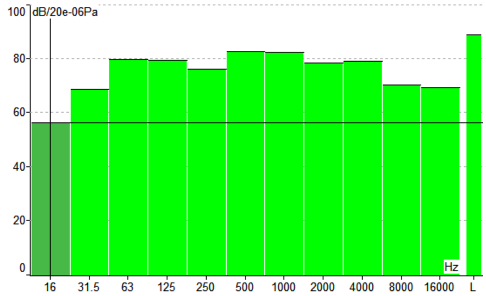

Fig. 13. Octave spectrum of the E15D85 blend at 20% load.

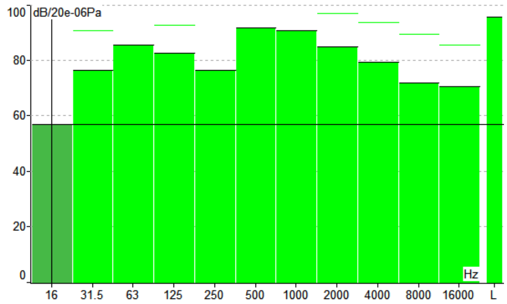

Fig. 14. Octave spectrum of the E15D85 blend at 40% load.

Noise levels were minimum at 20% load and maximum at 100% load across the board. Increases in input air flow rate, air pressure pulsation amplitude, and frequency with increasing engine loads were responsible for the subsequent increase in engine noise. The intake system was mostly determined by gas pressure wave dynamics, which in turn was affected by the workload of the engine. When the load was high, the noise level increased.

IV. CONCLUSION

This study investigated experimentally the noise and vibration produced by a single-cylinder diesel engine running at a constant 1500 rpm and varying loads. The lowest vibration was reported for B5D95, showing that engine vibration increases with increasing ethanol concentration in the fuel blend. Furthermore, vibrations in the horizontal direction were higher compared to those in vertical and axial directions at all loads due to the rapid changes in cylinder pressure during combustion. Vertical vibration was reduced because the piston, connecting rod, crankshaft, bearings, and camshaft had less degrees of freedom in this direction. A short ignition delay may be responsible for reducing vibration. The vibrations increased with increasing loads. Noise measurement was performed using an FFT analyzer and it was observed that the B5D95 blend had the lowest engine noise among the tested blends. The noise level of E5D95 was minimum (89.7dB) at 20% load and maximum (99.9 dB) at 100% load. The noise level of E10D90 was minimum (92.6dB) at 20% load and maximum (102dB) at 100% load. The noise level of E15D85 was minimum (93.9dB) at 20% load and maximum (102dB) at 100% load. It was noticed that the engine noise increased with increasing ethanol concentration in fuel blends. The engine noise for E15P85 was slightly higher than for E10P90. The engine workload had an impact on the gas pressure wave dynamics, which in turn influenced the intake system. Future research could focus on the correlation between performance analysis with vibration and noise. Furthermore, noise and vibration characteristics could be studied for flex-fuel engines using similar measurement techniques.

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