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Analysis of Vibration Signals from Cylinder Head of a Diesel Engine Fueled With Blends of Diesel and Oxy-Hydrogen Gas

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Abstract:** Many bio-diesels are tried and tested to reduce vibrations from diesel engines. Oxy-hydrogen gas is known to improve engine performance and combustion characteristics. This paper presents study on effect of addition of oxy-hydrogen in diesel on vibration signals from cylinder head of a twin cylinder diesel engine. Oxy-hydrogen is added in diesel at five different flow rates (100 (B1), 150 (B2), 200 (B3), 250 (B4) and 300 (B5) milliliters per minute). Changes in statistical parameters (Skewness, RMS value, Crest factor, Kurtosis and Peak amplitude) related to vibration signals are studied and compared with respect to non blended diesel (NB). 36.36% drop in skewness from cylinder head is recorded with B3 flow rate. RMS from cylinder head drops down by 6.68% with B3. Crest factor from cylinder head drops down by 7.97% with B2 and 8.14% with B4 blend. Kurtosis from cylinder head drops down by 20.56% with B4 and increases for B5. Peak amplitude of vibration signals from cylinder head shows drop of 13.34% with B1 flow rate of oxy-hydrogen gas. Overall B3 flow rate of oxy-hydrogen is observed to be most effective in reducing vibration signals from cylinder head of a diesel engine.

***Keywords:** Oxy-hydrogen gas; kurtosis; crest factor; skewness; RMS; peak amplitude.*

I. INTRODUCTION

Majority of diesel engines suffer from disadvantage of vibration due to the way in which fuel is burnt inside the combustion chamber and large peak pressure produced during process of combustion. Engines of present days also suffer from vibration especially due to dynamic misbalancing of various rotating and reciprocating parts. With modern techniques like direct injection, high injection pressure systems, electronic fuel injection system with multiple injection patterns of injectors as per the engine demand from electronic control unit the vibrations from these engines are very well under control. Apart from different techniques to predict and reduce vibrations from different engine parts by Charles et al. [1], Geng et al. [2], Vulli et al. [3] and Zheng et al. [4], alternative fuels are also tried and tested by number of researchers. Sastry et al. [5] studied the effect of mahua methyl ester as a diesel substitute on a vibration and noise from a diesel engine. Authors found that the engine vibration and noise levels are dropping down with use of mahua methyl ester and hence complete replacement of diesel with mahua methyl ester is possible. Rao and Rao [6] studied FFT spectrum indicating knocking frequency and the acceleration amplitude in order to investigate the effect triacetin addition to the coconut oil methyl ester on cylinder vibration. Measurement is carried out in radial direction of cylinder in line crankshaft axis. 10% addition of triacetin with coconut oil methyl ester is proven to reduce the cylinder block vibration effectively together with improved performance and reduced emissions. Manieniyan and Sivaprakasam [7] studied time vs. acceleration graphs at different engine locations for a single cylinder diesel engine fuelled with different blends of diesel and bio diesel (mahua MEOM). Significant reductions in vibration signals are recorded due to addition of biodiesel. Shaikh and Umale [8] carried out vibration and noise analysis of diesel engine fuelled with neat diesel and jatropha biodiesel. Cylinder block vibrations are recorded in two different radial directions (along crankshaft axis and lateral to crank shaft axis) for two different loading conditions. A reduction in vibrations (both directions) is recorded with use of jatropha biodiesel. Taghizadeh-Alisaraei et al. [9] studied effect of biodiesel from four stroke six cylinder diesel engine of tractor. It is observed that 20% and 40% blending had the lowest vibrations. Literature review also showed studies related to blending of conventional diesel, biodiesel and natural gas by Çelebi et al. [10], karanja by Patel et al. [11], jatropha and cooking oil by Asif and Suryakumari [12].

Oxy-hydrogen gas obtained through conventional water electrolysis process is known to improve performance and combustion characteristics of both gasoline and diesel engines. Musmar and Al-Rousan [13] reported reduction of 50% in NO and NOx values, 20% in CO and 20- 30 % in fuel consumption due to its blending with gasoline and use in a single cylinder engine. Yilmaz and Uludamar [14] bended a constant flow rate of oxy- hydrogen gas with diesel and showed 19.1% increase in engine torque, 13.5% reduction in CO, 5% reduction in HC and average 14 % reduction in specific fuel consumption. Milen and Barzev [15] showed that during process of combustion oxy-hydrogen increases the mixture calorific value, releases more heat and increases flame velocity. Bari and Esmaeil [16] reported higher thermal efficiencies at various power outputs due to oxy-hydrogen blending with diesel. Chakrapani and Neelamegam [17] reported drop in the engine operating temperature due to presence of oxy-hydrogen during combustion process. Wang et al. [18] reported similar results even for heavy duty diesel engine especially because of complete combustion of diesel in presence of oxy- hydrogen gas. Al-Rousan [19] showed that integration of oxy- hydrogen gas generator to the conventional engines is easy and reported reduction in fuel consumption potential without much engine modification. Yadav et al. [20] studied various methods for oxy-hydrogen generation and effect on the performance of internal combustion engine. Yadav and Sawant [21] compared oxy-hydrogen gas with producer gas and found oxy-hydrogen to be more suitable for automotive application. With reference to above discussion it would be interesting to study effect of oxy-hydrogen addition in diesel on vibration characteristics of diesel engines.

II. FUEL PREPARATION, TEST SETUP AND METHODOLOGY

Oxy-hydrogen gas is obtained with conventional electrolysis process using a water fuel cell consisting of a glass container filled with electrolytic solution prepared from distilled water and potassium hydroxide to increase conductivity. Two 316L stainless steel electrodes with a 6 mm gap are placed inside the container and connected to DC current source via switch, fuse, ammeter and rheostat. Ammeter and rheostat are used to record and regulate current flowing through electrolytic cell. Every cell is calibrated to generated 50 milliliter per minute of oxy-hydrogen gas at 5 ampere current. Total six electrolytic cells are used to produce oxy-hydrogen flow rates of 100 (B1), 150 (B2), 200 (B3), 250 (B4) and 300 (B5) milliliter per minutes. Acceleration signals are taken from cylinder head in axial direction (along direction of piston displacement) of a twin cylinder diesel engine using unidirectional accelerometer. Specifications of the test engine are presented in table 1. Vibration signals from accelerometers are processed through virtual instrumentation setup with Lab-View to calculate five statistical parameters (a) skewness, (b) kurtosis, (c) root mean square, (d) crest factor and (e) peak amplitude. Signals are taken at no load condition when engine is fuelled with neat diesel and five blends of diesel and oxy-hydrogen gas where in at given experimental condition oxy-hydrogen gas was flowing at B1, B2, B3, B4 and B5 flow rates together with neat diesel. Oxy-hydrogen is supplied to the engine via a nozzle in intake manifold. Changes in the statistical parameters due oxy-hydrogen blending with diesel are studied and compared with non blended diesel (NB). Figure 1 shows experimental setup with oxy-hydrogen cell and location of accelerometers on cylinder head and figure 2 shows block diagram for calculation of statistical parameters through Lab-view.

III. RESULTS AND DISCUSSION

A. *Effect of oxy-HYDROGEN Addition on Skewness of Vibration Signal*

Distribution is normally spread or distributed around mean on positive and negative side symmetrically. The distribution is said to be skewed when it is not symmetric around mean. This is because of large experimental values compared to other experimental values called outliers which pull mean towards right or left depending on their own value. Mathematically skewness is defined as the ratio of averaged cubed deviation from mean and cube of standard deviation [22].

$$\text{Skewness} = \frac{\sum_{n=1}^{N}(X-\overline{X})^3}{N\,\sigma^3} --- (1)$$

$(X-\overline{X})^3$ is the cube of deviation from arithmetic mean, N is the number of observations and σ is the standard deviation. Skewness is dimensionless number and ideally has a zero value.

Table I. Specifications of test engine

Make	Comet Engineering
Bore × Stroke in mm	87.5 × 110
Compression ratio	18:1
Rated power in HP	13 BHP at 1600 RPM
Fuel	Diesel
Injection system	Individual pump and injector type with speed governor
Number of cylinders	2 with inline individual block configuration

(a) (b)

Fig. 1 (a) Experimental Setup showing oxy-hydrogen cell and (b) position of accelerometers on cylinder head

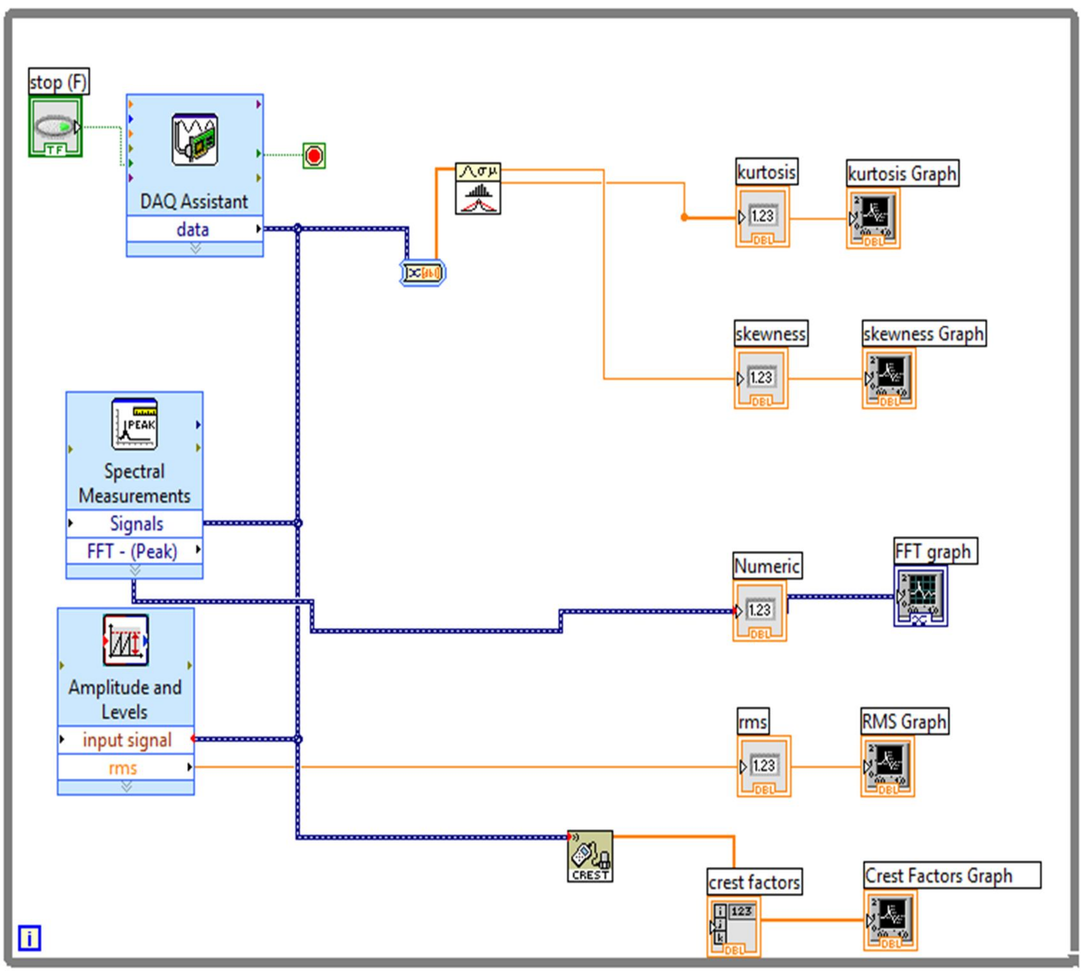

Fig. 2 Block diagram for signal extraction and analysis using Lab-View

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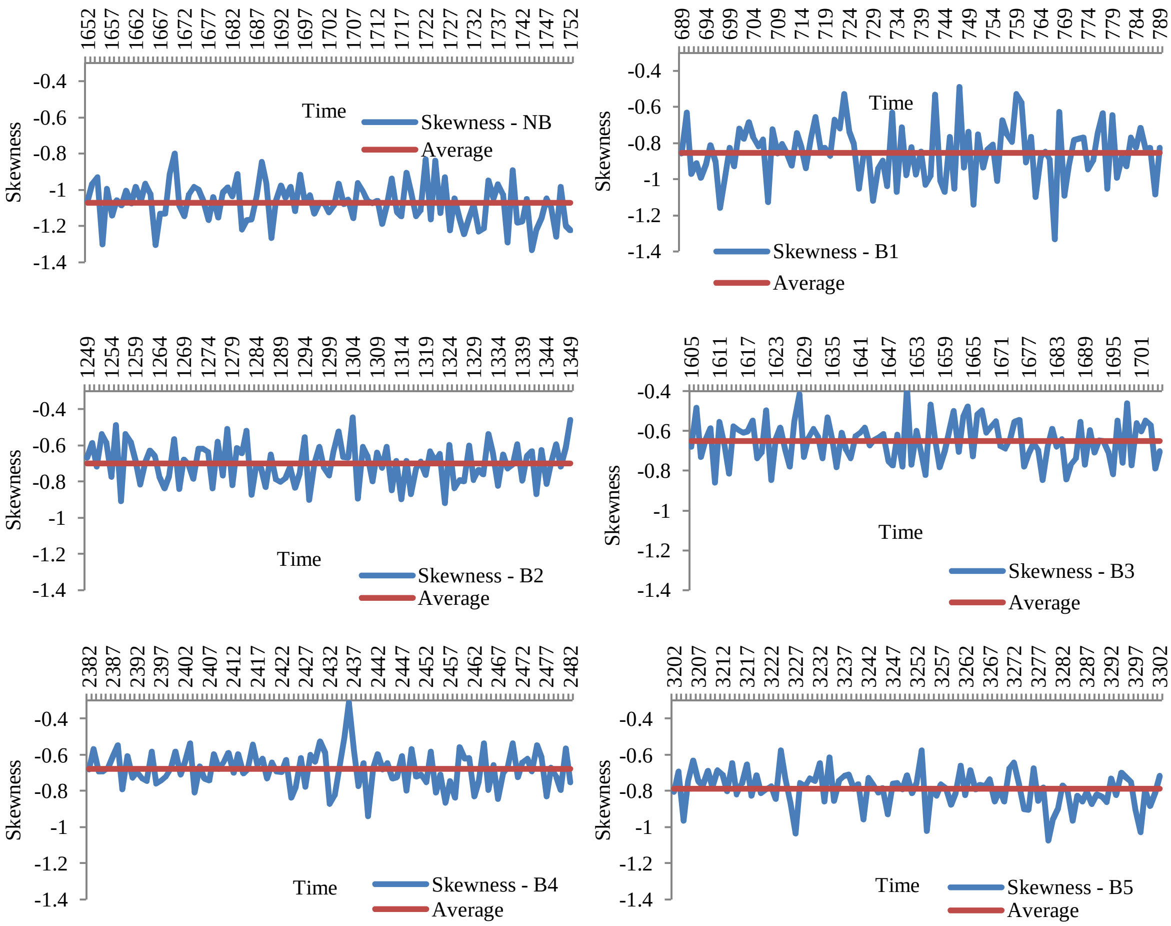

Fig. 3 Recorded skewness of acceleration signals from cylinder head with respect to time for each blend of diesel and oxy-hydrogen gas

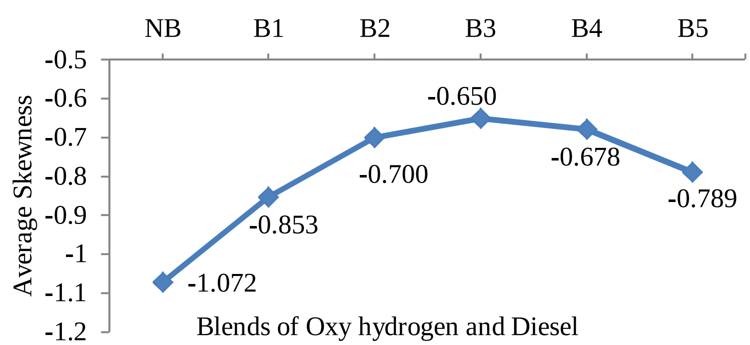

Fig. 4 Variation of average skewness of acceleration signals from cylinder head with respect to various blends of diesel and oxy-hydrogen

Figure 3 shows recorded skewness of acceleration signals from cylinder head with respect to time for each blend of diesel and oxy-hydrogen gas. Figure 4 shows variation in average skewness of acceleration signals from cylinder head with respect to various blends of diesel and oxy-hydrogen. It is clear from these figures that distribution is negatively skewed and oxy-hydrogen addition in diesel reduces the nature of skewness up to blend B3 where it records a 39.36% drop in average skewness value compared to neat

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diesel at same condition. Further addition of oxy-hydrogen in diesel increases negative nature of skewness progressively with B4 and B5 blends remains lesser than NB condition though. Thus initial blending of oxy-hydrogen with diesel helps in reducing skewness, however power produced inside combustion chamber progressively increases with richness of oxy-hydrogen inside combustion chamber and further oxy-hydrogen addition increases skewness of vibration signals.

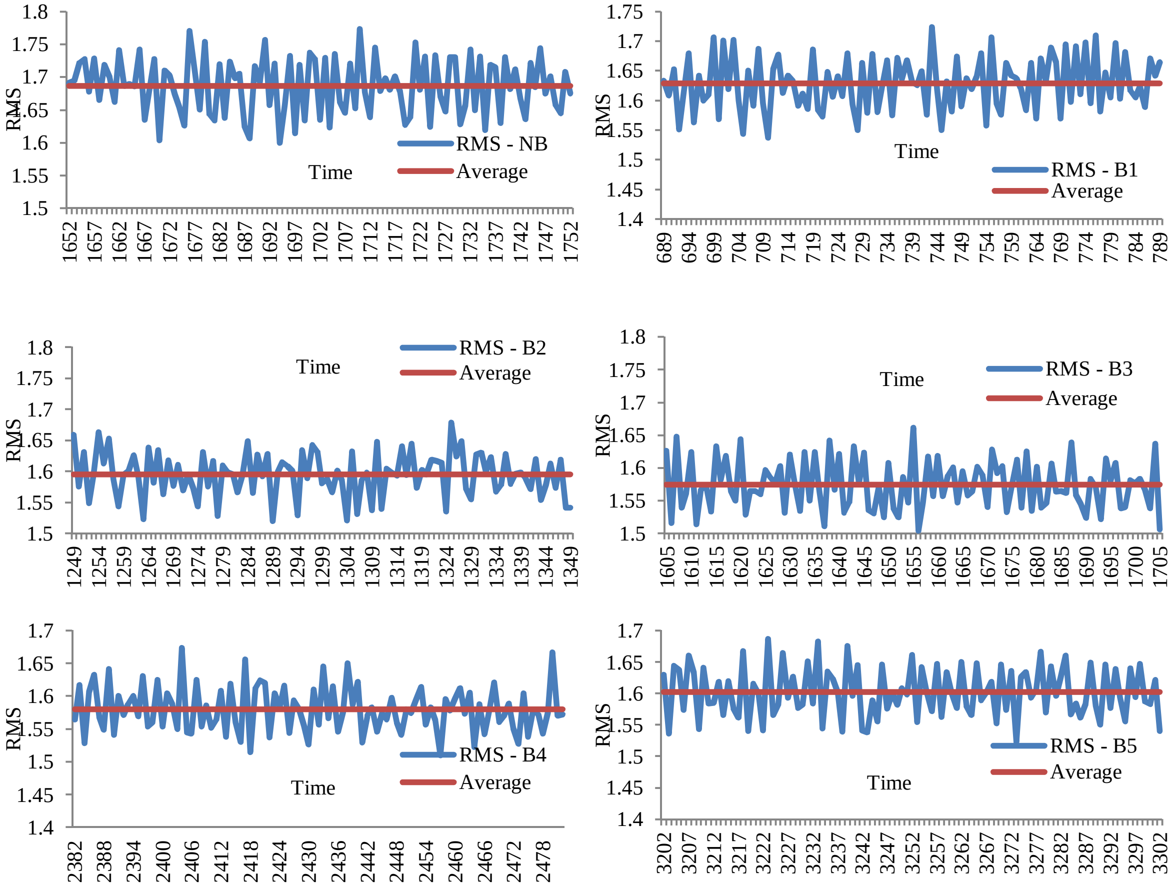

Fig. 5 Recorded RMS of acceleration signals from cylinder head with respect to time for each blends of diesel and oxy-hydrogen gas

B. Effect of oxy-hydrogen Addition on RMS of Vibration Signal

The RMS value is proportional to the area under the curve of vibration signal waveform where negative peaks are rectified by making them positive and then the area is averaged to a constant level over a certain length of time. RMS value gives the idea about the power or energy of waveform, higher the RMS values higher the power or energy in waveform. RMS value is also used to study engine body vibrations and with increase in RMS value engine vibrations increases [23]. Root mean square is the square root of average of squared values of vibration signal waveform and mathematically expressed as:

$$\text{RMS} = \sqrt{\sum_{i=1}^{N} \frac{(X_i)^2}{N}} ------ (2)$$

Figure 5 shows recorded RMS of acceleration signals from cylinder head with respect to time for various blends of diesel and oxy-hydrogen gas and figure 6 show variation of average skewness of acceleration signals from cylinder head with respect to various blends of diesel and oxy-hydrogen. From these figures it is pretty much clear that the RMS value of vibration signals from cylinder head decreases from no blend condition to B3 blend and records a highest drop of 6.698% in average RMS value. It is observed that amplitude of vibration signals progressively drops down with oxy-hydrogen blending and thus helps in dropping down the RMS value and energy or power from the vibration signals through cylinder head thereby smoothening engine operation. However beyond B3; RMS value further increases progressively for B4 and B5 blends, still less than the no blend condition though.

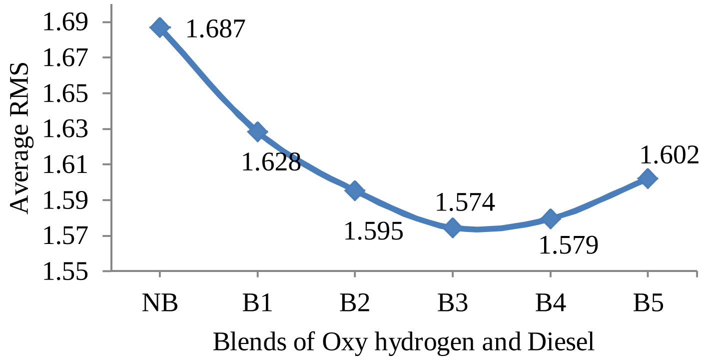

Fig. 6 Variation of average RMS of acceleration signals from cylinder head with respect to various blends of diesel and oxy-hydrogen

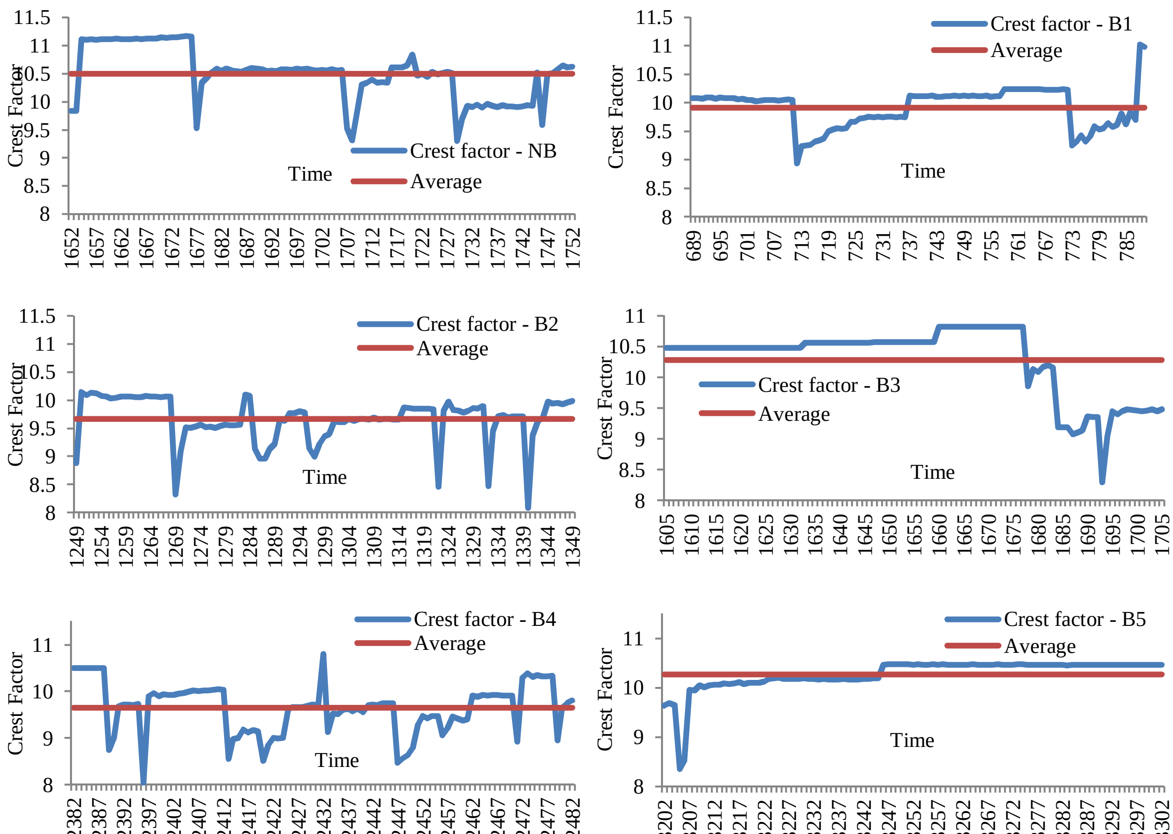

Fig. 7 Recorded Crest factor of vibration signals from cylinder head with respect to time for each blends of diesel and oxy-hydrogen gas

C. *Effect of oxy-Hydrogen Addition on Crest factor of Vibration Signal*

Ratio of peak amplitude of vibration signal to the RMS value of vibration signal is called as crest factor. Crest factor gives a quick idea about how much impacting is occurring in a waveform. In a perfect sine wave with amplitude equal to one, the RMS value is equal to 0.707 and hence the crest factor is 1.4144. A perfect sine wave form contains no impacting and hence a crest factor above 1.4144 implies that there is some degree of impacting. Higher values of crest factor indicate strong impacting [24]. Figure 7 shows recorded crest factor of vibration signals from cylinder head with respect to time for each blend of diesel and oxy-hydrogen gas. Figure 8 shows variation of average crest factor of vibration signals from cylinder head with respect to various blends of diesel and oxy-hydrogen gas. It is clear from these figures that the crest factor value is much higher than ideal 1.4144. This suggests strong impacting of vibration signals from cylinder head. Decreasing nature of graph in figure 8 shows that oxy-hydrogen blending helps in reducing the crest factor with all blends. Up to blend B2 a significant drop of 7.97% is recorded with oxy-hydrogen blending with diesel. However with further addition of oxy-hydrogen increases the crest factor at B3 and drops down the improvement to 2.085% compared to crest factor of vibration signals from cylinder head when engine is fuelled with neat diesel. At blend B4 once again the average crest factor value drops down thereby increasing the improvement to 8.14%, highest amongst all experimental conditions. This improvement further drop down to 2.17% with B5 blend compared to non blended diesel. Overall a sinusoidal trend in crest factor variation is recorded due to oxy-hydrogen blending with diesel. Due to drop in peak amplitude of vibration signals due to oxy-hydrogen addition in diesel drop in degree of impacting is recorded with reduced value of crest factor.

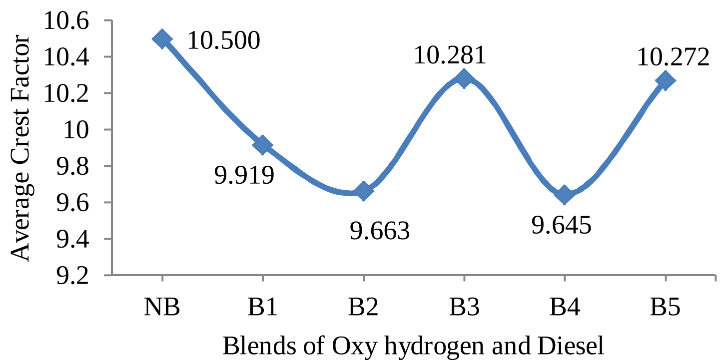

Fig. 8 Variation of average of crest factor of acceleration signals from cylinder head with respect to various blends of diesel and oxy-hydrogen

D. Effect of oxy-Hydrogen Addition on Kurtosis of Vibration Signal

Kurtosis of vibration signals shows the degree of peakedness or flatness of a distribution compared to normal distribution. Mathematically kurtosis is defined as the ratio of fourth moment to the square of variance [22].

$$\text{Kurtosis} = \frac{\sum_{n=1}^{N}(X-\overline{X})^4}{N\sigma^4} ------(3)$$

A distribution more peaked than normal distribution is called leptokurtic distribution where in more values of the distribution are clustered close to the mean value however far higher than the mean. A distribution where in values are more dispersed have a flatter nature and tend to have a thinner tails than normal distribution is called platykurtic distribution. A normal distribution has kurtosis value equal to 3 and hence distribution with kurtosis values more than 3 are called leptokurtic and the one with kurtosis value less than 3 are called platykurtic. The one with kurtosis value equal to 3 is called mesokurtic. Kurtosis criteria are also used to evaluate the performance of engine, the inside pressure of cylinder and sharp fluctuations of the vibration of engine body. Higher kurtosis value shows irregular engine performance or rough engine operation and with decrease in its value engine runs smoother [23]. Figure 9 shows variation of kurtosis of vibration signals from cylinder head with respect to time for various blends of diesel and oxy-hydrogen. Figure 10 shows variation of average of crest factor of acceleration signals from cylinder head with respect to various blends of diesel and oxy-hydrogen gas. The calculated values of kurtosis of vibration signal from cylinder head suggests that the distribution is more peaked than normal distribution and is called leptokurtic distribution. Hence more values of the distribution are clustered close to the mean value however far higher than the mean. Even in this case oxy-hydrogen blending with diesel helps to reduce the kurtosis value of acceleration signals. Kurtosis value drops down progressively up to B4 blend and it records a highest drop of 20.56% compared to non blended diesel. Further oxy-hydrogen addition in diesel increases the kurtosis value. Still at B5 blend the kurtosis value is much lower than non blended diesel. Oxy-hydrogen addition in diesel helps to disperse the vibration signals to have a flatter nature and thinner tails thereby decreasing the leptokurtic nature of distribution close to normal distribution. Thus oxy-hydrogen blends helps in reducing the pickedness of vibration signal distribution and sharp fluctuations as well thereby reducing the probability of the generation of periodic impulses with large amplitudes in cylinder head.

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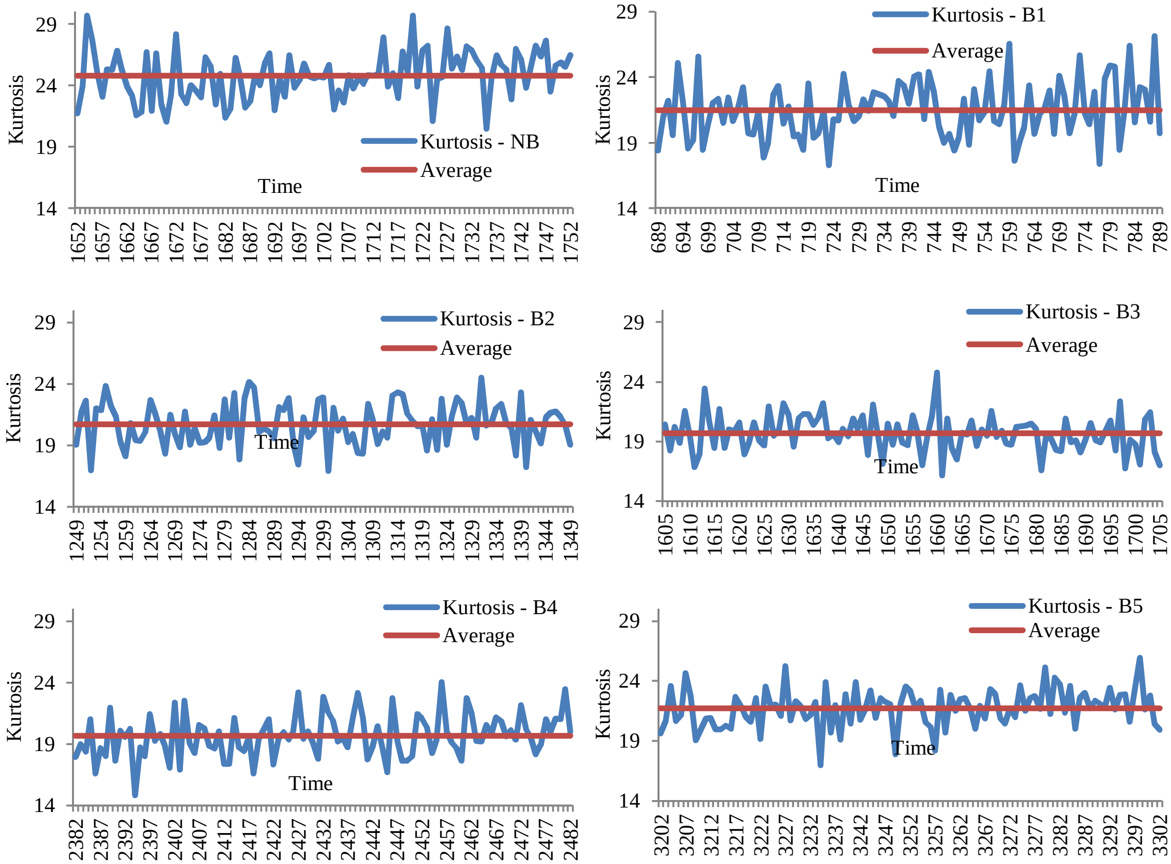

Fig. 9 Recorded kurtosis of vibration signals from cylinder head with respect to time for each blend of diesel and oxy-hydrogen gas

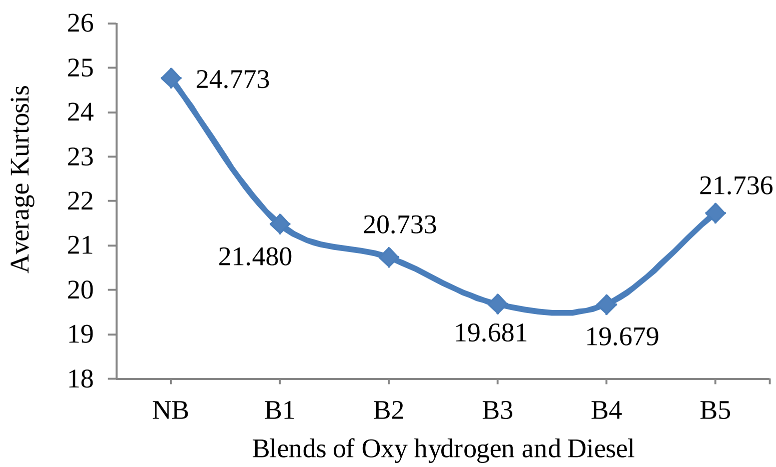

Fig. 10 Variation of average of kurtosis of acceleration signals from cylinder head with respect to various blends of diesel and oxy-hydrogen gas

E. Effect of oxy-hydrogen Addition on Peak Amplitude of Vibration Signal

Fourier transform, transform signals from time domain to frequency domain and back again with inverse Fourier transform. Fast Fourier Transform is used in conventional frequency domain signature analysis techniques for conversion of time domain signal in frequency domain signal. The sudden peak in the frequency spectrum of the system than normal behaviour of the system will help to indicate abnormal working of the system. In case of internal combustion engine, the vibration of cylinder head can be determined with the help of FFT of the output signals. The amplitude obtained in the frequency spectrum of a system using FFT is nothing but the amplitude of vibration and it is used for analysis. Figure 11 shows FFT of vibration signals from cylinder head with respect to time for each blend of diesel and oxy-hydrogen. Figure 12 shows variation of peak amplitude of vibration signals from cylinder head with respect to various blends of diesel and oxy-hydrogen gas. These figures show that there is definite reduction in the amplitude of vibration signals from cylinder head at a given frequency. Blending shows progressive decrement in average amplitude of vibration signal from cylinder head up to B3 blend. At B3 highest 13.34% drop in average amplitude is recorded compared to non blended diesel. Further addition of oxy-hydrogen increases the average amplitude up to B5. Even at B5 average amplitude is much lower than the one when engine is running on neat diesel.

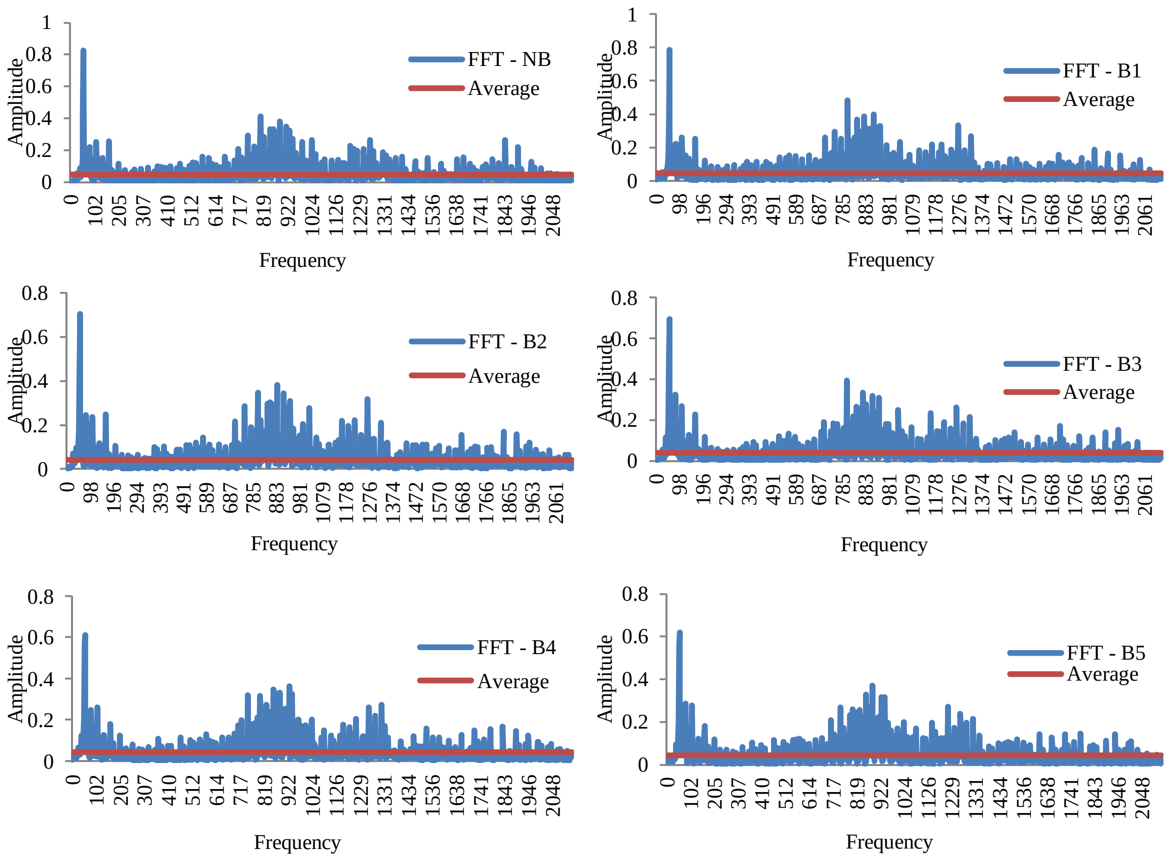

Fig. 11 Recorded amplitudes of vibration signals from cylinder head with respect to time for each blend of diesel and oxy-hydrogen gas

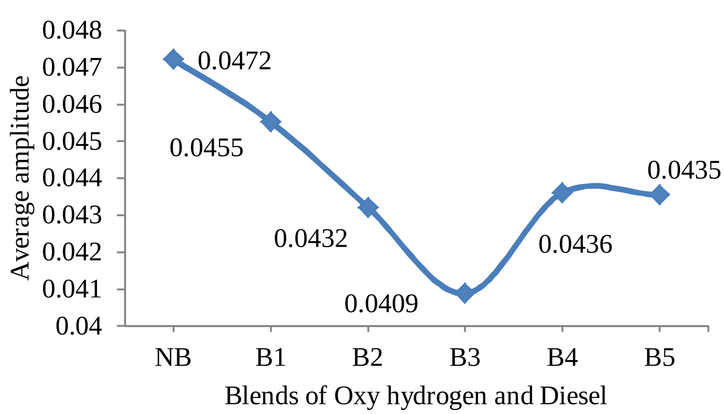

Fig. 12 Variation of average peak amplitues of acceleration signals from cylinder head with respect to various blends of diesel and oxy-hydrogen

II. CONCLUSIONS

Following conclusions can be drawn from the analysis.

A. Skewness of vibrations signals from cylinder head drops down with oxy-hydrogen blending. 36.36% drop is recorded for cylinder head with B3 blend but increases thereon.
B. RMS of vibration signals from cylinder head drops down by 6.68% with B3 and increases thereon.
C. Crest factor of vibration signals from cylinder head drops down by 7.97% with B2 and 8.14% by B4 blend.
D. Kurtosis of vibration signals from cylinder head drops down by 20.56% with B4 blend and increases for B5.
E. FFT of vibration signals from cylinder head shows drop of 13.34% in peak amplitude with B1 blend.

Overall oxy-hydrogen blending with diesel helps to reduce the vibration signals from cylinder head. B3 blend is observed to be most effective in reducing vibration signals.

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