# INVESTIGATING A POWER TILLER VIBRATION TRANSMISSIBILITY USING DIESEL-BIODIESEL FUEL BLENDS ON STATIONARY CONDITIONS

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***ABSTRACT***

*The wide use of fossil fuel in internal combustion engine cause reduction in these fuel resources and also increase in greenhouse gasses and environmental pollution, for conquering these problems, so many researches have done for finding the renewable herbaceous fuel. Between these different kinds of fuel, biodiesel seems to be appropriate because of the nonexistence of air pollutions and the existence of similar trait with diesel fuel. In this research, vibration of 13hp power tiller in 5 levels of engine speed and 6 levels of consuming fuel blends for investigating the power tiller engine vibration behavior and the vibration transmissibility. Results showed that vibration transmissibility is decreased by increasing the engine speed. The maximum of the vibration transmissibility is happened in B20 and B5 and minimum of it is happened in B15 and D respectively. Also it is observed that the amount of vibration acceleration in longitudinal axis is much more than other two axes. The vibration acceleration value, in the frequency range of 8 to 100 Hz was higher than a dangerous frequency range of hand-arm vibration transmission and the total weighted acceleration has the maximum value at the frequency of 20, 31.5, 40 and 63 Hz with the vibration amplitude reach up to 20, 12.6, 18.6 and 40 m/s2 respectively. The best engine speed are 1400, 1600 and 2000 rpm, in this Engine speed using the B20 and B5 seems appropriate.*

***KEYWORDS****: Vibration, Power tiller, Fuel, Diesel and Biodiesel blends, Vibration Transmissibility*

## 1.0 INTRODUCTION

The wide use of fossil fuel in internal combustion engines causes reduction the available reserves of oil resources, increase in greenhouse gasses, ozone layer destruction, high environmental pollution, different outbreak disease and respiratory disease in big cities. For conquering these problems many research works have been carried out to find alternative energies which have being renewable, non-toxic, safe and reduce environmental pollutions. Biodiesel as an alternative liquefied biofuel has made significant progress and access to it is possible. The biodiesel could be produced by natural resources such as plant oils, animal fats, waste oils and algae (Carratto et.al., 2004; Ghobadian and Khatamifar, 2006). The specifications of biodiesel are similar to diesel fuel but it has not some disorder such as sulfurs, nitrogen and aromatic polycyclic. The biodiesel can be used pure or blend with diesel fuel in transportation systems, heating buildings and factories, and also in industrial processes without any change in fuel supply systems (Zenoozi., 2007; lee et.al., 2004). Biodiesel during combustion produces less pollution compared to fossil fuel (Dorado et.al., 2004).

Power tillers are agricultural machines which are fitted with small diesel engines. Economical features and user capabilities of power tillers in various conditions have caused these machines are used as a main source of power in small and medium size farms (Sam and Kathirvel, 2006; Hassan-Beygi et.al., 2005). Single cylinder diesel engine of power tiller has not a good balance. The forces acting on the piston during compression and power strokes transmitted to the crankshaft and engine block. Due to lack of using vibration dampers between engine and power tiller chassis the engine forces entering to the tractor chassis as shocks and then through the chassis transmitted to the power tiller handle. Power tiller handle also acts like cantilever beam so that one end is attached to the tractor chassis and free vibration of the other end is high (Salokhe et.al., 1995). Operators of the walking type power tillers are exposed to high levels of noise and vibration because these machines are guided entirely by operator hands. Long time working with these machines might be caused damage to various organs of the body including hearing loss, spine and gastrointestinal disorders and even neurological disorders. Furthermore it causes decrease in work efficiency and quality (Goglia et.al., 2006). In order to reduce the risks of working with these machines the regulations have been developed by international organizations to limit working hours and duration of vibration exposure.

Regarding to fossil fuel limitations application of renewable energies would be a necessity. Change in kind of fuel cause for changing in combustion process of internal combustion engines. Since the main portion of power tiller vibration is due to the diesel engine, so using the diesel-biodiesel fuel blends could be varied the vibration behavior of this type of tractors. Literature survey showed that some researchers were evaluated sound and vibration of power tillers by using conventional fossil fuel (Hassan-beygi and Ghobadian, 2005; Taghizadeh-Alisaraei, 2007; Sam and Kathrivel, 2006; Dewangan and Tewari, 2009; Sam and Kathrivel, 2009). However, the vibration behavior of power tiller fuelled by diesel-biodiesel fuel blends did not yet investigate .

In this study, the vibration of a power tiller was measured on stationary mode for various engine speeds and diesel-biodiesel fuel blends at the power tiller handle position and vibration transmissibility to operator hand was evaluated.

The data obtained from this research could be used for choosing appropriate diesel-biodiesel fuel blends in order to reduce vibration harmful effects on the operator.

## 2.0 MATERIALS AND METHODS

The power tiller used for this research study was fitted with a single cylinder, four-stroke, naturally aspirated, water-cooled, indirect injection diesel engine, providing 13-hp power at rated engine speed of 2200 rpm. The vibration of the power tiller was measured on stationary conditions on asphalt surface in open area. The instruments used in this study, consisted of three accelerometers, a tachometer, a lap-top computer and a few other devices. The detailed specifications of the instruments are given in Table 1.

TABLE 1
Specifications of the used instruments

| Name of instrument | Model | Accuracy/ Resolution | Range |
|---|---|---|---|
| Accelerometer | CTC-AC102 | ±3 dB | 0.4 to 14000 Hz |
| Tachometer | Lutron DT- 2268 | 1 rpm | 1-20000 rpm |
| Laptop computer | Sony VPC-F12-LGX | - | |
| A/D converter | Advantech 4711 | 12 bits | 150000 Hz- |
| Signals capture software | Lab View 2009 | - | - |

In this research the selected variables were engine speeds, diesel-biodiesel fuel blends and directions of vibration measurement. The range of variables considered to perform the test could cover the normal and safe operating range of the power tiller during operation. Table 2 shows the test matrix for this study. All of the experiments were replicated three times.

TABLE 2
Matrix of experimentations

| Parameters | Levels of parameters | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Engine Speed (rpm) | 1400 | 1600 | 1800 | 200 | 22000 | - |
| Diesel-biodiesel fuel blends | $B_0$ (0% biodiesel) | $B_5$ (5% biodiesel) | $B_{10}$ (10% biodiesel) | $B_{15}$ (15% biodiesel) | $B_{20}$ (20% biodiesel) | $B_{100}$ (100% biodiesel) |
| Position of sensors | - | Handle | Chest of operator | - | - | - |
| Orientations of measurement | Lateral | Longitude | Vertical | - | - | - |

Vibration occurs in lateral, longitudinal and vertical translational axes so in order to measure the vibration of the power tiller at positions in front of engine, handle grip and chest of operator, three accelerometers were screwed on a steel cube with dimensions of 2×2×2 $cm^3$ according to ISO 5349 standard directions (Fig. 1). The cube was installed on the power tiller handle by a strong metallic grip, also it glued on a wide leather belt, which was fastened on the user chest so tightly with a little pain and upset in user (Fig. 2). The required power for the accelerometers was supplied from a 24-volt power supply and an electronic circuit. Using an A/D converter which was recognized and controlled by LABVIEW software program, the accelerometer analog output voltage was converted to digital ones with 40000 Hz sampling rate and recorded on laptop computer hard disk for each accelerometer separately. The equipments that used for this research was shown in Fig. 3.

Human response to vibration is dependent on the frequency of vibration so for a detailed investigation of the vibration signals, the recorded time domain digital signals were converted to frequency domain narrow band signals by Fast Fourier Transform (FFT) algorithm using MATLAB software program. Due to sudden change and uncertainty of the narrow band signals as well as complication of comparing the independent parameters, as shown in Table 2, on the narrow band signals of vibration acceleration, the narrow band signals were converted to 1/3rd octave frequency band signals by using a subroutine computer program. Different parts of Fig. 5 shows a recorded vibration signal of the power tiller in time domain (part a) and corresponding narrow band frequency domain signal (part b) as well as $1/3^{rd}$ octave broadband frequency signal (part c).

Human perception of vibration is the most at low frequency and the perception greatly decreases with frequency, so the weighting factor for vibration varies with frequency. The $1/3^{rd}$ octave frequency band weights were defined on ISO 5349 standard. The $1/3^{rd}$ octave spectra of the power tiller vibration signals were weighted in accordance with ISO 5349 standard (Dewangan 2009, Goglia et.al. 2006, Griffin1996). The weighted acceleration value, ahw, was calculated as: (ISO 5349, 2001; Dewangan 2009, Goglia et.al., 2006)

$$a_{hw} = \sqrt{\sum_{j=1}^{n} (k_j a_{h,j})^2} \qquad (1)$$

Where: kj is the weighting factor for j-the frequency according to ISO 5349 standard factors, ah,j is the RMS value of measured vibration in $1/3^{rd}$ octave frequency band ($m/s^2$) and n is the number of frequencies used in one third octave band (from 6.3 to 1250). The power tiller vibration acceleration RMS (Root Mean Square) values calculated by Equation (2):

$$a_{RMS} = \left[ \frac{1}{T} \int_0^T a(t)^2 dt \right]^{1/2} \qquad (2)$$

Where: arms are the root mean square of vibration acceleration ($m/s^2$), a(t) is measured vibration acceleration amplitude ($m/s^2$), and T is the duration of measured vibration acceleration (s).

The evaluation of vibration transmissibility in accordance with ISO 5349 standard is based on three axes vibration combination named total weighted vibration acceleration, $a_{hv}$. The vibration total value, $a_{hv}$, was determined as: (ISO 5349, 2001; Dewangan, 2009; Goglia et.al., 2006)

$$a_{hv} = \sqrt{a_{hwx}{}^2 + a_{hwy}^2 + a_{hwz}{}^2} \quad (3)$$

Where: eve is the total rms value of vibration acceleration (m/s$^2$), ahwx is total weighted vibration acceleration in x axis (m/s$^2$), ahwy is total weighted vibration acceleration in y axis (m/s$^2$) and ahwz is total weighted vibration acceleration in z axis (m/s$^2$) (Mansfield, 2005).

Vibration transmissibility is defined as the ratio of the vibration measured on the hand–arm system to the input vibration on the handle of power tiller. It can be represented as (Dewangan, 2008):

$$\text{Vibration transmissibility} = \frac{a_{hv}\ hand\ or\ chest}{a_{hv}\ handle} = \frac{a_m}{a_{hv}} \quad (4)$$

Where: $a_m$ is the total weighted reams' the measured accelerationion at the hand or chest of the user.

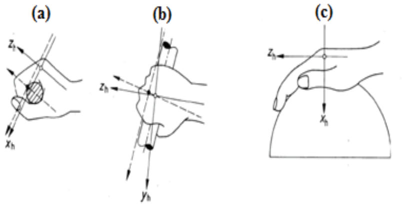


FIGURE 1
Orientation of the axes for the vibration measurement on the power tiller (ISO 5349, 2001)

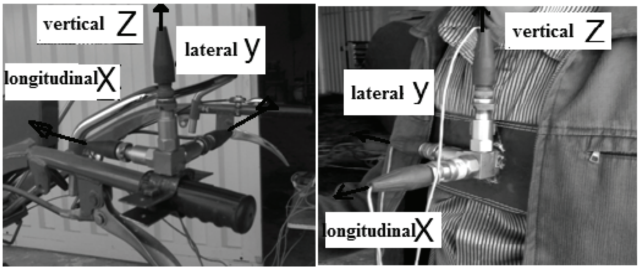


FIGURE 2
Monitoring of accelerometers and Orientation of measurement axes


FIGURE 3
Equipments used for the vibration measurement

The reason of investigating of vibration acceleration in stationary mode was its stability, this mode could be used for investigating and comparing with other modalities, furthermore it could be used as a basis of vibration assay.

The total weighted vibration acceleration (eve) was calculated and vibration transmissibility was calculated by 6 levels of fuel blends and 5 level of engine speed by relation 3 and in different frequencies in relation 4. The vibration transmissibility were analyzed statistically by using factorial tests with completely random design in SAS and EXCELL software, for obtaining the effect of speed and fuel blends.

## 3.0 RESULTS AND DISCUSSION

This paper presents the results of hand-transmitted vibration in a stationary condition for engine position and handle and chest of user in three axes of vertical, longitudinal and lateral axes and in 6 levels of engine speed and 6 levels of diesel and biodiesel fuel blends. These levels of parameter are independent variable, and the tests were carried out with 3 replications. Data was analyzed for vibration acceleration in rms (ah,j) at 1/3 octave band in the frequency range between 2.15 and 20000 Hz for each test fuel mixture and each axis.

For each axis the frequency-weighted rms acceleration (ahwx, ahwy and ahwz) was calculated using the filter suggested by (ISO 5349-2, 2001). An average of the three trials to test was calculated. Vibration total value (ahv) was calculated for each test fuel mixture. Vibration exposure during operation of the hand tractor was calculated for each test fuel blend as (ISO 5349-2, 2001). Finally an optimum percentage of biodiesel and diesel mixture was represented.

### 3.1 Weighted vibration acceleration (rms)

The total weighted vibration acceleration ($a_{hv}$) at the power tiller handle position is shown in Figure 4. It could be also observed from this figure that with increasing engine speed from 1400 to 2200 rpm, the weighted vibration acceleration was increased in the range of 7.44 m/s$^2$ to 21.52 m/s$^2$. The maximum of vibration acceleration was 21.52 m/s$^2$ belongs to B15 in 1800 rpm and 15.39 m/s$^2$ belongs to B20 in 1800 rpm and 15.23 m/s$^2$ belongs to B100 in 1800 rpm. The least of the vibration acceleration happened in B10, B15, B20 and B100 respectively.

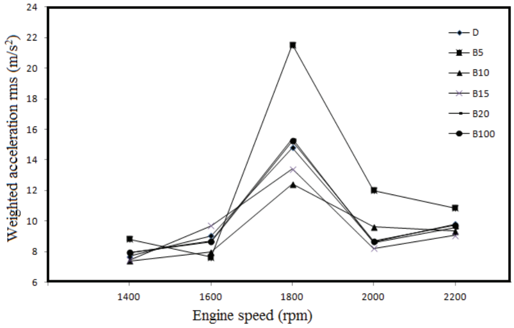


FIGURE 4

The total weighted vibration acceleration ($a_{hv}$).

As the Figure 5 shows, comparing the vibration acceleration values in three axes of vertical, lateral and longitudinal directions showed that the rms vibration acceleration in the vertical direction was the maximum and in longitudinal axis was minimum. In almost all the engine speeds the fuel blends B5 and D showed more vibration acceleration rms than B15, B20 and B100 and B10 respectively.

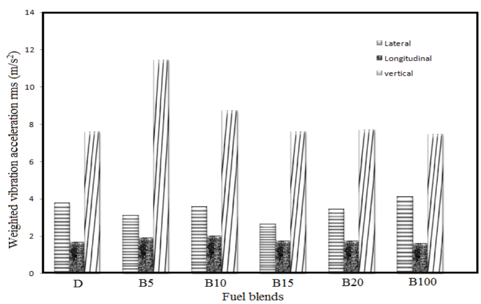


FIGURE 5

The weighted vibration acceleration in 2000 rpm engine speed for different fuel blends.

## 3.2 Vibration Transmissibility

In considering the effect of engine speed and fuel blends variants at vibration transmissibility (year), the variance analysis in SAS software is done and the results are shown in Table 3. The parameter of engine speed and fuel blends and the interaction of engine speed and fuel blends are prominent in 1% level as has been shown in Table 4. Comparing the mean squares is shown in Table 4 and Figure 6 and 7.

It is observed that the least of the vibration transmissibility from handle to the hand and body of user happened in b5, b10 and b20. The vibration transmissibility is decreased by increasing the engine speed, just one exception exists and that was 1800 rpm engine speed, the reason was intensification that happened at this speed and the handle has severe vibration but it had no effect on transmitted vibration. Also it is observed that vibration transmissibility is most in vertical and longitudinal axes.

TABLE 3
Intraction of fuel blends and engine speeds

| Sl. No. | Variant source | Freedom degree | Mean square |
|---|---|---|---|
| 1 | Replication | 2 | $0.00182529^{ns}$ |
| 2 | Engine speed | 4 | 0.00757560* |
| 3 | Fuel blend | 5 | 0.00322901* |
| 4 | Engine speed * fuel blend | 20 | 0.00020926* |
| 5 | error | 58 | $0.00013761^{ns}$ |

*means significant at 1% level

TABLE 4
Vibration Transmissibility on different fuel blend at various engine speed

| | Fuel blends | | | | | |
|---|---|---|---|---|---|---|
| speed(rpm) | B100 | B20 | B15 | B10 | B5 | D |
| 1400 | 0.062 | 0.043 | 0.073 | 0.052 | 0.047 | 0.053 |
| 1600 | 0.059 | 0.064 | 0.082 | 0.052 | 0.048 | 0.064 |
| 1800 | 0.112 | 0.099 | 0.131 | 0.079 | 0.07 | 0.116 |
| 2000 | 0.095 | 0.093 | 0.107 | 0.076 | 0.085 | 0.12 |
| 2200 | 0.085 | 0.072 | 0.104 | 0.056 | 0.052 | 0.084 |

Figure 6 and 7 show that the vibration transmissibility is decreased by increasing the engine speed, and it is decreased significantly in 1400, 1600, 2000 and 2200 respectively. Just in 1800 rpm engine speed the vibration transmissibility decrease severly and the reason was vibration intensification that happened in this speed and the handle has severe vibration but the hand of operator damp the vibration so no change in vibration were observed at the hand and chest of operator. The maximum of vibration transsmissibility happened in engine speed of 1400 rpm and the minimum happened in 1800 rpm. The maximum of vibration transmissibility in 1400 rpm engine speed happened in B20 and B5. The minimum of vibration transmissibility in 1800 rpm of engine speed happened in B15 and D respectively but the magnitude of vibration acceleration in this engine speed was high on engine and handle of powertiller. It shows that the body of operator damp this vibration and so using the engine speed of 1800 rpm may damage to operators health and put them in to high risk of inducing white finger and vascular disease. The best engine speed are 1400, 1600 and 2000 rpm, in this Engine speed using the B20 and B5 seems appropriate. Also it is observed that the amount of vibration acceleration in longitudinal axis is much more than other two axes and in there is no difference between vertical axis and lateral axis.

The results of this research were corresponded with the results of (Dewangan, et.al., 2008) research were corresponded the results of this research, he measured the acceleration at metacarpal, wrist, elbow and acromion, in transportation and rota-puddling. He showed the maximum transmissibility was observed during the rota-tilling operation with the mean values of 0.91, 0.47, 0.30 and 0.21 at the metacarpal, wrist, elbow and acromion, respectively. He also showed the resonance at the metacarpal was observed in the frequency range of 31.5–100 Hz High-frequency vibration (100–1250 Hz) was primarily localized to the hands. He showed with increasing in engine speed transmissibility increased and he also showed the maximum transmissibility was occurring in X-axis.

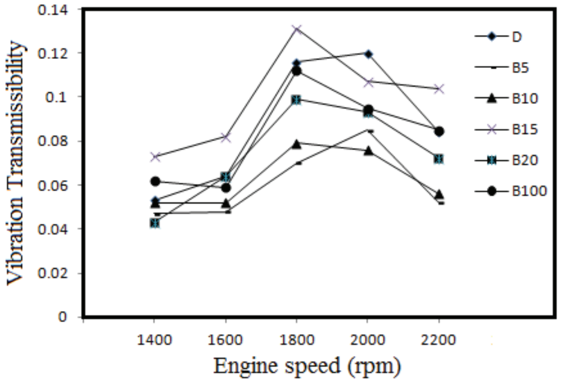


FIGURE 6
The engine speeds and fuel blends intraction

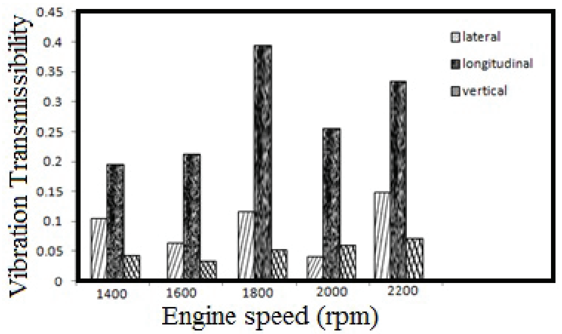


FIGURE 7
The engine speeds and fuel blends intraction

The envelope curve of total weighted acceleration (m/s$^2$) of the power tiller handle at different engine speeds was illustrated in Figure 8. According to this figure, the vibration acceleration value, in the frequency range of 8 to 100 Hz was higher than a dangerous frequency range of hand-arm vibration transmission according to Figure 1 the total weighted acceleration has the maximum value at the frequency of 20, 31.5, 40 and 63 Hz with the vibration amplitude reach up to 20, 12.6, 18.6 and 40 m/s$^2$ respectively (Figure 8). According to this figure, the vibration acceleration value, in the frequency range of 12.5 to 125 Hz was higher than exposure limit, 2 m/s$^2$, for hand-arm vibration exposure for 8-hour working per day. However, the mean value of total vibration acceleration in low frequencies, which is the most sensitive frequency of hand- arm system, has considerable values. At frequencies above 40 Hz for all of the fuel blends and engine speeds, the acceleration value is less than 1 m/s$^2$. The frequency less than 1 Hz is approximately negligible so the motion sickness doesn't appear in operators of 13 Hp power tiller. In this study it was found that hand-arm acts like a low pass filter and high frequency range of vibration energy, decreased by the fingers and wrist joints and the amplitude of vibration is reduced. This trend is also observed by Sam and Kathirvel (2006), while they were studding 13 Hp power tiller with an empty trailer on transportation.

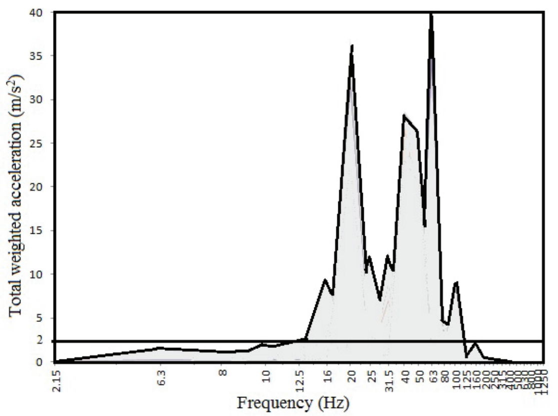


FIGURE 8
Frequency ranges and magnitudes of hand-transmitted vibration

## 5.0 CONCLUSIONS

The following major conclusions can be drawn from the present study:

1. Vibration transmissibility is decreased by increasing the engine speed.
2. It shows that the body of operator damps this vibration and so using the engine speed of 1800 rpm may damage to operator health and put them in a high risk of inducing white finger and vascular disease.
3. The amount of vibration acceleration in longitudinal axis is much more than other two axes.
4. The vibration acceleration value, in the frequency range of 8 to 100 Hz was higher than a dangerous frequency range of hand-arm vibration transmission.
5. The total weighted acceleration has the maximum value at the frequency of 20, 31.5, 40 and 63 Hz with the vibration amplitude reach up to 20, 12.6, 18.6 and 40 m/s$^2$ respectively.
6. The best engine speed are 1400, 1600 and 2000 rpm, in this Engine speed using the B20 and B5 seems appropriate.

## 6.0 REFERENCES

Agilent technologies, (2002). Understanding Dynamic Signal Analysis, Fundamental of Signal Analysis Series, *application note* 1405-2.

Sam, B., Kathirvel, K., (2009). Development and Evaluation of Vibration Isolators for Reducing Hand Transmitted Vibration of Walking and Riding Type Power Tillers, *Biosystems Engineering*, Vol.103, 427– 437.

Dewangan, K.N, Tewari, V.K., (2009). Characteristics of hand-transmitted vibration of a hand tractor used in three operational modes, *International Journal of Industrial Ergonomics*, Vol.39:239–245

Dewangan, K.N, Tewari, V.K., (2008). Characteristics of vibration transmission in the hand–arm system and subjective response during field operation of a hand tractor, *International Journal of biosystem engineering* Vol.100: 535 – 546.

Dorado, M.P., Ballesteros, E., Arnal, J.M., Lopez, F.J., (2003). Exhaust Emissions From a Diesel Engine Fueled with Transesterified Waste Olive Oil. *Journal of Fuel*, Vol.82: 1311-1315.

Grau, B., Bernat, E., Antoni, R., Jordi-Roger, R., Rita, P., (2009). Small-scale production of straight vegetable oil from rapeseed and its use as biofuel in the Spanish territory, *Energy Policy*.

Griffin, M.J., (1996). Hand Book of Human Vibration. Academic Press, London.

Griffin, M.J., Bovenzi, M., Nelson, C.M., 2003. Dose–response patterns for vibration-induced white finger. *Occupational and Environmental Medicine 60*,16–26.

Goglia,V., Gospodaric, Z., Filipovic, D., Djukic, I., (2006). Influence on operator'shealth of hand-transmitted vibrations from handles of a single-axle tractor. *Annals of Agricultural and Environmental Medicine 13*, 33–38.

Ghobadian, B., Hassan-Beygi, S., (2005). Acquisition and Processing Sound Pressure Signals of a Power tiller, *conference of cukurova university*, Adana, Turkey

Hassan-Beygi, S., Ghobadian, B., (2005).Noise Attenuation Characteristics of Different Road Surfaces during Power Tiller Transport, Agricultural Engineering International, *CIGR E-Journal*. Vol. VII. Manuscript PM 04009.

Hassan-Beygi, S., Ghobadian, B., Amiri, R., Kianmehr, M,H., (2009). *Prediction of Power Tiller Noise Levels Using a Back Propagation Algorithm*, Vol.11, P 147-160

Hassan-Beygi, S., Ghobadian, B., Kianmehr,M,H., Amiri,R., (2007). Prediction of a Power Tiller Sound Pressure Levels in Octave Frequency Bands Using Artificial Neural Networks, *International Journal Of Agriculture and Biology*, Vol.3, P 494–498

ISO 5349-1, (2001). Mechanical Vibration – Guidelines for the Measurement and Assessment of Human Exposure to Hand-transmitted Vibration. Part – 1:*General Requirements*. International Standard Organization, Geneva.

ISO 5349-2, (2001). Mechanical Vibration – Guidelines for the Measurement and Assessment of Human Exposure to Hand-transmitted Vibration. Part – 2: *Practical Guidance for Measurement at the Workplace*. International Standard Organization, Geneva.

ISO 8041, (1993). human response to vibration- measuring instrumentation standard. International Standard Organization, Geneva.

Mansfield, N.J., (2005). Human Response to vibration, CRC Press, P.244

Nurun Nabi, Md., Shamim-Akhter, Md., Shahadat, Z., Mhia, Md., (2006). Improvement of Engine Emissions with Conventional Diesel Feul and Diesel-Biodiesel Blends. *Journal of Biosource Technology*, Vol.97,P 372-378.

Sarmidi A., (2005). Review on biofuel oil and gas production processes from microalgae, *Energy Conversion and Management*, Vol.50, P 1834–1840, 20

Taghizadeh, A, Hashjin, T. T, Ghobadian, B, Nikbakht, A. M(2007). Evaluation of vibration in Power Tiller on the asphalt surface, *Proceedings of the International Agricultural Engineering Conference, Bangkok*, Thailand, 3-6 December 2007. Cutting edge technologies and innovations on sustainable resources for world food sufficiency

A. Taghizadeh, T. Tavakoli Hashjin, B. Ghobadian, A. M. Nikbakht, Evaluation of vibration in Power Tiller of the asphalt surface, *Proceedings of the International Agricultural Engineering Cutting edge technologies and innovations on sustainable resources for world food sufficiency Conference*, Bangkok, Thailand, 3-6 December 2007.

B. Sam, K. Kathirvel, Development and evaluation of vibration Isolators for reducing hand transmitted vibration of walking and riding type power tillers, *biosystem journal*, 103 427– 437, 2009.

B. Sam, K. Kathirvel, Vibration Characteristics of Walking and Riding Type Power Tillers, *Biosystem Engineering, 95*:517–528, 2006.

B. Ghobadian, M. Khatamifar, Biodiesel Fuel Production Using Transesterification of Waste Vegetable Oils, *The Journal of Engine Research*, P.8-9, 2006.

C. Carraretto, A. Mac, A. Mirandola, A. Stoppato, S. Tonon, Biodiesel as alternative fuel: Experimental analysis and energetic evaluations, Elsevier Science, Vol.29, P.2195-2211, 2004.

C.R. Mehta, P.S. Tiwari, A.C. Varshney, Ride Vibrations on a 7.5kW Rotary Power Tiller, Agricultural Engineering, Vol.66, P.169-176, 1997.

K.N. Dewangan, V.K. Tewari, Characteristics of hand transmitted vibration of a hand tractor used in three operational modes. *International journal of industrial ergonomics,* 39: 239-245. 2009.

K. N. Dewangan, V. K. Tewari, Characteristics of vibration transmission in the hand–arm system and subjective response during field operation of a hand tractor, *International Journal of biosystem engineering*, 100, 535 – 546, 2008.

M. P. Dorado, E. Ballesteros, J. M. Arnal, F. J. Lopez, Exhaust Emissions From a Diesel Engine Fuelled with Transesterified Waste Olive Oil. *Journal of Fuel, 82*, 1311-1315, 2004.

M. J. Griffin, Hand Book of Human Vibration. Academic Press, London, 1996.

V. Goglia, Z. Gospodaric, D. Filipovic, I. Djukic, Influence on operator'shealth of hand-transmitted vibrations from the handles of a single-axle tractor. *Annals of Agricultural and Environmental Medicine* 13 33–38, 2006.

S. Hassan-Beygi, B. Ghobadian, Noise Attenuation Characteristics of Different Road Surfaces During Power Tiller Transport, *Agricultural Engineering International, CIGR E-Journal.* Vol. VII. Manuscript PM 04009, 2005.

S. Hassan-Beygi, B. Ghobadian, R. Amiri, M. H. Kianmehr, *Prediction of Power Tiller Noise Levels Using a Back Propagation Algorithm,* 11 147-160, 2009.

S. Hassan-Beygi, B. Ghobadian, M. H. Kianmehr, R. Amiri, Prediction of a Power Tiller Sound Pressure Levels in Octave Frequency Bands Using Artificial Neural Networks, *International Journal Of Agriculture and Biology, 3* 494–498, 2007.

ISO 5349-2, Mechanical Vibration – Guidelines for the Measurement and Assessment of Human Exposure to Hand-transmitted Vibration. Part – 2: Practical Guidance for Measurement in the Workplace. International Standard Organization, Geneva, 2001.

J. A. Raff, R. D. H. Perry, Review of Vehicle Noise Studies Carried Out at The Institude Of Sound and Vibration Research With a Reference To Some Recent Research On Petrol Engine Noise, *Journal of Sound and Vibration, 28* (3) 433–470, 1973.

N. J. Mansfield, Human Response to vibration, CRC Press, 244, 2005.

O.O. Okunribido, M. Magnusson, M.H. Pope, Low Back Pain in Drivers: The Relative Role of Whole-Body Vibration, Posture and Manual Materials Handling, *Journal of Sound and Vibration*, *298* 540–555, 2006.

P.S. Tiwari, L.P. Gite, Physiological Responses During Operation of a Rotary Tiller, *Biosystems Engineering*, Vol.82 (2), P.161–168, 2002.

S. W. Lee, T. Her age, B. Young, Emission Reduction Potential From The Combustion of Soy Methyl Ester Fuel Blended with Petroleum Distillate Fuel, *Canment Energy Technology Control,* Vol.83, P.1607-1613, 2004.

V.K. Tewari, K.N. Dewangan, K.Subrata, Operator's Fatigue in Field Operation of Hand Tractors, *Biosystem Engineering, 89:*1-11, 2004.

V.M. Salokhe, B. Majumder, M.S. Islam, Vibration characteristics of a Power tiller. *Journal of Terramechanics, 32*:181-196, 1995.