Shahid Bahonar University of Kerman

Biomechanism and Bioenergy Research

Online ISSN: 2821-1855
Homepage: https://bbr.uk.ac.ir

Iranian Society of Agricultural Machinery Engineering and Mechanization

Measurement and Analysis of Body Vibrations of Goldoni Tractor Operator in Time and Frequency Domain

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ARTICLE INFO

Article type:

Research Article

Article history:

Received 27 May 2026

Received in revised form 22 June 2026

Accepted 11 August 2026

Available Online 30 September 2026

Keywords:

Acceleration, Convenience, Exposure time, 1/3 octave band

ABSTRACT

The agricultural machinery vibration to the driver's body causes discomfort, injury and pain and reduces work efficiency. Goldoni Tractors is widely used as a power source in small and medium farms for agricultural and horticultural operations. The transmitted vibration signals of a Goldoni Tractor to the different body parts of the driver, ankle, wrist, seat, chest and head, were investigated and recorded based on ISO 5349 and ISO 2631 standards in three directions: vertical, longitudinal, and lateral. The effects of gear ratio (1, 3 and 6), engine rotational speed (1500 and 2500 rpm), load mode (loaded and unload) and road condition (asphalt and farm) were examined on the vibrations. The signals were converted to the frequency domain using the FFT Algorithm and 1/3 octave band of vibration spectrum was obtained. The peak of vibration accelerations were observed at 20.7 and 41.5 Hz frequencies which are related to the engine rotational speed and maximum piston acceleration. Comparison of the vibration acceleration in different body parts showed that the ankles and wrists had the highest and head and chest had the least amounts. Studying the comfort limits revealed that the vibration between 10 to 80 Hz had a range of 0.33 to 0.43 m.s-2, which was in the alittle uncomfortable range. It was also found that the vibration acceleration values in the vertical direction exceeded the allowable working time. The acceleration of the vibration in the longitudinal and lateral directions had not exceeded the allowable working time.

Cite this article: **Maleki, M., & Heidarbeigi, K. (2026).** Measurement and Analysis of Body Vibrations of Goldoni Tractor Operator in Time and Frequency Domain. *Biomechanism and Bioenergy Research*, *5*(3), 1-17. https://doi.org/10.22103/bbr.2026.27297.1155

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DOI: https://doi.org/10.22103/bbr.2026.27297.1155

INTRODUCTION

The human health is one of the most important issues during working with machines in industry and agriculture which is raised in the field of ergonomics. Vibration and sound are the two undesired factors in industrial environments (Samadi & Heidarbeigi, 2020). Many workers and peoples are exposed to the intensities of machine vibrations and the energy of vibration waves is direct contact with body that may be received in hazardous limits (Cutini et al., 2012). The transfer of mechanical energy from a vibrating source to the worker's body can disrupt the comfort or well-being of the person, reduce work efficiency, disrupt the physiological functions of the worker, reduce the health of exposed people and in some cases cause skeletal injuries and some diseases (Jahanbakhshi et al., 2020). In agricultural machinery, this issue is more complicated (Goswami et al., 2025; Taghizadeh-Alisaraei, 2017). Drivers of agricultural machines are constantly exposed to whole body vibration which may lead to disorders of musculoskeletal, neurological, circulatory and occupational diseases caused by vibration (Barač et al., 2026). Reducing the time of agricultural activities and increasing production capacities emphasise more using and higher efficiency of agricultural machinery on the farm. Tractors are the most important sources of mechanical power in agriculture (Scarlett et al., 2007). However, the entry of agricultural machinery into farms and gardens creates many problems for users in terms of occupational safety and health (Goglia et al., 2006; Singh & Kaul, 1972). The researches show that the drivers of agricultural machines exposed to vibration have more back pain than other agricultural workers. But it is not yet clear how the injuries were inflicted on their bodies. Numerous studies have suggested that spinal movements due to the destructive effects of body vibration are the cause of these injuries, but so far no exact reason has been given for that (Dewangan & Tewari, 2009a, 2009b). The tractors that have not suspension systems have higher vibration intensity than those that have a suspension system. This problem becomes more critical when the frequency of its vibrations is between 1 to 8 Hz (Futatsuka et al., 1998; Pope & Hansson, 1992). In addition, excessive vibration affects driving comfort and control, operating speed, and field capacity. High vibration also increases wear on seats and various mechanical parts (Surendrakumar et al., 2025). Goldoni Tractor is one of the agricultural tractors that vastly are used in farms. It is small and medium-sized articulated tractor that has hydraulic steering system. These features enable the tractor to move and work with tools around and under trees. Usually, it has a short chassis and four-wheel drive system (Mohammadi et al., 2023). These tractors have diesel engine with a power in the range of 15-40 hp and have 2-3 cylinders (Emami et al., 2018; Negrete, 2020). According to the previous studies, there is no reported research on the vibrations exerted to the driver’s body of Goldoni Tractor. Hence, the purpose of the present study was to measure the vibrations which are transmitted to the operator body of the Goldoni Tractor in time and frequency domain and compare the measured data with global standards. Then this study was undertaken to analyse the data to assess the health and comfort level and calculate the user's exposure time to to develop a suitable program to reduce transmited vibration while using the tractor. The novelty of this study is that this type of tractor could be representative of the category of small iso-diametric articulated tractor, not suspended that is poorly studied. Effectively there are some interesting considerations in results that can be considered valid only for this tractor and not for big open field tractor.

MATERIALS AND METHODS

Experimental set-up and data acquisition

A Goldoni Tractor (Model 230, Italy) was evaluated in the present study (Figure. 1 (a)). The mentioned tractor has 1055 mm support length, 2-cylinder diesel engine (30 hp) and 6-

speed gearbox (3 light gears and 3 heavy gears) and is of articulated type.

A three-axis accelerometer (ADXL345) was used to measure the vibration of the studied Goldoni Tractor. The maximum detection rate of the accelerometer is 16g (m.s^{-2}) (g: gravitational acceleration). The required voltage of this sensor is 2-3.6 V. This sensor has a digital output and the UNO-R3 electronic circuit (Arduino Co., Italy) was used to transmit the outputs data to a computer. If the period of the input signal is greater than the length of the sample interval, the FFT cannot detect that frequency; therefore, the lowest nonzero frequency line corresponds to the reciprocal of the sample interval, and there is also a frequency line at zero. Now we can determine the maximum frequency measurable by the FFT. According to the Nyquist criterion, sampling must provide at least two samples per period for frequencies up to the Nyquist frequency. Based on this reason, in the present study, a sampling rate was adjusted to be 1000 Hz and sampling time of 10 s was considered. The UNO-R3 electronic circuit is connected to the computer via a USB cable which supplied the required voltage of the circuit and the accelerometer sensor (Figure. 1 (b)). The accelerometer sensor data was received through Arduino Software and analyzed using MATLAB software and the initial vibration diagrams were drawn.

a **b**

Figure 1. (a) The studyied Goldoni Tractor, (b) The used accelerometer to measure the vibration signals.

The engine rotational speed of the Goldoni Tractor was determined by measuring crankshaft rotational speed. A Lutron (DT-2234BL, Taiwan) laser tachometer was used to measure the engine rotational speed.

The methods for measuring and controlling vibrations on the user's body can be an important issue that should be given more attention (Zamanian et al., 2014). To measure the vibration transported to the operators, it should be seen that the user is in contact with the tractor through the seat and steering so that the vibration is transmitted to the user through these two positions. According to the international standards, the measurement of vibration on the body should be done at three main points of body contact with the seat: seat floor, seat support and foot position. Vibration at waist was measured at the point where it has the most contact with the seat.

As seat provides only a surface for sitting, the more vibration is transmitted to the driver via the seat floor, so in the present study, the vibration of the seat floor was measured using a sensor that was magnetically connected to a rigid metal disk. The sensor must not be placed under pressure, as it could be damaged if the driver sits on it. Therefore, to prevent damage and obtain accurate results, a hole larger than the accelerometer was made in the seat floor. A rigid metal disk was fabricated with an area equal to that of the seat and a constant thickness so it would not deform when the driver sat on it. The disk was glued to the seat with strong adhesive, and then tests were carried out to acquire seat vibration signals. Also, because driver weight affects the results of vibration signals, the tractor was operated by a single driver weighing 80 kg.

To study the vibration transmitted to the user's body and the need for acceleration values of different organs of the user's body, the vibration signals were recorded at three directions and for seat back and four body parts (wrist, ankle, chest and head). The investigated influential factors were the two levels of engine rotational speed and three gear ratios of Goldoni tractor in two modes of transport (Table 1). The sum of the measurements considering three repetitions was equal to 3(gear ratio)× 2(engine rotational speed)×2(load)×2(road)×3(vibration direction)×5 (measured point)×3 (repetitions) =1080.

Table 1. Experimental conditions of tractor vibration measurement

Variable	Levels
Road/Operating condition	Asphalt road, Farm road
Load condition	With load, Without load
Engine rotational speed (rpm)	1500, 2500
Measurement location	Wrist, Ankle, Chest, Head, Seat
Vibration direction	Vertical, Longitudinal, Lateral
Gear ratio	1, 3, 6

Because the accelerometer is a three-axial type and the three directions are perpendicular to each other, medical adhesive tape was used to attach the accelerometer to the body at different positions. To avoid connecting the accelerometer circuit to the body and causing disturbances, a tape was first placed at the desired point, and then the accelerometer was attached to that point. For the chest position, in addition to the above-mentioned adhesive, a thin, wide rubber band was used. The required considerations regarding the measurement of human vibration, measuring devices and principles, and test accuracy conditions were performed in accordance with ISO-8041-E. The vibrations were measured on the operator's head, chest, wrist, and ankle (Figure 2).

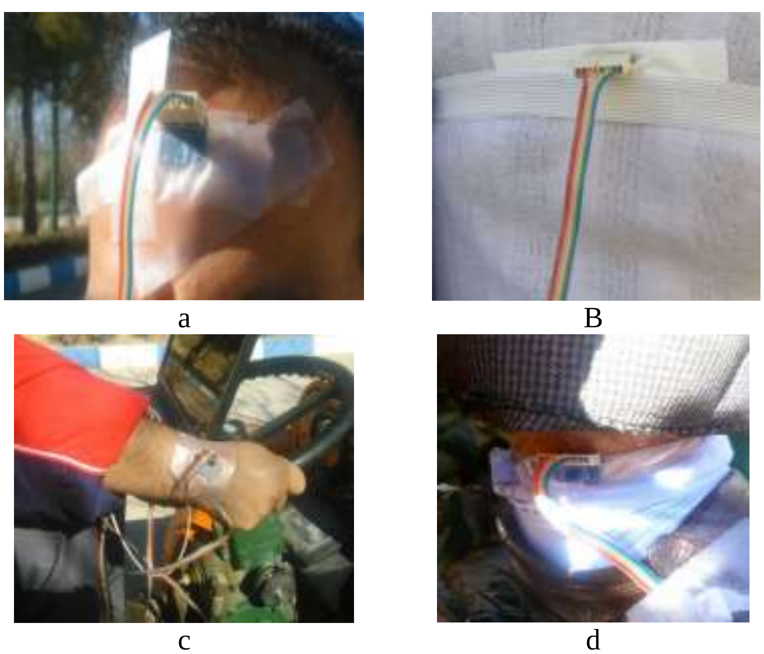


Figure 2. Connection of the accelerometer sensor to the body parts, a) head, b) chest, c) wrist, and d) ankle.

Data Analysis

After measuring and storing the vibration acceleration signals of the Goldoni tractor in different treatments, the signals were analyzed. The performed analyzes in the present study can be divided into three main categories, which were: data analysis in the time domain, data analysis in the frequency domain, and statistical analysis of data. The output signals of the accelerometer (time domain) were stored in a computer by Arduino Software and then transferred to MATLAB Software for processing and analysis of the data by Fast Fourier Transform. The root mean square values of the acceleration were calculated and the signals were converted to the frequency domain (narrow band) and 1/3 octave spectrum band was obtained.

Time domain analysis shows the general trend of the data changes due to variables (Jahanbakhshi et al., 2017). It is very difficult to identify and study the effect of each variable on the vibration generated by the device in the time domain. So, it is necessary to convert the signals from the time domain to the frequency domain. To convert these data into frequency domain, Fast Fourier Transform analysis was done in MATLAB Software.

The result of converting signals from the time domain to the frequency domain is to achieve a narrowband of vibration acceleration. In general, it is relatively difficult to observe changes in the narrowband spectrum, and since the changes made by the variables are much more pronounced in broadband analysis, the narrowband vibration acceleration spectra were processed to obtain a 1/3 octave vibration acceleration signal. Calculating the 1/3 octave spectrum and analyzing the signal of hand and arm vibration (HTV) and whole body vibration (WBV) are available in global standards. To calculate the 1/3 octave band, the values of narrowband data in certain frequency ranges are logarithmically summed and therefore big peaks and deep valleys and sudden and large fluctuations in narrowband signals are eliminated.

To assess the level of health and comfort of drivers, the values of accelerations obtained in their frequency domain should be multiplied by specific values that are different in each direction and in each band, so that they can be used to assess different levels of human health and comfort. The weight coefficients are based on the frequency and amount of vibration transmitted in the global standards, based on them the different weighted accelerations were calculated. As the fatigue decreases the working time range, in order to have high working efficiency, the exposure time is different based on the magnititute, direction and frequency of the vibration. The amount of allowed vibration in the vertical, longitudinal and lateral directions for periods of 1 min to 24 h per day is determined from the graphs in the international standards. Increasing the exposure time increases the potential for damage to body tissues, and successive periods of vibration-free rest can reduce the risk of injury; therefore, based on the amount of energy consumed, the allowable expopser time can be calculated according to the acceleration exerted on the user's body. In the present study, the effect of vibration on the driver in various conditions is described based on ISO 2631. In order to evaluate the vibration on the driver based on the global standards, different methods have been stated, three of which will be considered in this study:

1- Initial evaluation

2- Assessing the driver's comfort and convenience

3- Assessing the driver's health range

For the initial evaluation, the root mean squared of weighted accelerations is used that is expressed for linear accelerations in m.s^{-2} and for angular accelerations in rad.s^{-2} (Eq. 2). Numerical values of weighting coefficients in different frequencies are also available in the world standard tables.

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

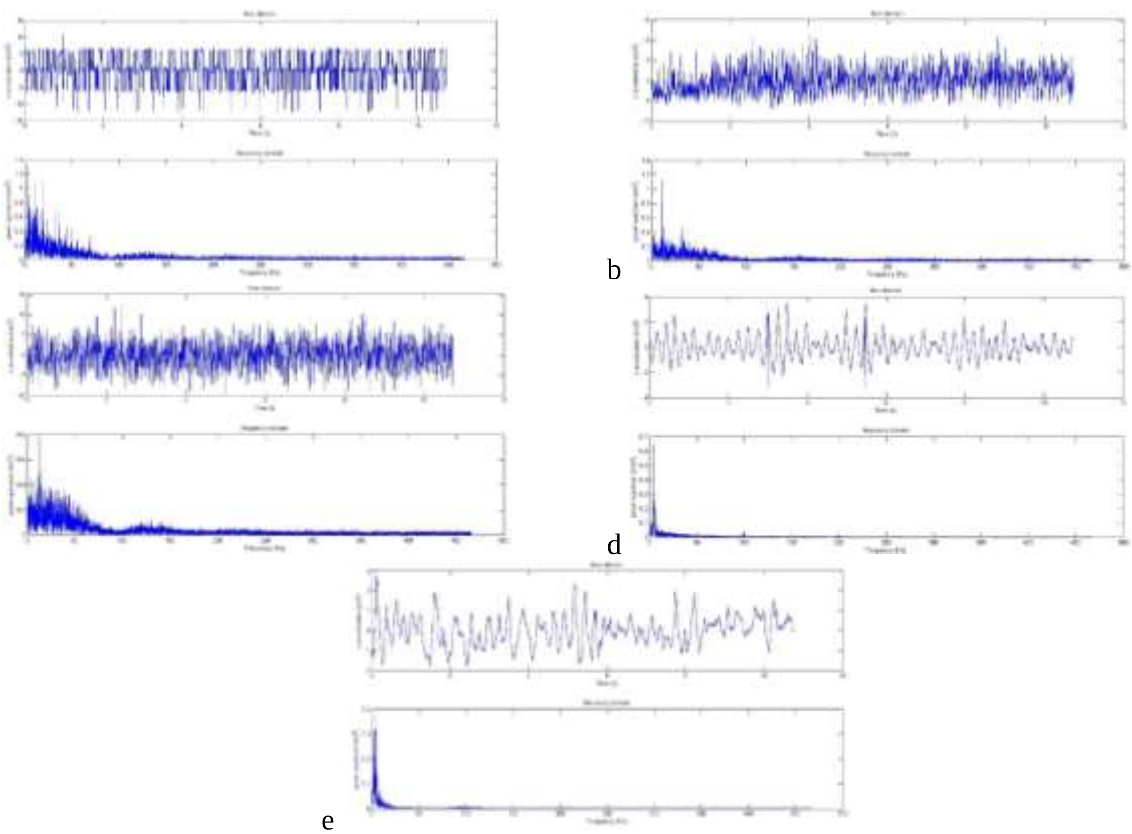
Where a_{RMS} is the root mean squared of the weighted accelerations ($m.s^{-2}$), a(t) is measured acceleration in units of time, and T is time duration of the measured acceleration period (s). To evaluate the driver's comfort and convenience after obtaining the accelerations in all directions, these values are multiplied by the constant coefficients stated in the global vibration standards and the final acceleration is calculated separately. Existing in these standards will be evaluated. For example, these coefficients are the same at all directions for a person sitting in a chair and exposed only to linear accelerations, but if the same person is exposed to angular acceleration simultanesly, these coefficients depend on the type and direction of acceleration from 0.25 to 0.80. Reducing the comfort range according to global standards occurs at approximately one-third of the fatigue level, which depends on the duration and frequency of vibration. In global standards, the comfort range is often presented in the form of a Table 1. It shows the human response to the sum of the root surfaces of the weighted acceleration mean squared:

$$Sum = \sqrt{(1.4a_x)^2 + (1.4a_y)^2 + a_z^2} \qquad (2)$$

Where a_z, a_y, a_x are root mean squared of wheighted acceleration at in three directions of the coordinate axis.

RESULTS AND DISCUSSION

The time domain signals of all measurements were transferred to FFT signals. Figure. 3 shows the vibration acceleration signals at the time domain (A_t) and the narrow band spectrum of the corresponding frequency range (A_f) of the Goldoni tractor user on the asphalt road with a loaded trailer at the engine speed of 2500 rpm and the average gear ratios for different parts of the driver.



a b c d e

Figure 3. The vibration acceleration signals at the time domain and narrow band spectrum of vibration acceleration level of a) ankle, b) wrist, c) seat, d) chest, and e) head position.

As can be seen in Figure. 3-a, not much information can be obtained from the time domain signal. This signal consists of the infinite harmonic functions in the form of $Ae^{\omega t}$ which ω is frequency and A is the amplitude of the harmonic functions. These quantities are obtained by converting the time domain signal to the frequency domain using the Fourier Transform. Each of these components is related to a part of the Goldoni tractor. The Goldoni tractor has a four-stroke two-cylinder diesel engine. The various components of engine of the Tractor are: engine body, cylinder, cylinder head, piston, connecting rod, crankshaft, cranwheel, valve system (valves, camshaft gear), fuel system (fuel tank, fuel pipes, fuel pump, throtle control system, fuel injection pump, and filters), and lubrication system (oil pump, oil pipes and oil filter). The shocks and inertial forces of each rotating and reciprocating component are transmitted to the engine body and then the chassis and finally the user body of the Goldoni Tractor.

Each cylinder of the engine with an engine speed of 2500 rpm has a piston stroke frequency equal to 41.5 Hz. This means that a maximum acceleration occurs in each crankshaft cycle and since in a 4-stroke engine there is one combustion in both crankshaft cycles, in a time domain signal with 2s duration the number of combustions will be a half of this amount, i.e. 20.7. For engine speed of 1500 rpm, the maximum value is observed at frequency of 25 Hz. Existing two cylinders in the Goldoni Tractor engine causes some balance in piston hits. In the tractor engine, there are four valves, two for the exit of smoke and the other two for the entry of air. Opening and closing the valves strikes the engine body which is applied to the engine once at each turn of the crnkshaft with a frequency of 1.60 times of the engine speed. The rotational speed of the camshaft is also half of the engine speed, so its corresponding frequency is equal to 1.120 times of engine speed. The injector pump also has a shock with a frequency of 1.120 times of engine speed. Fluid turbulence in the engine creates low frequencies that are visible at frequencies below than 10 Hz. A more accurate analysis of these frequencies and the sources of their generation require detailed calculations of the speed of the engine components and obtaining the normal frequencies of the system which is very complex.

As can be seen in Figure. 3-b, the amount of vibrations received by the hands occurs at frequencies commensurate with the engine speed, but occurred at the frequency peaks with slower acceleration than those of ankle. Given the position of the hand and the distance from the engine to the foot, this result is expected.

Figure. 3-c shows the tractor seat vibration. As can be seen in the figure, the amount of vibration coming into the seat, like the ankle, occurs at frequencies commensurate with the engine speed wherase occured at at peak frequencies with lower acceleration. This is due to higher distance of the seat to the engine compare with the foot position.

The amount of vibration in the chest and head in Figure. 3-d and 3-e were close to each other but lower than other parts of the operator body (hands, feet and seat) which are directly in contact with the tractor body. This is due to higher distance from the source of vibration and the anti-vibration property of the operator body. According to the figure, the frequency peaks occured in the range below than 10 Hz which is due to the movement of the tractor and vibrations coming from the ground.

According to Figure. 3, it can be understood that the amplitude of vibrations from the user's foot to the head is decreasing because of the distance from the vibration source and the damping property of the operator body. The different organs of the human body have different mass, stiffness, and damping values and cause to damp the amplitude of the vibration signal. As the vibration is transmitted to the body through the legs, arms and seats which are directly connected to the tractor body and considered as input ports, the signals recived to the far body parts loses some of its energy and enters to the next member with smaller amplitude.

According to the narrow band diagram of the vibration frequency domain (A_f) in Figure. 3, in general and regardless of the body position (target member), it can be seen that the organs of the human body further reduce the amount of vibration amplitude at higher frequencies and the amount of vibration transmission is a revers function of frequency and decreases with increasing frequency. Accordingly, the vibration acceleration range does not exceed to 0.1-0.2 $m.s^{-2}$ for the wrist, ankle, and seat, at the frequency higheir than 100 Hz and for the chest and head at the frequency higher than 20 Hz.

1/3 Octave Band

The results of the 1/3 octave spectrum of the vibration acceleration of the Goldoni Tractor at engine speed of 1500 and 2500 rpm, in the loaded and unloaded modes, on the asphalt and farm roads, in gear ratios of 1, 3 and 6 and for differen operator body parts, ankle, wrist, chest, and head in three directions, vertical, lateral and longitudinal have been calculated.

Effect of Vibration Direction

Figure. 4 shows the effect of direction of vibration on the 1/3 octave spectrum of vibration acceleration at engine speed of 2500 rpm, loaded trailer mode, on asphalt road and average gear ratios for the different operator body parts. According to the Figure 4-a, the amount of vibration acceleration received by ankle in the vertical direction (Z) is greater than the longitudinal direction (X) and lateral direction (Y) for all frequencies. The main reason can be considered as the direction of movement of the piston in the vertical direction and the force coming from the ground, which are the main source of vibration and are all in the vertical direction.

At higher frequencies, the amount of vibration acceleration decreases with a greater slope, which is due to the lack of acceleration components at higher frequencies and damping of various engine and chassis parts at these frequencies (Salokhe et al., 1995).

As shown in the Figure. 6-a, the vibration of 41.5 and 20.7 Hz, which are related to the engine speed and maximum piston acceleration, occurred at peak. According to Figure. 4-b, although at all frequencies the amount of vibration acceleration in Z, X, and Y directions is almost the same, it is slightly higher in the vertical direction. The reason is the position of the operator hand relative to the tractor.

As Figure. 4-c shows the 1/3 octav band status of seating position, the amount of vibration acceleration in the Z is greater than the X and Y for all frequencies. The main cause as in other situations is the movement of the piston in the vertical direction and the force coming from the ground. The peak acceleration appeared for 41.5 Hz which is related to the engine speed and maximum acceleration of the pistonsas.

Figure. 4-d and 4-e show the effect of direction on the 1.3 octave spectrum for chest and head positions. Similar to other positions, the amount of vibration acceleration in the vertical was greater than those in the longitudinal and lateral directions but due to the position of the chest and head and the distance from the source of vibration and also the damping property of the body, the vibration acceleration of chest and head were lower than those of other parts.

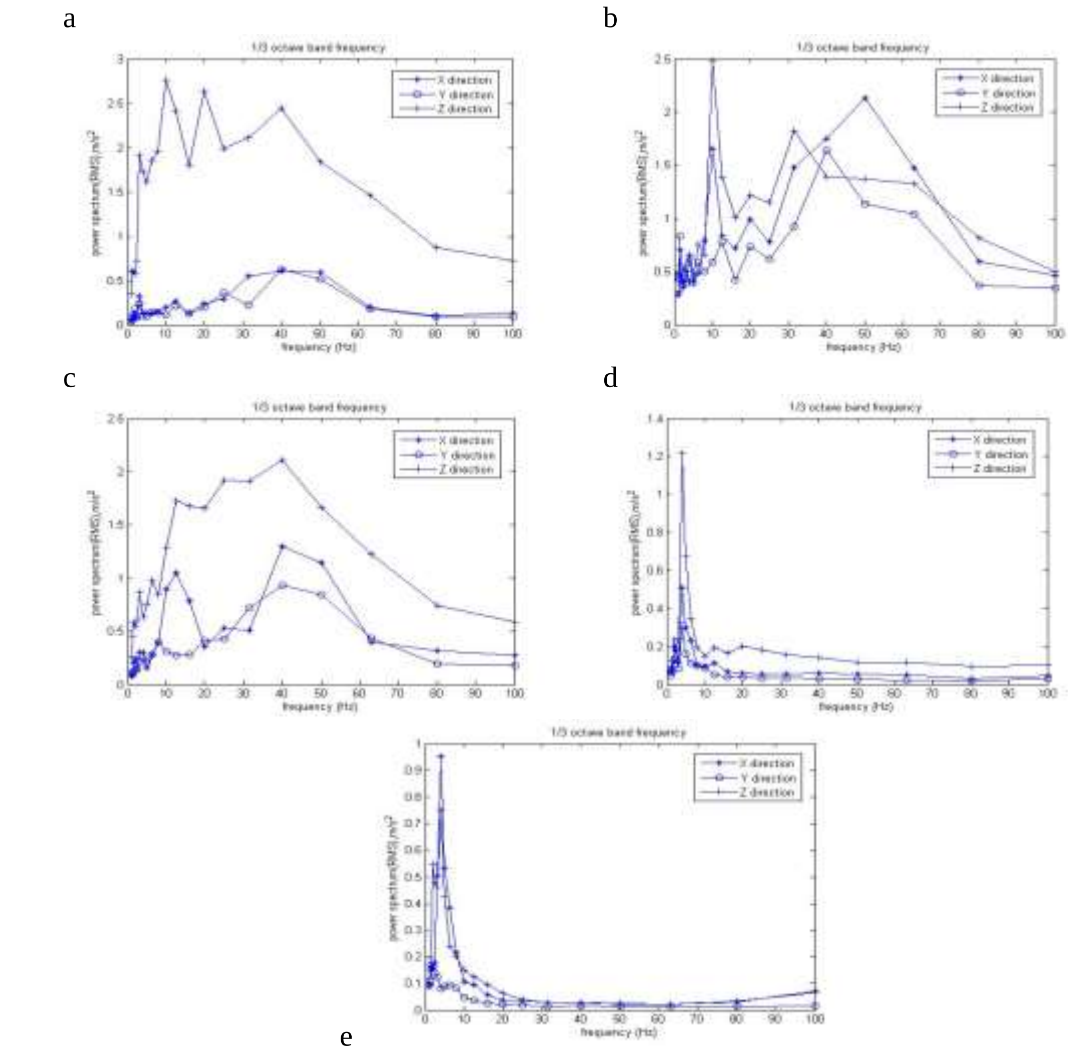


Figure. 4. The effect of direction on the 1/3 octave acceleration spectrum at engine speed of 2500 rpm, average gear ratios, loaded trailer mode and asphalt road in a) ankle, b) wrist c) seat, d) chest, and e) head position.

Effect of Load

Figure. 5 shows the effect of load on the 1/3 octave spectrum of vibration acceleration at different driver position at engine rotational speed of 2500 rpm, on asphalt road, the average gear ratios, and total directions.

According to the Figure. 5-a, at frequencies below than 10 Hz of ankle vibration, the amount of vibration acceleration in loaded/unload mode is at the same level, but at higher frequencies, the amount of vibration acceleration in the loaded mode was higher than that unload mode.

Figure. 5-b and 5-c show the effect of load on the 1/3 octave band of vibration for wrist and seat positions, respectively. In both positions the amount of vibration acceleration in the unloaded mode was slightly higher than in the unloaded state in almost all frequencies below than 40 Hz, while at frequencies above 40 Hz, load and unload mode had the same level.

Figure. 5-d and 5-e show the effect of load mode on the 1/3 octave band for the position of chest and head, respectively. In the chest position, in almost all frequencies lower than 40 Hz, the amount of vibration acceleration in the unload trailer mode was greater than those of load mode. At frequencies above 40 Hz the difference between the amount of vibration acceleration in both trailer modes with and without load had decreasing trend.

In the head position, the amount of vibration acceleration in the loaded trailer mode was a little more than in the unloaded mode at lower frequencies, it had the revers trend at medium frequencies and was the same at frequencies between 80 and 100 Hz had the same values. There can be said that the accelerations were the same at all frequeincies. The reason may be attributed to the damping properties of the body.

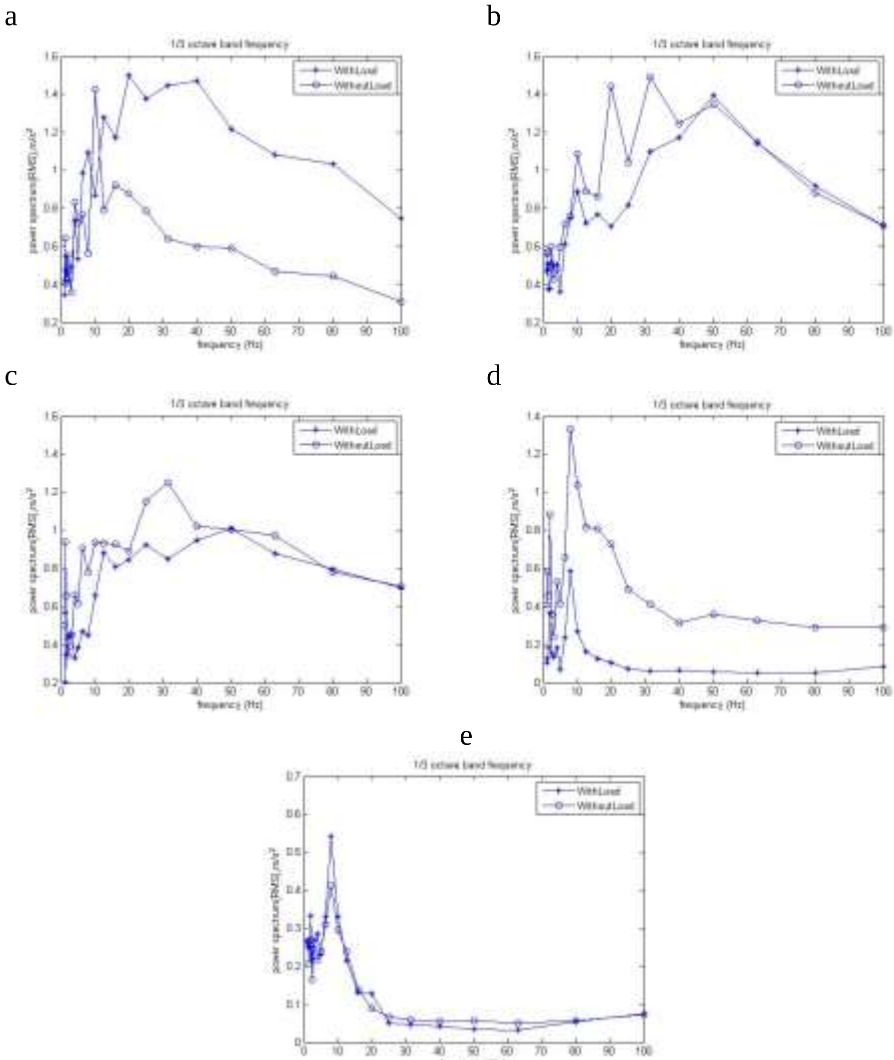


Figure. 5. The effect of load on the 1/3 octave acceleration spectrum at engine speed of 2500 rpm, on asphalt road, the average gear ratios, and the total directions for, a) ankle, b) wrist, c) seat d) chest, and e) head position.

Effect of Road

Figure. 6 shows the effect of the road on the 1/3 octave spectrum of vibration acceleration at engine rotational speed of 2500 rpm, the trailer mode with load, average gear ratio, and total directions at ankle, wrist, seat, chest, and head positions.

According to the Figure. 8-a, the amount of vibration acceleration on the asphalt and the farm roads was the same and they have only a very small difference (less than 0.2 $m.s^{-2}$) in almost all frequencies.

Figure. 6-b and 6-c show the effect of road type on the 1/3 octav band of the wrist and seat, respectively. According to the figures, the amount of vibration acceleration on the farm road was more than that of asphalt road in almost all frequencies. Although this amount of acceleration difference is small, but the cause can be the unevenness of the farm road and its effect on increasing the vibration acceleration on this road compared to the asphalt road.

The effect of road on the 1/3 octave band for chest and head position were ploteed in Figure. 6-d and 6-e, respectively. As shown in the figures, the amount of vibration acceleration on both roads is the same in almost all frequencies. In the position of chest the vibration corresponding to farm road was lightly more than that of asphalt road (0.1-0.2 $m.s^{-2}$) but the effect of the two roads on the 1/3 octav band is same especially at higher frequencies. This is also because of the damping property of the body organs.

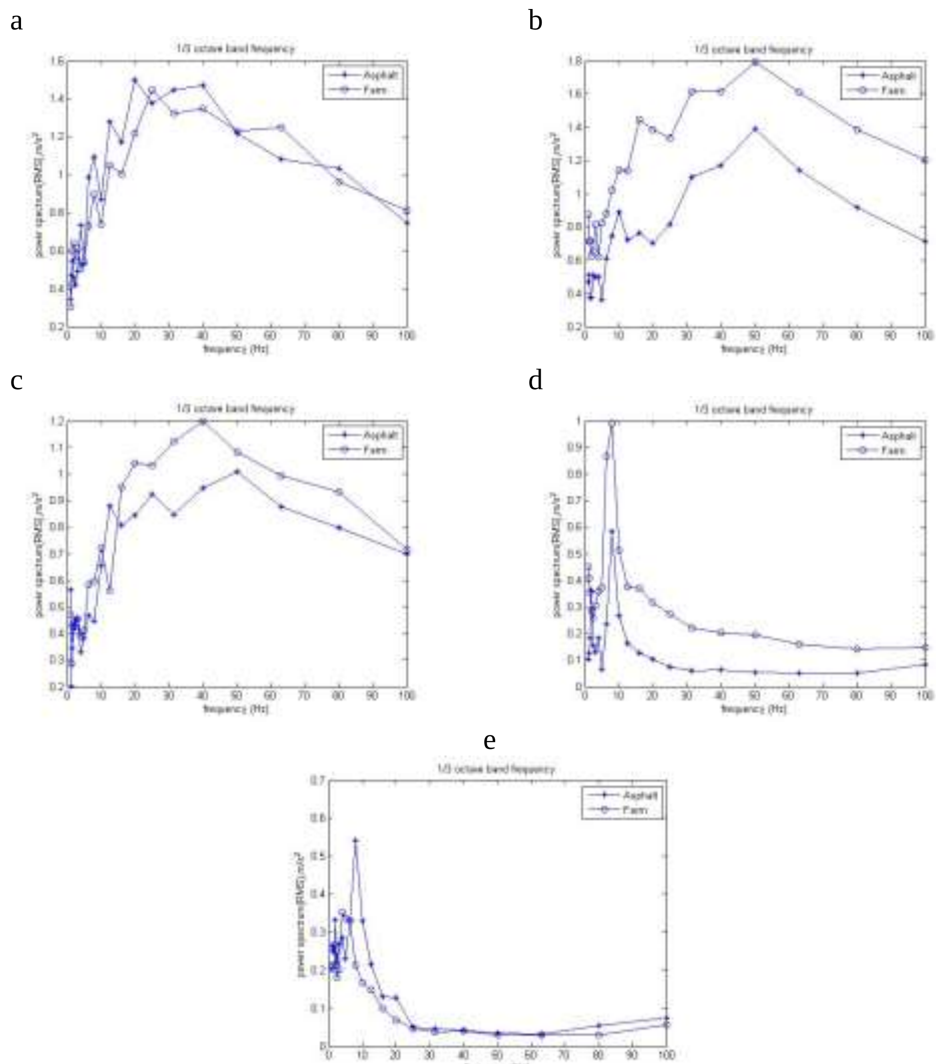


Figure. 6. The effect of the road on the 1/3 octave acceleration spectrum at engine speed of 2500 rpm, in load mode, average gear ratios, and total directions for a) ankle, b) wrist, c) seat, d) chest, and e) head position.

Effect of Engine Rotational Speed

Figure. 7 shows the effect of engine rotational speed on the 1/3 octave spectrum of vibration acceleration on asphalt road, in loded mode, average gear ratios, and total directions for all studied body parts of the tractor driver. As Figure. 7-a shows, the amount of vibration acceleration at 2500 rpm was greater than at

1500 rpm at all frequencies. As Figure. 7-b and 7-c show the effect of engine speed on the 1/3 octave at the wrist and seat positions, respectively, like the ankle position, the amount of vibration acceleration at 2500 rpm was greater than that of at 1500 rpm for all frequencies although the vibration acceleration of the both speeds was close to each other for frequencies below than 10 Hz.The 1/3 octave diagrams in Figure. 7-d and 7-e for chest and head position, respectively, show that the amount of vibration acceleration corresponding to the two speed appeared with a very small difference for almost all frequencies. At frequencies below than 10 Hz, the vibration acceleration had more close to each other. As can be seen in the figures, the vibration acceleration in the head was lower than that of the chest position. Similarly, the vibration acceleration in the chest was lower than that in the seat and less than that in the wrist and ankle, respectively.

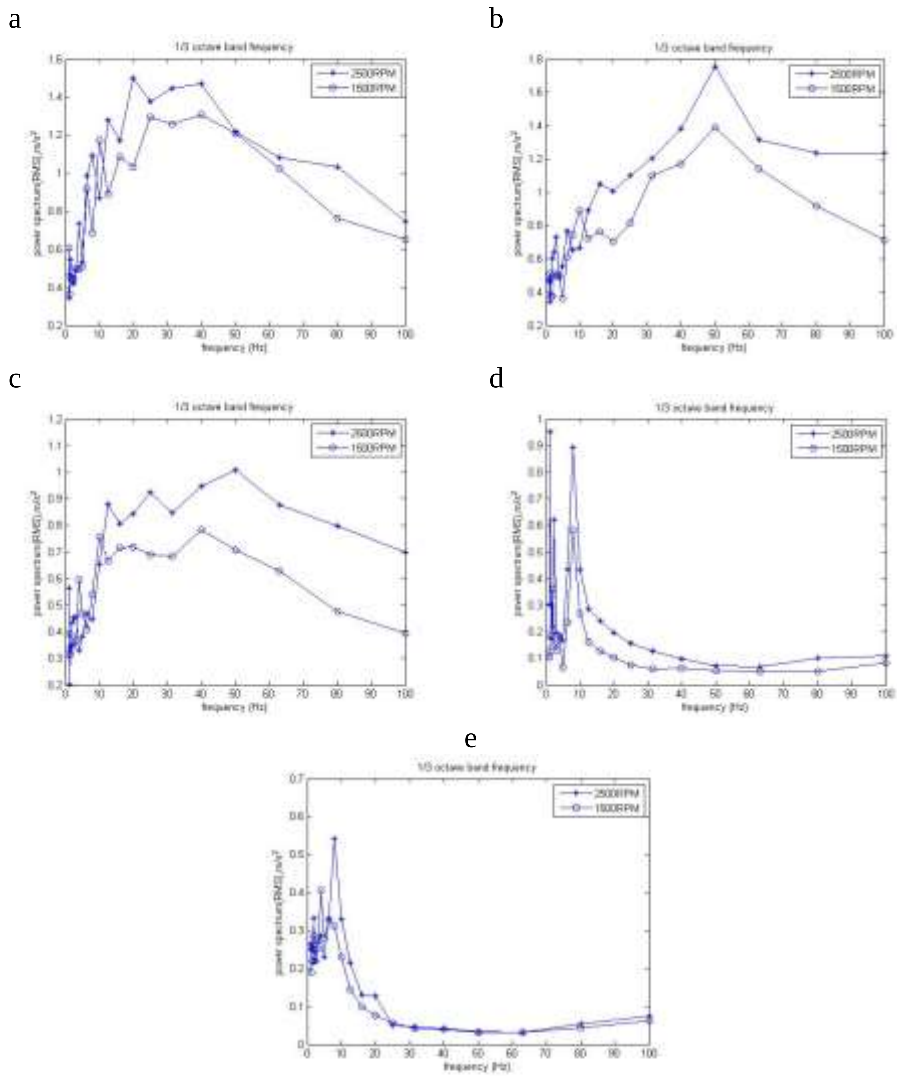
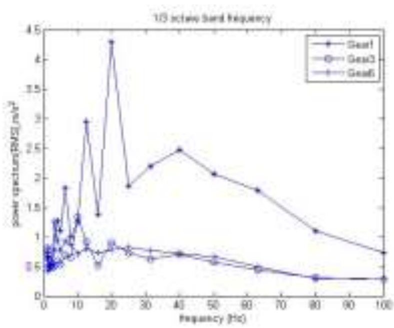


Figure. 7. The effect of engine rotational speed on the 1/3 octave acceleration spectrum, on the asphalt road, in loaded mode, average gear ratios, and total directions for a) ankle, b) wrist, c) seat, d) chest, and e) head position.

Effect of Gear Ratio

Figure. 8 shows the effect of gear ratio on the 1/3 octave band of vibration acceleration at engine speed of 2500 rpm, on asphalt road, in loaded mode, and total directions for ankle, wrist, seat, chest, and head position. According to Figure 8-a, the amount of vibration acceleration in gear 1 was higher than that of gear 3 and 6 for all frequencies. The rate of vibration acceleration of gears 3 and 6 was the same. As can be seen in Figure. 8-b and 8-c for the effect of gear ratio on the 1/3 octave band of vibration acceleration for the position of the wrist and seat, respectively, the average of vibration acceleration amounts was the same for the two positions. Figure. 8-d and 8-e show the effect of gear ratio on the 1/3 octave spectrum of vibration acceleration for positions of the chest and head, respectively. As can be seen, the amount of vibration acceleration for gear 1 and 3 was the same but it was higher for the gear 6 due to higher movmen speed of the tractor. Due to the damping property of the driver body, it can be said that the amount of vibration acceleration transmited from the engine and moving parts of the engine, gearbox, and so on of the studied tractor to the the body parts for gear 1 and 3 are somewhat damped and only the acceleration of vibration due to the movement of the tractor and vibration entered from the ground to the tractor and then the driver appeared. Therefore, vibration accelerations of were more different at frequencies of 10 Hz and below than that.

a



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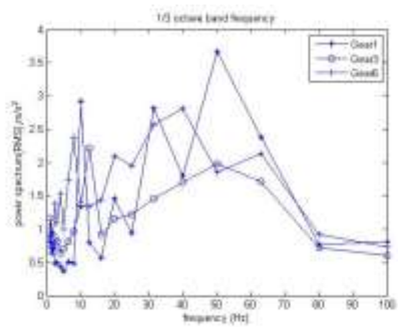

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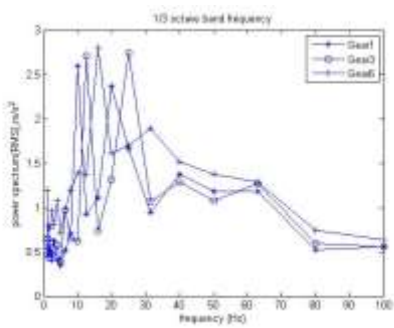

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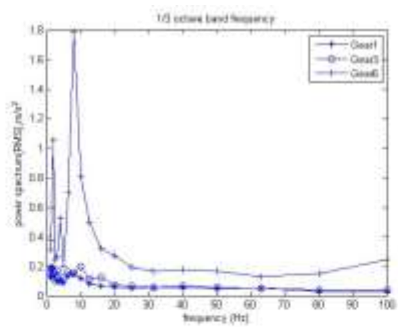

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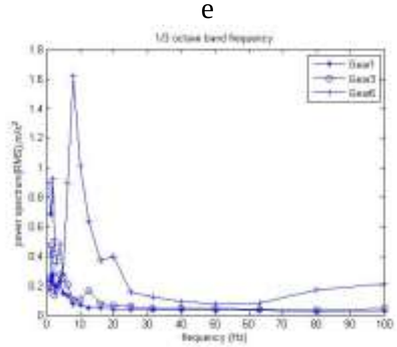

Figure. 8. The effect of gear ratio on the 1/3 octave acceleration spectrum at engine speed of 2500 rpm, on asphalt road, in loaded mode, and total directions for a) ankle, b) wrist, c) seat, d) chest, and e) head position.

Health Condition

As the sensitive frequency range for exposeing the whole body to vibration is between 1 to 80 Hz and the effect of vibration on the body depends on both frequency and amplitude (ISO 2631, 1997), the 1/3 octave band values of vibration acceleration spectra were calculated as weighted data using the corresponding coefficients. The effect of engine speed on the 1/3 octave spectrum of total vibration acceleration (sum of Z, X, and Y directions) weighted in the position of the seat of Goldoni Tractor considering the average of asphalt and farm roads, the average of loaded and unload modes, the average of gear ratios in the frequency range of 1 to 100 Hz was shown in Figure. 9-a. Comparison of this diagram with the limits specified for discomfort condition in Table 2 (Molaei et al., 2024), shows that the vibration between the frequencies of 10 to 80 Hz have 0.33 to 0.43 m.s^{-2} amplitude which were in the alittle uncomfortable range.

Table 2. The human responses to vibration (ISO 2631, 1997).

Response	Level of vibration (m.s^{-2})
Comfort	<0.315
Alittle uncomfortable	0.316-0.63
Fairly uncomfortable	0.50-1.00
Uncomfortable	0.80-1.60
Very uncomfortable	1.50-2.25
Extremely uncomfortable	>2.25

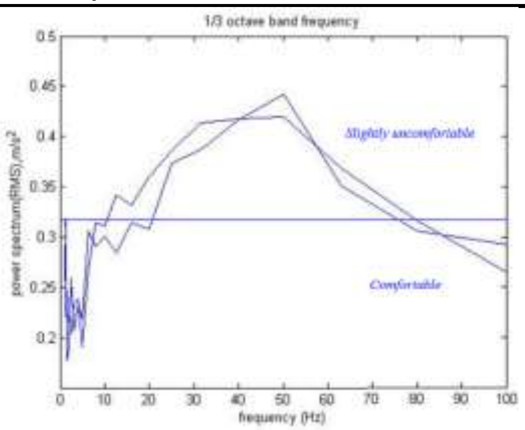

Figure. 9. Covering of 1/3 octave spectrum of total vibration acceleration of the seat of Goldoni Tractor at engine speed of 1500 and 2500 rpm.

Exposure Time

Figure. 10-a shows the 1/3 octave band of vibration acceleration in the vertical direction for the seat position, the average of asphalt and farm roads, the average of loaded and unload modes, the average of gear ratios and at engine speeds of 1500 and 2500 rpm. As it is seen, the rate of vibration acceleration in the vertical direction exceeded the allowable limit of 8 h working time and the allowable limit was 4 h working time, except for the frequency of 10 Hz. Figure. 10-b and 10-c show the 1/3 octave band of vibration acceleration in the longitudinal and lateral direction, respectively, for the seat position, average of asphalt and farm road, average of loaded and unload modes, average of gear ratios and at engine speed of 1500 and 2500 rpm. According to the diagrams, the vibration acceleration values at the longitudinal and lateral directions had not exceeded the allowable limit of 8 h working time (Surendrakumar et al., 2025).

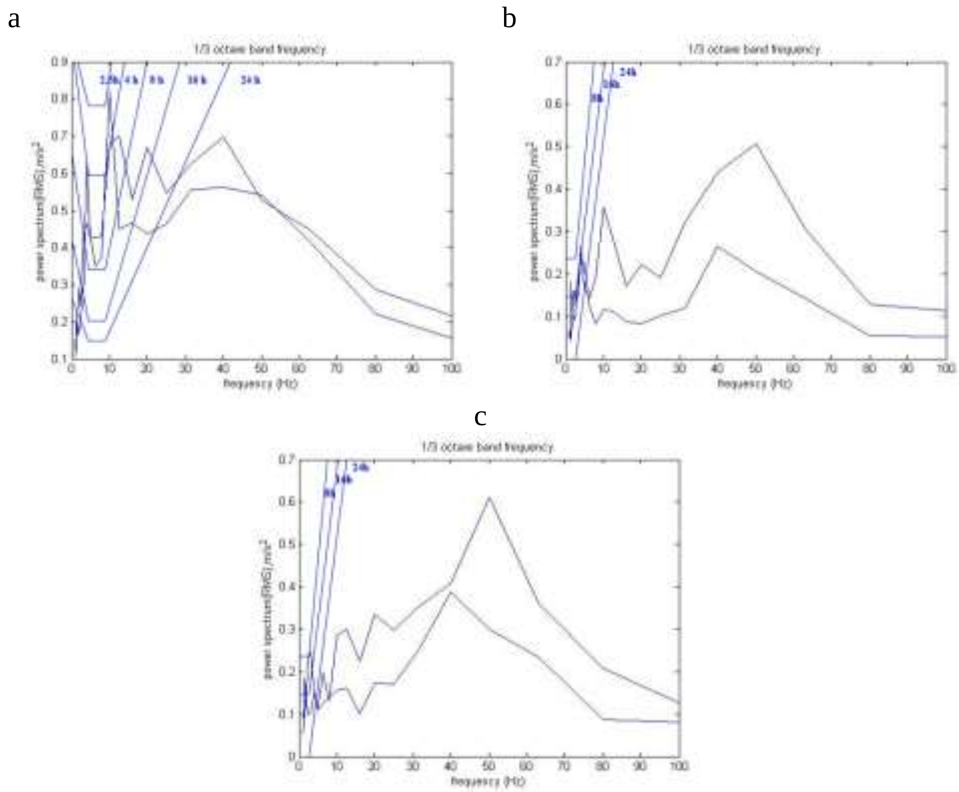

Figure. 10. Coverage of 1/3 octave vibration acceleration at average of roads, average of loaded and unload modes, average of gear ratios, and engine speeds of 1500 and 2500 rpm for the seat position in the a) vertical, b) longitudinal and c) lateral direction with allowable exposure limits

CONCLUSIONS

According to the performed experiments on the Goldoni Tractor in the present study, the vibration acceleration at the frequencies of 41.5 and 20.7 Hz appeared at the peak, which is related to the engine speed and the maximum acceleration of the pistons. Also it appeared at vibration acceleration at frequencies of 10 Hz and below. At all frequencies, the amount of vibration acceleration in the vertical (Z) direction was greater than that of longitudinal (X) and lateral (Y) directions due to the movement of the piston in the vertical direction and the force coming from the ground, which are the main sources of vibration that all are in the vertical direction. At all frequencies, the amount of vibration acceleration for unload mode was higher than that of loaded mode. In comparison of the amount of vibration acceleration on the asphalt and farm roads is almost the same, although the amount of vibration acceleration in the farm was same but vibraton corresponding of farm road was slightly higher than that of asphalt road. The vibration acceleration at 2500 rpm was more than 1500 due to piston reciprocating motion. Comparing the different gear ratios, it was observed that the acceleration of vibration of gear 6 was more than that of other gear ratios due to higher tractor forward speed. Also, in the chest and head positions, according to the damping property of the body, the amount of vibration acceleration from the engine and moving parts of the engine, gearbox, and so on, in these two positions were damped and only the vibration acceleration from the tractor movement and the transmited vibration from the ground to the tractor and then the driver apeared. Therefore, vibration acceleration at 10 Hz and lower than that further appeared. Comparing the rate of vibration acceleration for different positions of the driver body, the ankles and wrists had more and that of the head and chest had less amount of vibration acceleration due to the distance of different points from the vibration sources and also the damping property of the body, as the hands, feet and seat were in direct contact with the tractor body, so they had a higher values of vibration acceleration. In calculating the inconvenience limits, it was found that the vibration between the frequencies of 10 to 80 Hz had a range of 0.33 to 0.43 m.s-2 which is in the slightly uncomfort range. It was also found that the rate of vibration acceleration in the vertical direction exceeded the allowable limit of 8 h working time and it was 4 h working time except for the frequency of 10 Hz. The acceleration of the vibration in the longitudinal and lateral directions has not exceeded the allowable limit of 8 h working time. Based on the obtaine results in the present study, the factories can use efficient engineering solutions, such as pneumatic suspension seats or active vibration damping systems to reduce the vibration.

CONFLICT OF INTEREST

The authors have declared no conflict of interest.

FUNDING SOURCES

List funding sources in this standard way to facilitate compliance with funder's requirements.

ACKNOWLEDGMENTS

Collate acknowledgments in a separate section at the end of the article before References.

DECLARATION OF COMPETING INTEREST

All authors must disclose any financial and personal relationships with other people or organizations that could inappropriately influence their work. Examples of potential conflicts of interest include employment, consultancies, stock ownership, honoraria, paid expert testimony, patent applications/registrations, and grants or other funding. All authors, including those without competing interests to declare, should create a declaration of competing interest statement (which, where relevant, may specify they have nothing to declare).

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