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Effect of Oxy-Hydrogen Addition in Diesel on Vibration Signals from Engine Crankshaft Bearing

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ABSTRACT : *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 crankshaft bearing 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). 6.63% increase in skewness from crankshaft bearing is recorded with B3 and B2 flow rates. RMS of a vibration signal from crankshaft bearing increases by 3.53% with B1 flow rate. Crest factor of vibration signals from crankshaft bearing drops down by 20.59% with B3 flow rate. Kurtosis of vibration signal increases up to B3 blend and drops down with further addition. Peak amplitude of vibration signals from crankshaft bearing shows drop of 44.49% with B1 flow rate. Overall B3 flow rate of oxy hydrogen is observed to be most effective in reducing vibration signals.*
KEYWORDS - *Oxy-hydrogen gas, kurtosis, crest factor, skewness, RMS, peak amplitude*

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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].

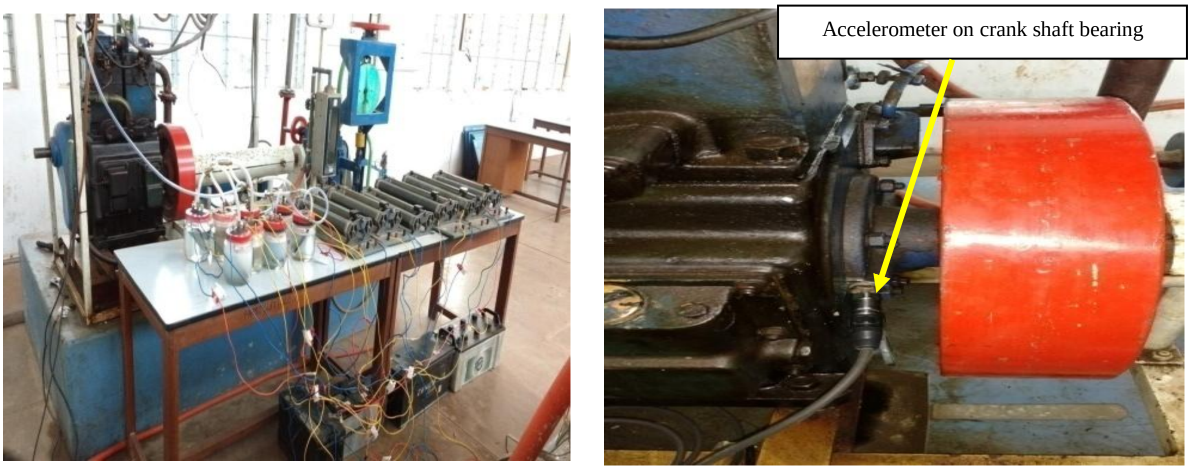
Oxy-hydrogen gas obtained through conventional water electrolysis process is known to improve performance and combustion characteristics of both gasoline and diesel engines. Musmar and Al-Rousan [13] reported reduction of 50% in NO and NOx values, 20% in CO and 20- 30 % in fuel consumption due to its 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. Each 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 in radial direction from crank shaft bearing of a twin cylinder diesel engine using unidirectional accelerometers. Specifications of the test engine are presented in table 1.

Table 1. 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
Cylinder configuration	Inline individual block



(a) (b)

Figure 1. (a) Experimental Setup showing oxy-hydrogen cell and (b) position of accelerometers on crankshaft bearing

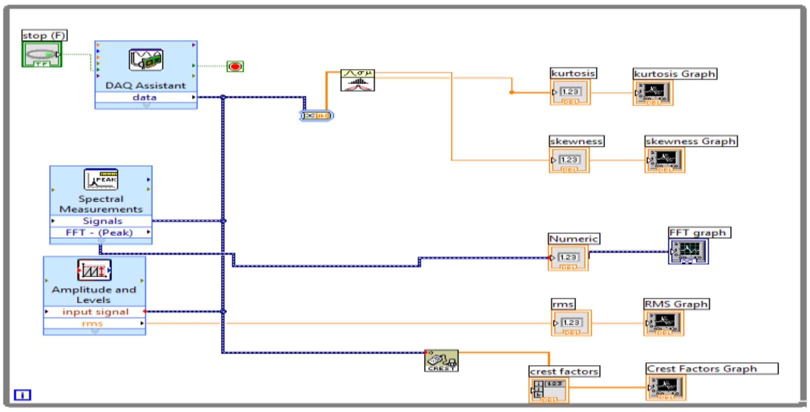


Figure 2. Block diagram for signal extraction and analysis using Lab-View

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). Fig. 1 shows experimental setup with oxy-hydrogen cell and location of accelerometer on crankshaft bearing and Fig. 2 shows block diagram for calculation of statistical parameters through Lab-view.

III. Results And Discussion

3.1 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].

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

$(X - \bar{X})^3$ 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. Fig. 3 shows recorded skewness of acceleration signals from crankshaft bearing with respect to time for each blend of diesel and oxy-hydrogen gas. Fig. 4 shows variation in average skewness of acceleration signals from crankshaft bearing with respect to various blends of diesel and oxy-hydrogen. From these figures it is clear that oxy-hydrogen addition in diesel progressively increases the skewness of vibration signals. With B2 blend its addition records a increase of 7.10% over non blended diesel. Further oxy-hydrogen addition improves the skewness with B3 and B4 flow rates remains more than NB diesel though. Highest flow rate of oxy-hydrogen records further increase in skewness. Presence of oxy-hydrogen increases complete combustion of diesel and increases peak pressure inside combustion chamber due to overall increase in calorific value of air fuel mixture. This progressively increases skewness of vibration signals from the crankshaft bearing with increase in gas forces on the crank shaft bearing.

3.2 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:

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

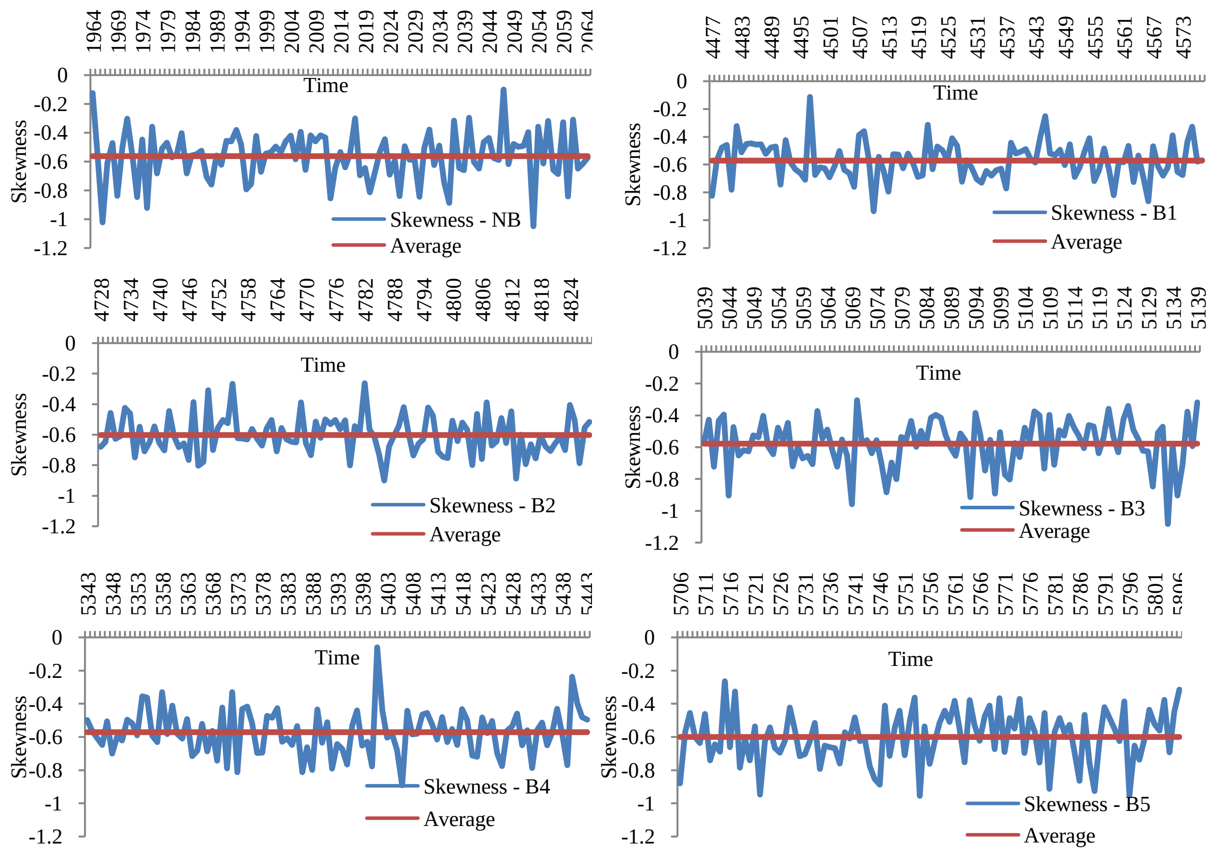


Figure 3. Recorded skewness of acceleration signals from crankshaft bearing with respect to time for each blend of diesel and oxy-hydrogen gas

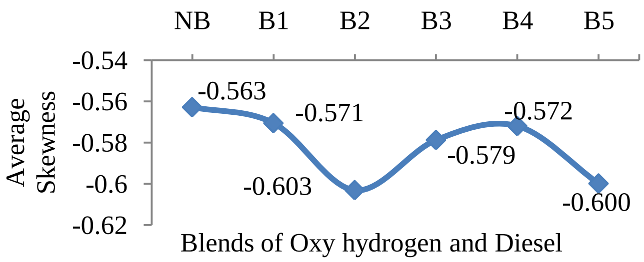
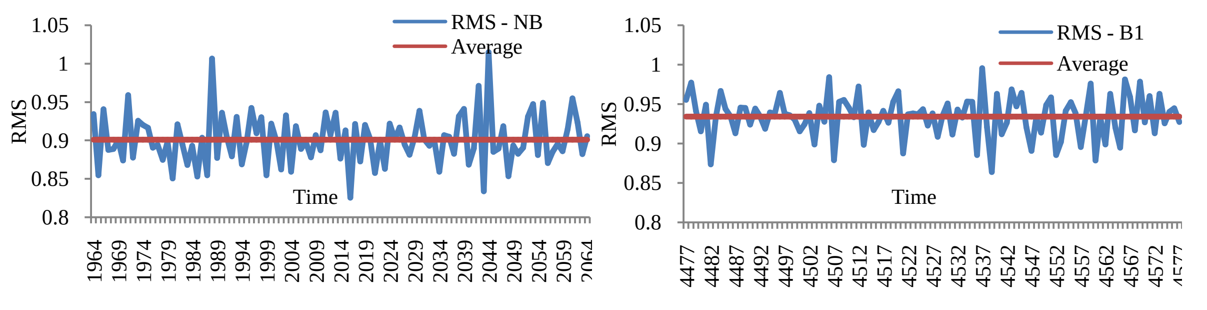


Figure 4. Variation of average skewness of acceleration signals from crank shaft bearing with respect to various blends of diesel and oxy-hydrogen gas

Fig. 5 shows recorded RMS of acceleration signals from crank shaft bearing with respect to time for each blend of diesel and oxy-hydrogen gas and Fig. 6 show variation of average RMS of acceleration signals from crankshaft bearing 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 crankshaft bearing increases by 3.66% due to first flow rate of oxy-hydrogen addition in diesel and remains almost unchanged with further bending. Increase in peak pressure inside combustion chamber in presence of oxy-hydrogen gas and corresponding increase in load on the bearing also increases power of vibration signals. This results in increased average RMS value of vibration signals.



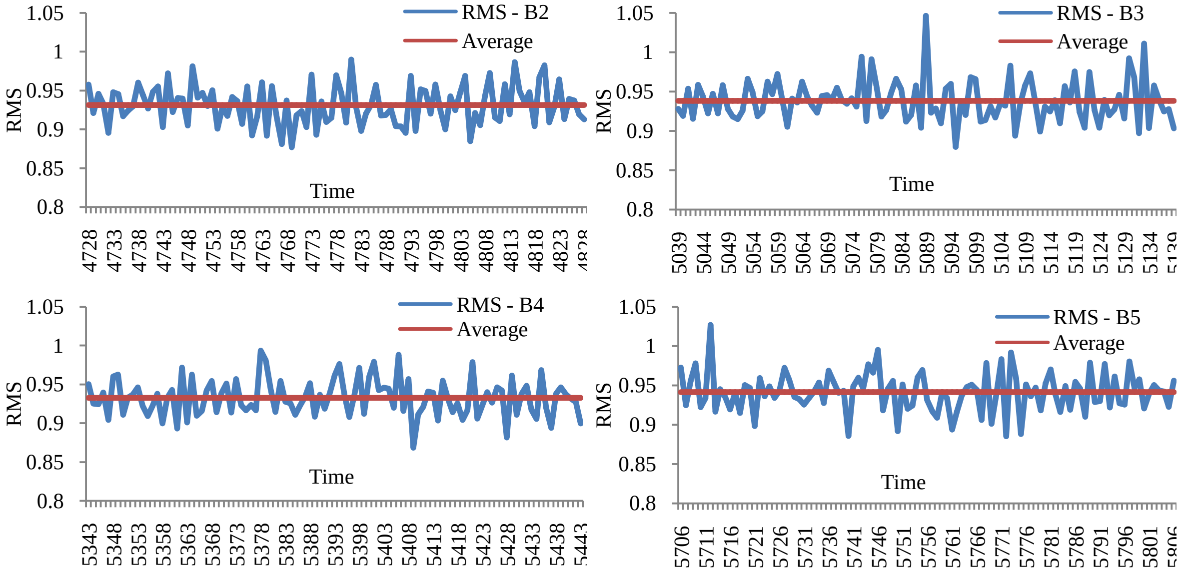


Figure 5. Variation of RMS of vibration signals from crankshaft bearing with respect to time for each blend of diesel and oxy hydrogen gas

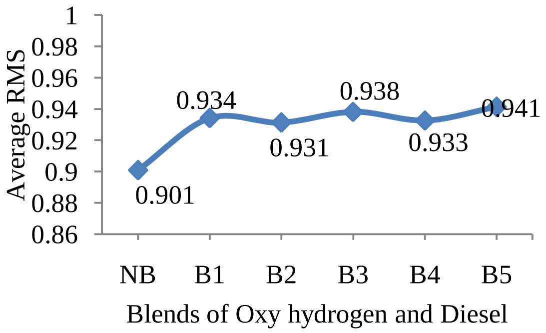


Figure 6. Variation of average RMS of acceleration signals from crankshaft bearing with respect to various blends of diesel and oxy-hydrogen gas

3.3 Effect of oxy-hydrogen addition on Crest factor of vibration signals

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]. Fig. 7 shows recorded crest factor of vibration signals from crankshaft bearing with respect to time for each blend of diesel and oxy-hydrogen gas. Fig. 8 shows variation of average crest factor of vibration signals from crankshaft bearing 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 crankshaft bearing. Decreasing nature of graph in Fig. 8 shows that oxy-hydrogen blending helps in reducing the crest factor with all blends. With B1 blend itself a significant drop of 16.73% is recorded with oxy-hydrogen blending with diesel. Even with further addition of oxy-hydrogen decreases the crest factor and at B3 records a highest drop of 20.59%. Further blending records slight increase in crest factors remains much lower than NB condition.

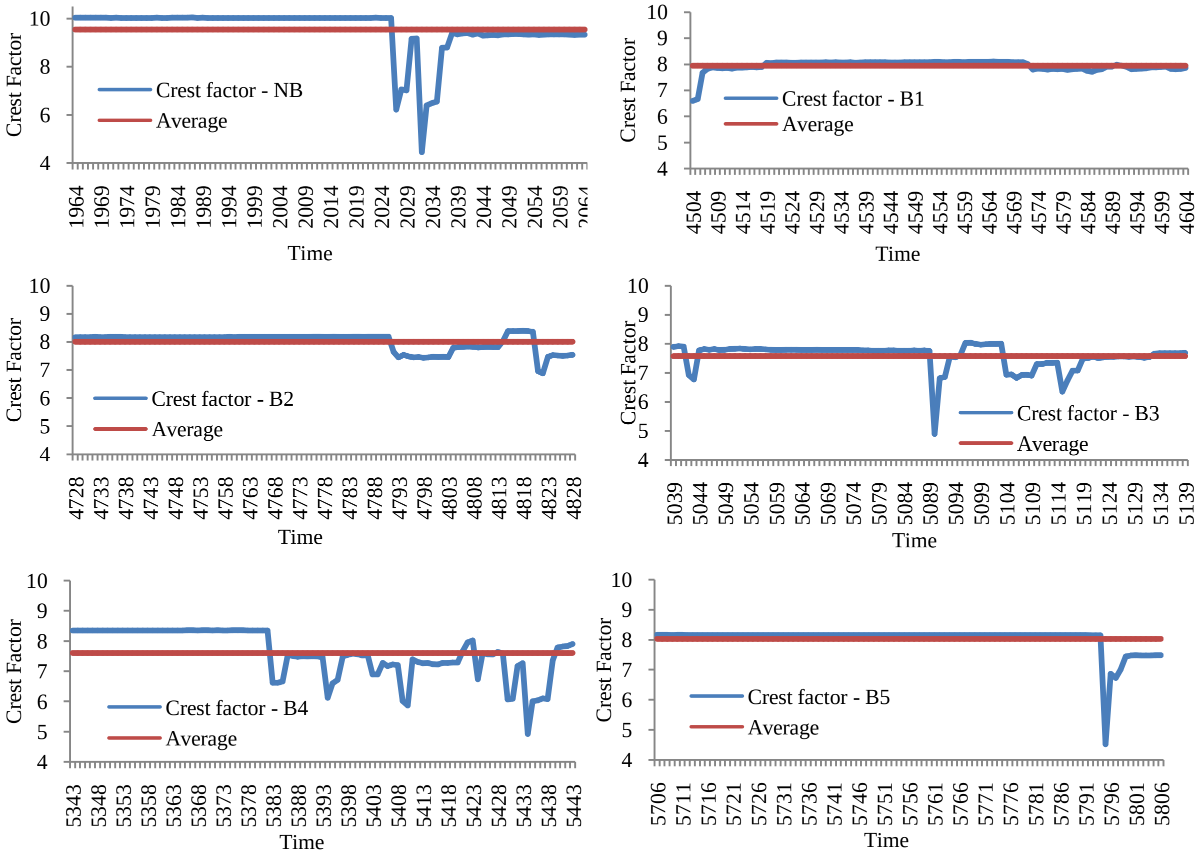


Figure 7. Recorded of Crest factor of vibration signals from crankshaft bearing with respect to time for each blend of diesel and oxy hydrogen gas

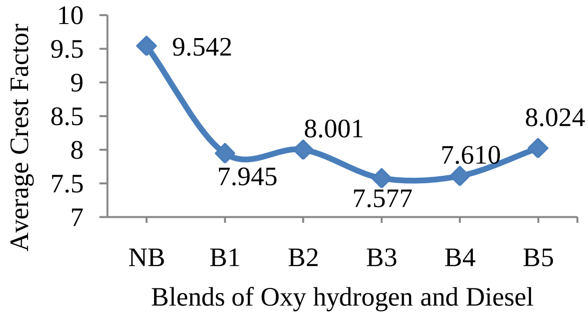


Figure 8. Variation of average of crest factor of acceleration signals from crankshaft bearing with respect to various blends of diesel and oxy-hydrogen gas

Overall a 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.

3.4 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].

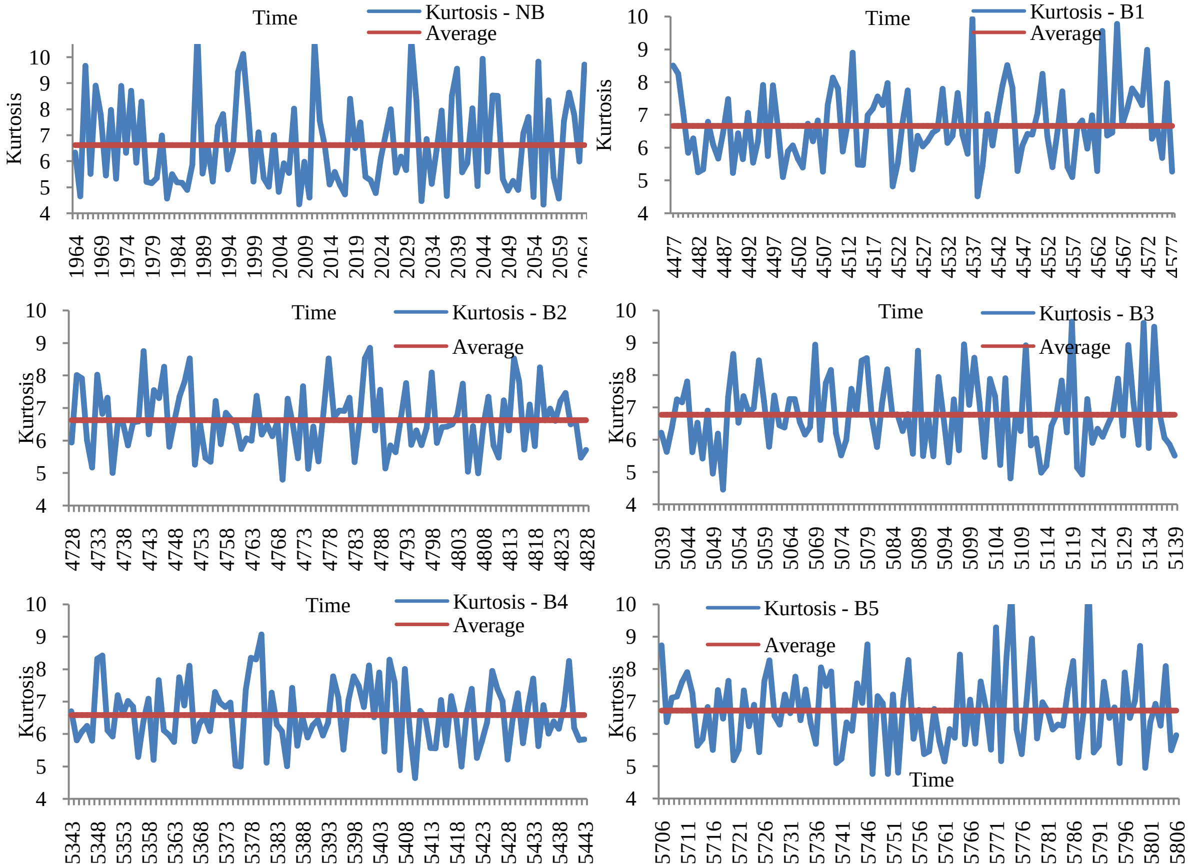


Figure 9. Recorded of kurtosis of vibration signals from crankshaft bearing with respect to time for each blend of diesel and oxy hydrogen gas

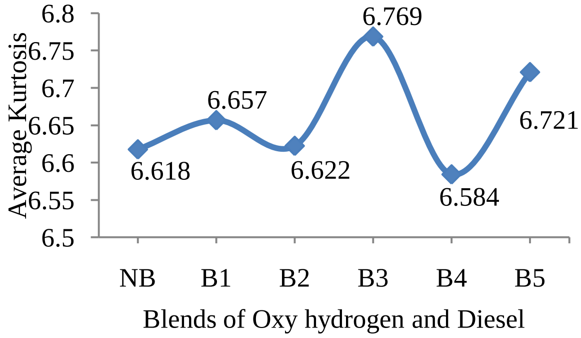


Figure 10. Variation of average of kurtosis of acceleration signals from crankshaft bearing with respect to various blends of diesel and oxy-hydrogen gas

Fig. 9 shows recorded kurtosis values of vibration signals from crankshaft bearing with respect to time for each blend of diesel and oxy-hydrogen. Fig. 10 shows variation of average of crest factor of acceleration signals from crankshaft bearing with respect to various blends of diesel and oxy-hydrogen gas. The calculated values of kurtosis of vibration signal from crankshaft bearing suggest that the distribution is more peaked than normal distribution and is leptokurtic in nature. Hence more values of the distribution are clustered close to the mean value however far higher than the mean. Oxy-hydrogen blending with diesel helps to increase the kurtosis value of acceleration signals. Kurtosis value increases progressively up to B3 blend and records a highest increment of 2.28% compared to non blended diesel. Further oxy-hydrogen addition in diesel reduces the kurtosis value slightly. Oxy-hydrogen addition in diesel helps to cluster the vibration signals close to mean with higher values to have a more peaked nature than normal distribution thereby increasing the leptokurtic nature of distribution. Thus oxy-hydrogen blends helps in increasing sharp fluctuations thereby increasing the probability of the generation of periodic impulses with large amplitudes in crankshaft bearing.

3.5 Effect of oxy-hydrogen addition on peak amplitude of vibration signal

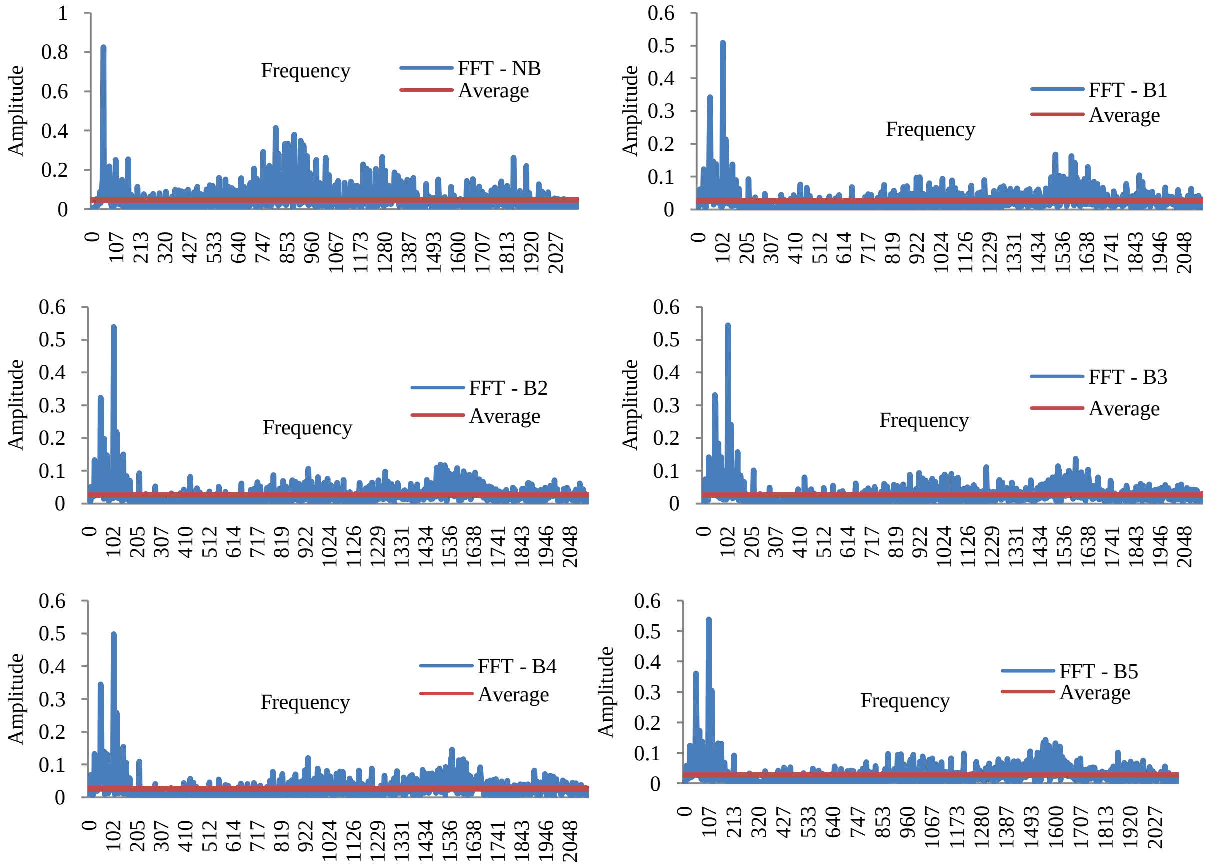


Figure 11. Recorded amplitudes of vibration signals from crankshaft bearing with respect to time for each blend of diesel and oxy-hydrogen gas

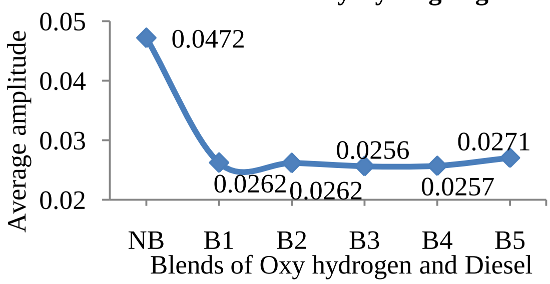


Figure 12. Variation of average peak amplitues of acceleration signals from crankshaft bearing with respect to various blends of diesel and oxy-hydrogen

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 behavior of the system will help to indicate abnormal working of the system. In case of internal combustion engine, the vibration of crankshaft bearing 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. Fig. 11 shows FFT of vibration signals from crankshaft bearing with respect to time for each blend of diesel and oxy-hydrogen. Fig. 12 shows variation of peak amplitude of vibration signals from crankshaft bearing with respect to various blends of diesel and oxy-hydrogen gas. Oxy-hydrogen addition shows significant 44.49% drop in average of peak amplitude of vibration signals with B1 and B4 flow rates. Slight increase in peak amplitude is recorded however remains much lower than non blended diesel.

IV. Conclusions

Following conclusions can be drawn from the analysis.

1. Oxy hydrogen blending increases skewness of vibration signals from crankshaft bearing almost by 6.63% with B2 blend, drops down with further blending however remains more than non blended condition

2. No significant changes are recorded with oxy hydrogen blending on RMS of vibration signals from crankshaft bearing.
3. Almost all blends shows significant effect on crest factor of vibration signals from crankshaft bearing B3 being highest with 20.59% drop.
4. Kurtosis of vibration signals from crankshaft bearing increases with oxy-hydrogen addition, effect is not so significant though.
5. Significant drop in peak amplitude of vibration signals is recorded with oxy-hydrogen addition highest being 44.49% with B1 and B4 flow rates.

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

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