Vibration Analysis of a Single-Cylinder Engine Fueled by Magnetized Biodiesel-Diesel Fuel Blend

Sadegh SAMADI
Mechanical Engineering of Biosystems, Ilam University, Ilam, Iran.
sadeghsamadi2014@gmail.com

Kobra HEIDARBEIGI *
Mechanical Engineering of Biosystems, Ilam University, Ilam, Iran.
k.heidarbeigi@ilam.ac.ir

* Author to whom correspondence should be addressed

Abstract: - The vibration of self-propelled machinery must be controlled as a drawback of them. The goal of the present research was to assess the vibration of four-stroke single-cylinder diesel engine of an agricultural tiller under the effect of magnetized biodiesel-diesel fuel blends. Biodiesel was consumed as a renewable fuel which is recycled from agricultural and food industry wastes or as the main product of oilseeds. Fuel magnetizing was applied as a new method to enhance the combustion process. A factorial experiment based on completely randomized design by conducting 12 treatments at three replications was doen on the engine. Two main factors were tested including biodiesel fuel (B0, B5, B10, and B20) and magnetic field (M0, M5300, and M7000). Engine vibration was measured at Z direction using VB 8203 accelerometer. The statistical analysis indicated that the main factors and their interactions had significant effects on vibration of the engine at 1% probability level. The root mean square of vibration was decreased by applying the magnetic fields. The data analysis in the frequency domain approved that the highest amount of vibration was observed in the tests without using magnetic field and the lowest root mean square was obtained for all blends with 5300 G magnetism intensity.

Keywords: - Diesel engine, Vibration, Root mean square, Biodiesel, Fuel magnetizing.

1. INTRODUCTION

The fuels' impact on the engines is one of the occupational and environmental concerns. One of the unwanted effects of machinery on the operators is vibration. So, the vibration characteristics of machineries are analyzed to reduce that [1]. Determining the root mean squire of the vibration acceleration is vital in vibration analysis [2-3]. Some attempts are done to reduce the vibration. Fuel magnetizing is one of the methods that have been recently considered to reduce emissions and fuel consumption of the internal combustion engines by applying an external magnetic field on the engines fuel line before the combustion chamber [4]. Magnetic fields affect non-polarized molecules of fuels to polarize them via changing the molecules' orientations. Also, the magnetic fields decrease the attraction forces between fuel hydrocarbon molecules and so allow establishing strong links between the fuel and oxygen molecules based on the Van der Waals law. This phenomenon causes to optimize combustion process in engines' combustion chambers and consequently reduces fuel consumption [5-6]. In this regard, Tao and Xu [7] applied magnetic fields on gasoline and diesel fuel and crude oil with different intensities and time durations. They observed that the viscosity of gasoline and diesel fuel was reduced by 10 and 4% respectively. They stated that the magnetic field changes the molecular surface properties and thus increases the internal energy of the fuels, separates the fuel molecules, and consequently increases the fuel reactivity with oxygen. This causes to improve the combustion process.

El Fatih and Saber [8] investigated the effects of magnetized fuel on a gasoline engine and reported that the applied magnetic field decreased the fuel consumption and CO, NO, and CH_4 emissions of the engine. Salih and Raheem [9] emphasized that magnetized gasoline causes a reduction in fuel consumption. Habbo et al. [10] used different magnetic intensities as 1000 and 2000 G to magnetize fuel and assessed their effects on an engine performance. They reported that the magnetized fuel improved the engine performance in point of engine power, thermal efficiency, and fuel consumption. Also, they stated that the effect of magnetic intensity of 2000 G was higher than that of 1000 G.

Patel et al. [11] in a research on magnetized diesel fuel, stated that it improves engine performance and decreases engine emissions. Kumar et al. [12] after conducting an investigation expressed that magnetized diesel fuel causes an increase in engine thermal efficiency and reduces engine emissions.

Biodiesel is a fuel that is produced from plant sources, the waste of agricultural products and food industries, or obtained as the main product of oilseeds [13-17]. Despite the energy demand in the industrial world, the problems related to environmental pollutions and greenhouse gases are expanding due to high consumption of fossil fuels. Therefore, renewable energies attracted more attention in recent years due to their lower negative impacts on the environment. Biodiesel is a clean renewable fuel that is well known as an alternative fuel or is consumed in combination with diesel fuel [18]. Biodiesel causes to increase exhaust oxygen fraction and reduce the equivalence ratio, water temperature, and oil temperature in diesel engines [19]. Besides its undesirable effects such as reducing engine brake power and increasing fuel consumption, it increases thermal efficiency [20]. Several studies have demonstrated that biodiesel has more positive effects on the engine such as reduction engine emission and vibration [21-23]. But, specialized literature highlights that there is still a need to further investigations on the performance, emission, vibrations, and sound characteristics of engines fueled by biodiesel blends. Samadi and Heidarbeigi [24] evaluated the sound emitted from a single-cylinder diesel engine using different percentages of the magnetized biodiesel-diesel fuel blends. They reported that the analysis approved significant differences between the effects of non-magnetized and magnetized fuel blends on the sound pressure level of the engine. Also, no research reported to examine the effect of magnetized biodiesel on engine vibration. So the present research aimed to examine the effects of magnetized biodiesel-diesel fuel blends by different magnetic intensities on the vibration of an agricultural tiller.

2. MATERIALS AND METHODS

An agricultural tiller with four-stroke single-cylinder MITSUBISHI engine, model ND75, was considered to be evaluated in the present research. Biodiesel fuel extracted from waste oils was brought from Mechanical Engineering of Biosystems Department, Tarbiat Modares University, Tehran, Iran. Different blends of biodiesel-diesel fuels were prepared with volumetric ratios of 0, 5, 10, and 20% biodiesel named B0, B5, B10, and B20, respectively.

Six neodymium magnet grips with 20×40×50 dimensions were brought to magnetize the biodiesel-diesel fuel blends. The two wooden boxes with inner diameters of 40×150 mm was used to avoid the fragility and adhesion of the magnets. The intensity of magnetic fields has a reverse relation with the distance of the magnets from each other. So, to provide the magnetic intensities of 5300 and 7000 G, two distances were considered as 10 and 5 cm, respectively.

An auxiliary fuel tank and fuel line were prepared and implemented on the studied tiller. Then the magnets were installed on the fuel line of the tiller, between the fuel tank and engine (Figure 1).

Figure 1. Implementing a magnet on the tiller fuel line.

The effective acceleration of vibration was determined based on IEC 1010, CE, and ISO 9001 standards. For measuring vibration of the tiller engine, a vibrometer device, model VB-8203, Lutron, Taiwan, with an accuracy of 0.1 $m.s^{-2}$ and the frequency range of 0.01-10 kHz was used. After calibration of the vibrometer, the vibration acceleration of the engine was measured at the Z direction. The time duration of each test was 2 min and each vibration signal was recorded in 2 s. The output signals of the vibrometer sensor were transferred to a personal computer by RS232 cable. To record the vibration signals, the device software, Lutron 801 model SW-U801-WIN, was used.

The most commonly used quantity for the analysis of vibrations is the root mean square (RMS) because the most important property of vibration is energy content [2-3]. The energy has a direct relationship with the amplitude so that an average based on the second power is a better idea to compare the vibrations. The RMS value for the engine vibration was calculated using Eq. 1.

$$\chi_{\mathrm{RMS}} = \sqrt{\frac{1}{N} \sum_{k=1}^{N} x^{2}(t_k)} \quad (1)$$

χ_{RMS}: The root mean square of vibration amplitude

$x(t_k)$: The vibration magnitude at the time t_k

N: The total number of vibration data [25].

Statistical analysis in the time domain was done as a factorial experiment based on the completely randomized design. A factorial experiment was conducting two factors: biodiesel at four levels and magnetic field intensity at three levels. So, twelve treatments were considered to be examined at three replications, so that totally 36 tests were done. The biodiesel levels were B0, B5, B10, and B20 and magnetic field intensity levels were 0, 5300, and 7000 G. The statistical analysis of the acquired data as well as drawing diagrams was done in SAS 9.1 and Excel 2013 Software.

FFT (Fast Fourier Transform) analysis was done to transform the data from time domain to frequency domain and then 1/3 octave band of the data was calculated. According to the definition, the 1/3 octave band is equal to the range of frequencies in which the ratio or distance of the frequency of the upper band (f_2) is $2^{1/3}$ of the frequency of the lower band (f_1). The frequency center (f_c) of the 1/3 octave band is also defined as the geometric mean of the high and low frequencies. So, for the 1/3 octave band:

$$f_c = \sqrt{f_1 \times f_2} \quad (2)$$

$$f_2/f_1 = 2^{1/3} \quad (3)$$

In the present study, the FFT was used based on $N=2^{17}$ [26]. To convert the acquired data from the time domain to the frequency domain by the FFT, the MATLAB R2010b Software was used to code a computer program based on Eq. 4-8.

$$X(j) = \left(\frac{1}{N}\right) \sum_{k=1}^{N} x(k)\, {\omega_N}^{-(j-1)(k-1)} \quad (4)$$

$$X(k) = \sum_{j=1}^{N} x(j)\, {\omega_N}^{(j-1)(k-1)} \quad (5)$$

$$\omega_N = e^{(-2\pi)/N} \quad (6)$$

The result of Eq. 4 is a complicated number that for n^{th} frequency in input signal can be:

$$X(n) = a_n + ib_n \quad (7)$$

That a_n is a real part and b_n is imaginary part of the complicated number. Xn can be obtained by Eq. 8:

$$X(n) = a_n + ib_n \quad (8)$$

The value of X(n) indicates the n^{th} frequency range in the frequency domain. The coded program then plotted these values versus the available frequencies.

3. RESULTS AND DISCUSSION

3.1. Time domain

The effects of different levels of fuel blends and magnetic field intensities on vibrations of the tiller engine in a factorial experiment based on the completely randomized design were analyzed. The results of the variance analysis have been presented in Table 1. The results relieved the significant effects of the main factors on the root mean squire (RMS) of the tiller engine vibrations at 1 % probability level. Also, the effect of interaction between biodiesel and magnetic field intensity factors on the RMS vibrations was significant at 1% probability level. According to the significant effects of the main factors and their interaction, the mean of the tested treatments was compared based on the Duncan's Multiple Range Test.

Table 1. The effects of the studied factors on the tiller vibration.

Source of variances	DOF	Sum of squares	Mean of squares	F value
Magnetic intensity	2	0.30	0.15	9.64*
Biodiesel	3	40.19	13.39	854.74*
Magnetic intensity ×Biodiesel	6	1.44	0.24	15.30*
Error	24	0.38	0.02	-
Total	35	42.31	-	-

*Significant at 1% probability level.

The results of the compare mean analysis of the RMS vibrations in the Z direction acquired from the tested treatments on the tiller engine have been presented in Table 2. The results approved the significant difference between all fuel blends without magnetic field (M0) and using a magnet with 7000 G (M7000) intensity at 1% probability level. Also, the analysis results in Table 2 showed the significant differences between the B0 and B5 fuel blends with the magnetic intensity of 5300 G (M5300).

Table 2. Compare mean results of the tested treatments on the tiller.

Magnetic intensity	Biodiesel			
	B0*	B5	B10	B20
M0	7.70^{b**}	5.88^{cd}	5.22^{f}	5.75^{d}
M5300	8.10^{a}	5.48^{e}	5.05^{fg}	5.02^{fg}
M7000	7.59^{b}	5.97^{c}	4.98^{g}	5.49^{e}

*B indicates biodiesel and M indicates magnetic field intensity.
**Non-similar letters show a significant difference at 1% probability level.

3.1.1 Effect of biodiesel on vibration

The RMS vibrations of the tiller engine corresponding to the different biodiesel levels have been shown in Figure 2. The results showed that the maximum amount of vibration was related to pure diesel fuel (B0) for all studied magnetic field intensities. By increasing the biodiesel percentage in the studied fuel blends to 10%, the vibration acceleration values decreased for all magnetic field intensities.

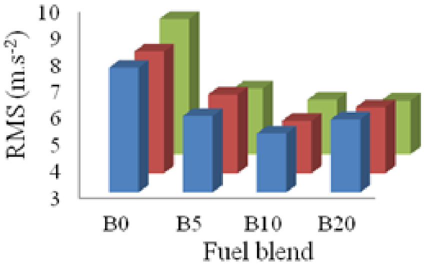

Figure 2. The mean values of vibration of tiller engine.

3.1.2 Effects of magnetism on vibration

As seen in Figure 2, the vibration values also decreased by increasing the magnetic intensity. The vibration reduction by increasing the magnetic field intensity is due to breaking the structure of the hydrocarbon clusters of the fuel blends, increasing penetration of oxygen into the inner part of the clusters, and hence increasing the numbers of molecular links with carbons [27]. Darvishi et al. [3] stated that the existence of the magnetic field increases the uniformity of combustion process and so decreases the engine vibration.

3.2 Frequency domain

The recorded data was transformed from the time domain to the frequency domain and the 1/3 octave band spectrum of vibration acceleration of the tiller engine was obtained.

Figures 3a-d show the effects of magnetic field intensity on the vibration of the tiller engine fueled by B0, B5, B10, and B20 fuel blends, respectively. As observed in Figure 3, the amount of vibration acceleration for all fuel blends and magnetic field intensity had an increasing trend at frequencies between 31.5 to 100 Hz. In this range, the vibration values corresponding to M5300 and M7000 magnetic field intensity were highest for all the studied fuel blends.

According to Figure 3, all blended fuels without using a magnet (M0) had the maximum value and magnetic field intensity of 5300 G had the minimum amount of vibration. In the figure, can be observed that the frequencies between 31.5 to 200 Hz had an increasing trend and the vibration reached the maximum values at the engine stimulation frequencies. At the higher frequencies, the vibration acceleration values are reduced by the greater slope due to the lack of engine acceleration components in those frequencies [28 - 30].

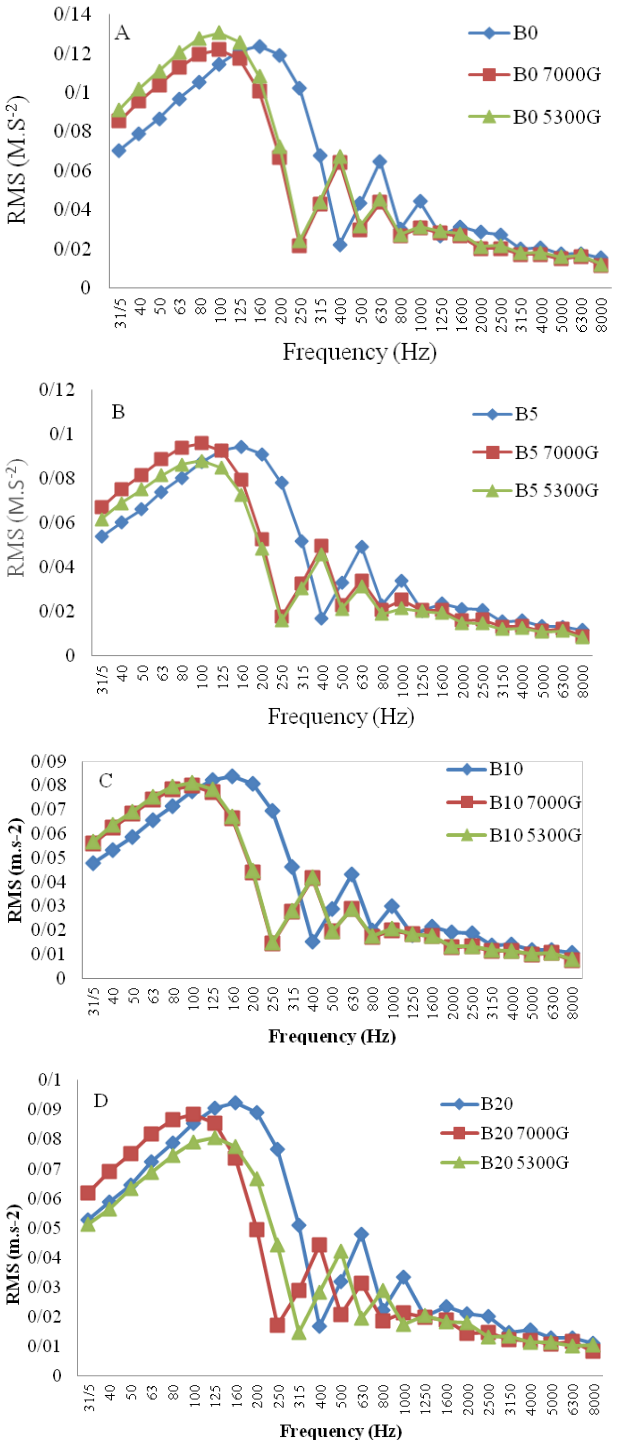

Figure 3. The 1/3 octave band frequency for A) B0, B) B5, C) B10, and D) B20.

4. CONCLUSIONS

The influences of magnetized biodiesel-diesel fuel blends on the engine vibration of an agricultural tiller at Z direction were studied. The effect of magnetic field intensity was significant at 1% probability level. There were observed significant differences between all studied fuel blends (B0, B5, B10, and B20) with all magnetic intensities (M0, M5300, and M7000) except for B10 and B20 with the magnetic intensity of 5300 G (M5300). By investigation on tiller vibration in the frequency domain and 1/3 octave band, there was specified that the highest amount of vibration belonged to the frequencies from 31.5 to 200 Hz and it decreased after 100 Hz. For all magnetic field intensity, the highest amount of vibration was related to pure diesel fuel and it decreased by increasing biodiesel percentage but the lowest amount of that has belonged to 10% biodiesel blended with 90% diesel fuel (B10). The lowest vibration value was obtained by B10 with the magnetic field intensity of 7000 G as 4.98 $m.s^{-2}$. The vibration value of B20 was higher than that of B10 due to the effect of biodiesel increasing on the decreasing thermal value of the blended fuel.

ACKNOWLEDGMENTS

The authors thank Mechanical Engineering of Biosystems Department, Ilam University, Ilam, Iran, for partial supports in the present study.

REFERENCES

[1] Jahanbakhshi, A., Ghamari, B., Heidarbeigi, K. (2020). Vibrations analysis of combine harvester seat in time and frequency domain. Journal of Mechanical Engineering and Sciences, 14(1), 6251-6258.

[2] Heidarbeigi, K., Ahmadi, H., Omid, M. (2010). Adaptive vibration condition monitoring techniques for local tooth damage in gearbox. Modern Applied Science, 4(7), 104-110.

[3] Heidarbeigi, K., Ahmadi, H., Omid, M., Tabatabaeefar, A. (2010). Evolving an artificial neural network classifier for condition monitoring of massy Ferguson tractor gearbox.

[4] International Journal of Applied Engineering Research, 5(12), 2097-2107.

[5] Darvishi S, Hasanbeygi R, Ghobadian B, Massah J. (2014). Magnetizing the Perkins A63544 Engine Fuel and Its Vibratory Assessment, J. of Engine Research, 38 (38), 17-26.

[6] Faris, A., Raed I., Mezher A., Zainab F., Akeel K., Hazim. (2012). Effects of Magnetic Field on Fuel Consumption and Exhaust Emissions in Two- Stroke Engine, Energy Procedia, 18, 327-338.

[7] Jain, S., Deshmukh, S. (2012). Experimental investigation of magnetic fuel conditioner (MFC) in IC engine. IOSR Journal of Engineering (IOSRJEN), 2(7), 27-31.

[8] Tao, R. Xu, X. (2006). Viscosity reductions by electric or magnetic fields. International Journal of Modern physics, 19, 7-9.

[9] Fatih, F. A., Saber G. M. (2010). Effect of fuel magnetism on engine performance and emissions. Australian Journal of Basic and Applied Sciences, 4(12), 6354-6358.

[10] Salih, A. M., Raheem, M. M. (2014). Effect of the magnetic field on the fuel consumption of a spark ignition engine. Engineering and Technology Journal, 32(11), 2760-2772.

[11] Habbo, A. R. A., Khalil, R. A., Hammoodi, H. S. (2011). Effect of magnetizing the fuel on the performance of an SI engine. AL Rafdain Engineering Journal, 19(6), 84-90.

[12] Patel, P. M., Rathod, G. P., Patel, T. M. (2014). Effect of magnetic field on performance and emission of single cylinder four stroke diesel engine. International organization of Scientific Research, 4(5), 28-34.

[13] Kumar, P. V., Patro, S. K., Pudi, V. (2014). Experimental study of a novel magnetic fuel ionization method in four stroke diesel engine. International Journal of Mechanical Engineering and Robotic Research, 3(1), 151-159.

[14] Ghobadian, B., Rahimi, H., Nikbakht, A.M., Najafi, G., Yusaf, T. (2009). Diesel engine performance and exhaust emission analysis using waste cooking biodiesel fuel with an artificial neural network. Renewable Energy, 34 (4), 976-982.

[15] Zoldy, M. 2011. Ethanol–biodiesel–diesel blends as a diesel extender option on compression ignition engines. Transport, 26, 303-309.

[16] Khoobbakht, G., Kheiralipour, K., Karimi, M. (2021). Optimization of Chlamydomonas alga biodiesel percentage for reducing exhaust emission of diesel engine. Process Safety and Environmental Protection, 152, 25-36.

[17] Khoobbakht, G., Kheiralipour, K., Yuan, W., Seifi, M. R., Karimi, M. (2020). Desirability function approach for optimization of enzymatic transesterification catalyzed by lipase immobilized on mesoporous magnetic nanoparticles. Renewable Energy, 158, 253-262.

[18] Khoobbakht, G., Kheiralipour, K., Rasouli, H., Rafiee, M., Hadipour, M., Karimi, M. (2020). Experimental exergy analysis of transesterification in biodiesel production, Energy 196, 117092.

[19] Abbaszaadeh, A., Ghobadian, B., & Omidkhah, M, R. (2012). Current biodiesel production technologies: A comparative review. Energy Conversion and Management, 63, 138-148.

[20] Khoobbakht, G.M. Karimi, M., Kheiralipour, K. (2019). Effects of biodiesel-ethanol-diesel blends on the performance indicators of a diesel engine: A study by response surface modeling. Applied Thermal Engineering. 148, 1385–1394.

[21] Torkian Boldaji, M., Ebrahimzadeh, R., Kheiralipour, K., Borghei, A.M. (2011). Effect of some BED blends on the equivalence ratio, exhaust oxygen fraction and water and oil temperature of a diesel engine. Biomass and Bioenergy, 35, 4099-4106.

[22] Chiatti, G., Chiavola, O., Palmieri, F. (2017). Vibration and acoustic characteristics of a city-car engine fueled with biodiesel blends. Applied energy, 185, 664-670.

[23] Siavash, N. K., Najafi, G., Hasanbeigi, R., Ghobadian, B. (2015). Acoustic analysis of a single cylinder diesel engine using biodiesel fuel blends, Energy Procedia, 75, 893-899.

[24] Rangasamy, M., Duraisamy, G., Govindan, N. (2020). A comprehensive parametric, energy and exergy analysis for oxygenated biofuels based dual-fuel combustion in an automotive light duty diesel engine. Fuel, 277: 118167.

[25] Samadi, S., Heidarbeigi, K. (2020). Acoustic analysis of a single-cylinder diesel engine using magnetized biodiesel-diesel fuel blends. Heliyon, 6 (9): e05113.

[26] Taghizadeh-Alisaraei, A., Ghobadian, B., Tavakoli-Hashjin, T., Mohtasebi, S. S. 2012. Vibration analysis of a diesel engine using biodiesel and petrodiesel fuel blends. Fuel, 102: 414-422.

[27] Cooley, J. W., Tukey, J.W. (1965). An algorithm for the machine calculation of complex Fourier series. Mathematics of Computation, 19 (90): 297–301.

[28] Hricak, R. Z. (1994). Air fuel magnetizer. U.S. Patent No. 5,331,807.

[29] Salokhe, V. M., Majumder, B., Islam, M. S. (1995). Vibration characteristics of a power tiller. Journal of Terramechanics, 32(4), 181-197.

[30] Faraji, H., Heidarbeigi, K., Samadi, S. 2021. Characterization of vibration and noise pollution of SI engine fueled with magnetized ethanol–gasoline blends by time–frequency methods. Noise & Vibration Worldwide 52(11): 356-364.