The driver responses to the vibration of tractor

Ali Mohammadi[1], Kamran kheiralipour[1*], Bahram Ghamary[1], Ahmad Jahanbakhshi[1], Reza Shahidi[2]

(1.Mechanical Engineering of Biosystems Department, Ilam University, Ilam, Iran, 69391-77111;
2. Occupational Health Engineering Department, Hamadan University of Medical Sciences, Hamadan, Iran, 65178-38695)

Abstract: Whole body vibration is one of the main causes of musculoskeletal disorders of drivers. The purpose of this study was to investigate the allowable exposer time, care limit, and driver response to the vibrations of the seat of tractor. A three-way accelerometer was used to measure the vibration of the seat of a four-wheel drive ITM 475 Tractor based on the ISO 2631-1 international vibration standard. The studied factors were evaluated engine rotational speed, gear ratio, and road. The obtained data were analyzed through a factorial experiment based on completely randomized design. The results showed that effects of the main factors and those of their interactions on the total vibration emitted from the tractor seat were significant at 1% probability level. The minimum allowable exposure time and care limit were 1.16 and 0.14 h, respectively, that was in very uncomfortable range. The effect of engine rotational speed on the driver allowable exposure time to vibration is more than that of shifting gear. The results of the present study are useful to reduce whole body vibration and increase exposer time of the tractor driver through adjusting suitable driving conditions.
Keywords: tractor; whole body vibration; exposure time, care limit.

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1 Introduction

According to the world statistics agency, around 20.04% of the laborers work in the agriculture sector across the world. In this regard, agricultural machinery is an important and influential element in agricultural development and productivity so that agricultural mechanization degree became a main indicator of agricultural progress in all countries. Tractor has a special place among agricultural machinery due to its role as the power source for other machinery, but it causes some problems such as seat vibration that need to be investigated (Boshuizen et al., 1990).

In terms of healthcare, what is important in the relationship between vibration of the objects in the environment and the human body is the risk of energy of vibration waves in direct contact with human organs. The transfer of mechanical energy from a vibrating source to human body can create disorders in convenience and comfort conditions of the operators, reduce work efficiency because of the fatigue caused by the vibration, disorders in the worker's physiological actions and in some cases result in skeletal lesions or other diseases.

Studying human vibration consists of two parts: whole body vibration and hand-arm vibration. Hand-arm vibration is caused by the hand-held vibrating equipment such as electric drills, hammers, axes, lumber saws, etc. The vibration that affects the whole body is studied within the critical frequency range of

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* **Corresponding author: Kamran Kheiralipour,** Mechanical Engineering of Biosystems Department, Ilam University, Ilam, Iran, Phone & Fax, +988432227015, E-mail Address: k.kheiralipour@ilam.ac.ir.

1-80 Hz and has been discussed by ISO-2631 standard. In whole body vibration, different organs of the body are in contact with the vibrating object. It can be even the case where the whole body is situated within a vibrating environment such as the instance of the agricultural machinery or some automobile drivers (Golmohammadi, 2010).

Currently, vibration is one of the main problems of the industrial world and the agricultural sector and a huge number of people are affected by its harms in their work environments and living places (Tewari et al., 2004). Several studies investigated the vibration and the operators' exposure time. Marsili et al. (2002) measured seat vibration of a tractor equipped with a suspension system and a shock absorber. They stated that the seat suspension system would reduce vibration acceleration from 15% to 36% in different working conditions. Mirzaei and Mohammadi (2010) studied exposure time to vibration and its effect on musculoskeletal disorders in tractor drivers. The highest frequency pain among the drivers was backache (56.8%). Kareem Abdullah and Al-Mafraji (2011) assessed tractor seat vibration during tillage operations in soil moisture content between 18% to 20% with two plowing depths (15 and 20 cm) and three tractor travel speeds (2, 3.5 and 6.8 km h^{-1}). The results of their study showed that the highest tractor seat vibration occurred in the vertical plane. They also reported that vertical vibration level usually raised beyond the ISO standards and the acceleration transferred to the tractor seat was increased with increase of the travel speed. Fereydooni et al. (2012) studied hand-arm vibration of Massey Ferguson 285 and Universal 650 driver and reported that the difference in the vibrations transferred to the hands and arms of the driver was not significant. Ahmadian et al. (2014) measured the tiller seat and handle vibration in the transportation mode. Their results showed that the tiller vibration increased due to increase of engine rotational speed in all gear positions and in all directions. They also reported that the amount of vertical vibration was higher than those of other directions. Jahanbakhshi et al. (2020) evaluated the vibration of John Deere 1055I Combine's seat under the effects of engine rotational speed and gear ratio. They determined the allowable exposer time and reported that the operator can drive the combine harvester for 8 h per day without any problem for 1st and 2nd gears with engine rotational speed of 1800 rpm and 1st gear with 2500 rpm engine rotational speed. Faraji et al. (2021) examined the vibration of a single-cylinder gasoline hand mover under the effects of magnetized ethanol–gasoline fuel blends and reported that the vibration decreased by increasing ethanol in magnetized blends up to 10%. Pochi et al. (2022) compared the whole-body vibrations of a tractor with and without self-levelling cabin.

The human responses to the vibration is one of the concerns of driver of machineries besides allowable exposer time and care limit. A review of the related literature revealed that there has not been reported any study about the driver responses to tractor vibration. Thus, the aim of this study was to investigate the whole body vibration and allowable exposer time and care limit, and driver responses to the vibrations of tractor at different conditions.

2 Materials and methods

A four-wheel drive ITM475 Tractor was used to measure the seat vibration in different driving condition. The tractor specifications have been presented in Table 1.

Table 1 The specifications of ITM475 Tractor

Item	Measurement
Manufacturer	Iran Tractor Manufacturing Co.
Year manufactured	2014
Engine model	152-3 AD
Number of gears	12f, 4r
Number of cylinders	4
Mass (kg)	3170
Power (hp)	75

The investigated factors in the present study were: engine rotational speed at three levels: 1000, 1500, and 2000 rpm, gear ratio at three levels: 1st, 2nd, and 3rd, and road at two levels: dirt and asphalt. Totally 18 driving conditions (treatments) associated with three replications were carried out. The tests were done in the form of a factorial experiment based on the completely randomized design in the Faculty of Health, Hamadan University of Medical Sciences, Hamadan, Iran. The moving course of the tractor in each test was 100 m.

The vibrations of the tractor seat were measured according to ISO 2631-1 (1997) and ISO 5008 (1979) standards. Since different masses affect the results of the vibration tests (ISO 5008, 1979), a driver with the body mass of 75 kg operated the tractor in all tests. To record vibration signals, a three-way vibration meter was used (Figure 1 and Table 2).

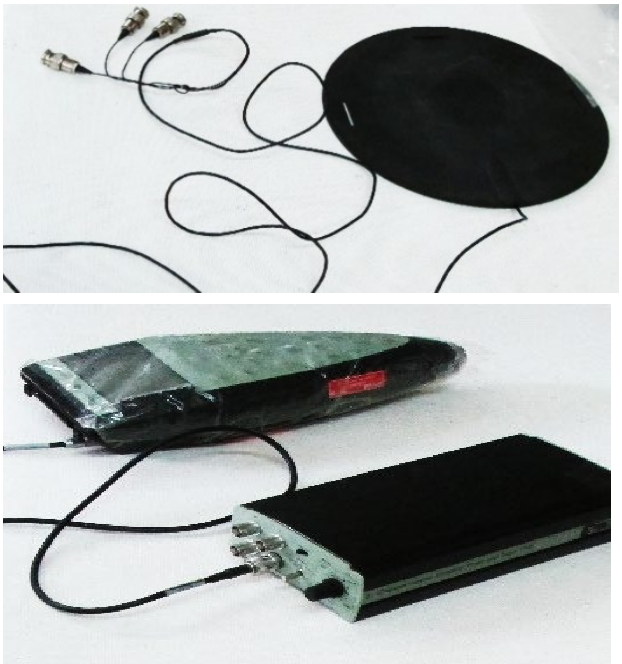

Figure 1 The B&K 2260 vibration meter used to record seat vibration in x, y and z directions, simultaneously (Mohammadi et al., 2021)

Table 2 The specifications of B&K 2260 vibration meter

Item	Measurement
Manufacturing country	Denmark
Precision	1 μm s^{-2}
Frequency range	0.4-100 Hz
Type of sensor	Three-way
Working moisture range	Up to 90% RH
Working temperature range	Up to 70°C

The vibration meter's sensor had been placed in a semi-rigid rubber plate with the thickness of 12 mm (Figure 1). The sensor was fixed on driver seat of the tractor using some glue in order to transfer the vibration signals from the seat to the sensor. The tractor seat and the sensor attached to that have been shown in Figure 2.

Figure 2 The tractor seat and the vibration measurement sensor (Mohammadi et al., 2021)

In this study, the seat vibration data were acquired in three directions (X, Y, and Z) while the tractor traveled on the asphalt and dirt roads (Figure 3).

Figure 3 Measurement of seat vibration of the studied tractor

The total vibration as the resultant of the three directions was calculated using following equation (ISO 2631-1, 1997):

$$a_t = \sqrt{(1.4a_x)^2 + (1.4a_y)^2 + a_z^2} \qquad (1)$$

where a_t is the total acceleration and a_x, a_y, a_z are accelerations in longitudinal, latitudinal, and vertical directions (m s^{-2}), respectively.

Body responses to vibrations are proportional to the amount of energy exerted on the body. So, if a specific range of the effect or a physiological response is taken into account, there is always a relationship between the acceleration exerted to the operators and the amount of time they are exposed to the vibration. This means that in order to create similar conditions, increasing the amount of acceleration exerted to the body would lead to decrease the allowable exposure time and vice versa.

Whenever the acceleration exerted to the body is small, a longer time is required to see the same effects on the body. Therefore, the following two models are proposed for this proportion (Golmohammadi, 2010).

$$(B.1)\ A_{eq(T1)} \times T_1^2 = A_{eq(T2)} \times T_2^2 \tag{2}$$

$$(B.2)\ A_{eq(T1)} \times T_1^{1/4} = A_{eq(T2)} \times T_2^{1/4} \tag{3}$$

where T_1 and $A_{eq(T1)}$ are exposure time and total equivalent acceleration in the first condition and T_2 and $A_{eq(T2)}$ are the corresponding values in a second condition, respectively.

In both models, the risk range is determined through the total equivalent acceleration. As shown in Figure 4, two boundaries are specified for each of the proposed models. One of them is the minimum as the care or the action limit where exposure to the vibration is riskless (Equation 3 and line B.2 in Figure 4) and the other is the maximum limit which exposure to vibration causes to fall within the health risk range (Equation 2 and line B.1 in Figure 4). The range between the two limits is the allowable exposure zone or the caution area. Based on the total vibration, line B.1 in Figure 4 and Equation 2 were used to find allowable exposure time and line B.2 and in Figure 4 and Equation 3 were applied to specify care limit.

Table 3 Description of human response to the vibration exerted to the body (ISO 2631-1, 1997)

Description of human response	Root mean square of total acceleration (m s^{-2})
Comfortable	Lower than 0.315
A little uncomfortable	0.315-0.63
Almost uncomfortable	0.5-1
Uncomfortable	0.8-1.6
Very uncomfortable	1.5-2.25
Extremely uncomfortable	Higher than 2.25

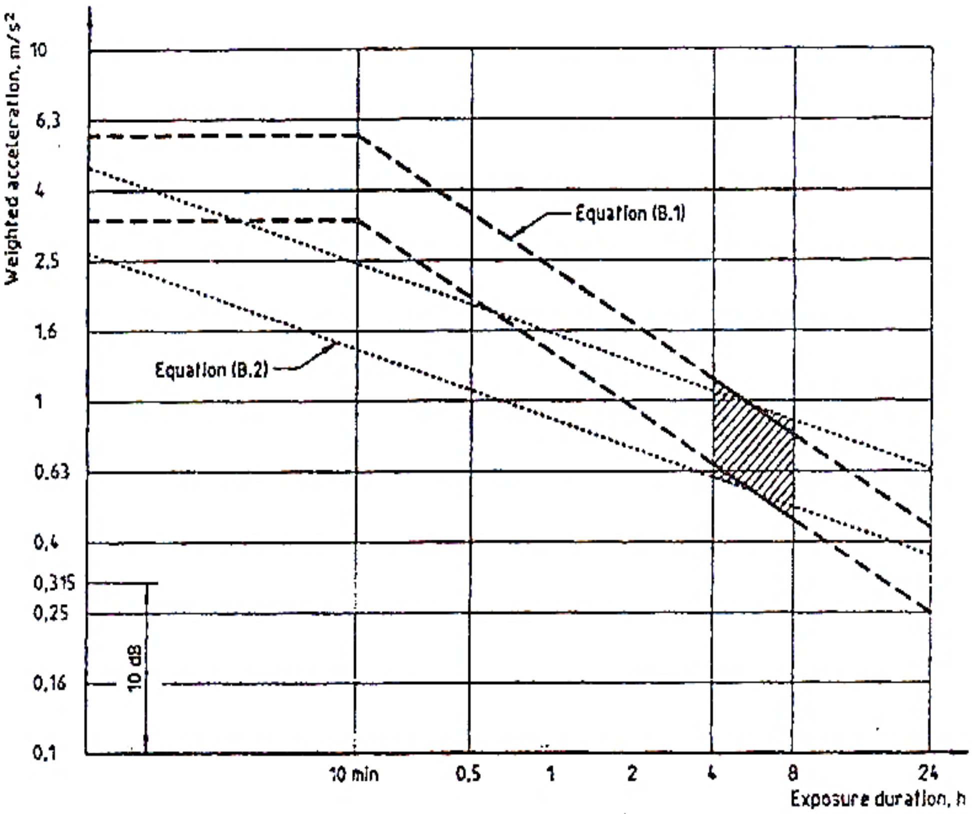

Figure 4. Allowable range and care limit of exposure time to vibration (ISO 2631-1, 1997).

After calculation of the total vibration, the driver responses to the vibration exerted to the body was specified using Table 3.

The SAS 9.1 Software was used to analyze data and carry out statistical analyses. In addition, Duncan's multiple range test was applied to measure significance levels and to compare the means of the vibrations affected by the investigated main factors and their interactions.

3 Results and discussion

The results of variance analysis of the effects of the investigated main factors and their interactions on whole body vibration in X, Y, and Z directions and the total vibration (the resultant of the three X, Y, and Z directions) has been reported in Table 4. The effects of the main factors and their interactions on the vibration emitted from the studied tractor seat in X, Y, and Z directions and the resultant acceleration were significant at 1% probability level.

Table 4 Variance analysis of the effects of the main factors and their interactions on whole body vibration in X, Y, and Z directions and total vibration (m s^{-2})

Sources of variations	DF	Mean squares			
		X	Y	Z	Total vibration
Engine rotational speed	2	0.069*	0.014*	0.537*	0.614*
Gear ratio	2	0.237*	0.026*	0.711*	1.112*
Road	1	0.413*	0.435*	1.456*	3.241*
Engine rotational speed × Gear ratio	4	0.0015*	0.0012*	0.049*	0.023*
Engine rotational speed × Road	2	0.009*	0.0098*	0.041*	0.015*
Gear ratio × Road	2	0.038*	0.0008$^{n.s}$	0.044*	0.084*
Engine rotational speed × Gear ratio × Road	4	0.008*	0.0021*	0.028*	0.034*
Error	36	0.0002	0.0002	0.0007	0.0007
Total	53	-	-	-	-

Note: *Significant at 1% probability level, ^{ns}non significant.

The mean square of total vibration in different engine rotational speeds and gear ratios while the tractor was operated on asphalt and dirt roads have been shown in Figures 5-7. According to Table 5, increasing of engine rotational speed from 1000 to 2000 rpm and gear ratio from 1st to 3rd gear caused to increase the total tractor seat vibration. This could be due to the increase in the number of combustions and piston strokes and travel speed. Also total vibration in dirt was more than that of asphalt road.

The results of Duncan's multiple range test of the interaction effects of engine rotational speed and gear ratio on the whole body vibration have been shown in Figure 5.

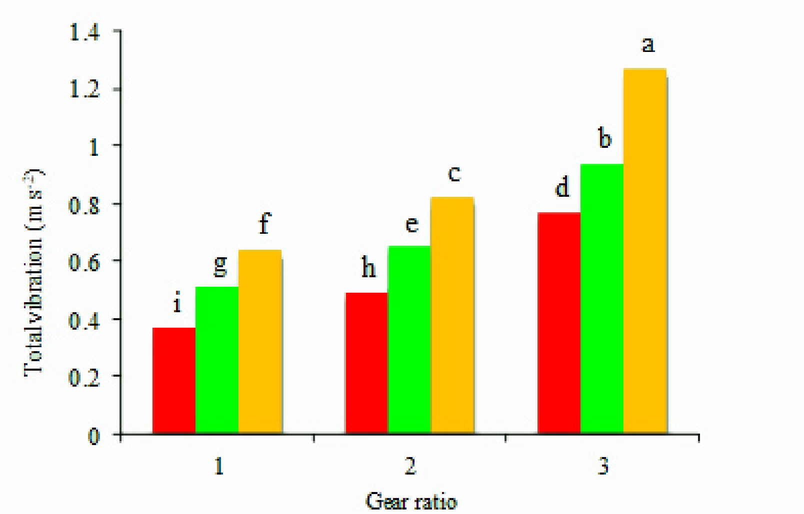

Figure 5 The effects of engine rotational speed and gear ratio interaction on the total vibration. Different letters show significant difference at 1% probability level.

Figure 5 shows significant effects of interaction between all levels of engine rotational speed and gear ratio on total vibration at 1% probability level. In addition, increase in engine rotational speed from 1000 to 2000 rpm and change of gear ratio from 1st to 3rd and road from asphalt to dirt, the total seat vibration increased. This trend is due to the increasing of the number of combustion and piston strokes and travel speed and the effects of road surface. These results are consistent with the findings of Mehta et al. (2000), Scarlett et al. (2007), Servadio et al. (2007), Stayner et al. (1984), Ahmadian et al. (2014), and Taghizadeh-Alisaraei et al. (2007).

The results of Duncan's multiple range test of the effects of different engine rotational speed on the total vibration emitted by the tractor seat for different road surfaces has been shown in Figure 6.

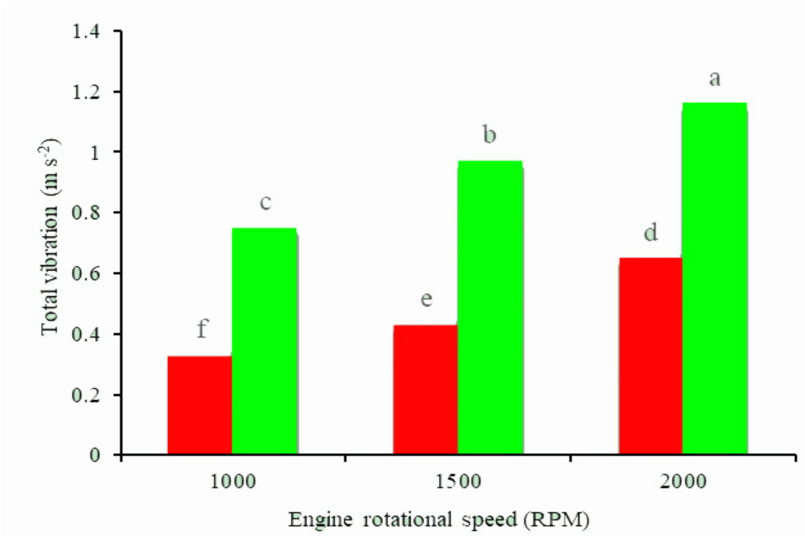

Figure 6 The effects of interaction between engine rotational speed and road on the total vibration. Different letters show significant difference at 1 % probability level

As can be seen in Figure 6, interactions between engine rotational speed and road had significant effects on the total vibration at 1% level of probability. Also, increasing of engine rotational speed from 1000 to 2000 rpm caused to increase the total vibration of tractor seat while it travels on different road surfaces (asphalt and dirt) and this can be due to the increasing of the number of combustion and piston strokes in the unit of time. This is in line with the results reported by Taghizadeh-Alisaraei et al. (2012), Mehta et al. (2000), Taghizadeh-Alisaraei et al. (2007), and Jahanbakhshi et al. (2016). It can also be observed that the total vibration emitted from a tractor seat while it moves on a dirt road was higher than that of asphalt road. The reason is the effect of dirt road surface on the rate of vibration which is greater than that of the asphalt road surface.

The results of Duncan's multiple range test related to the effects of different gear ratios on the total vibration of the tractor seat while traveling on different road surfaces have been shown in Figure 7.

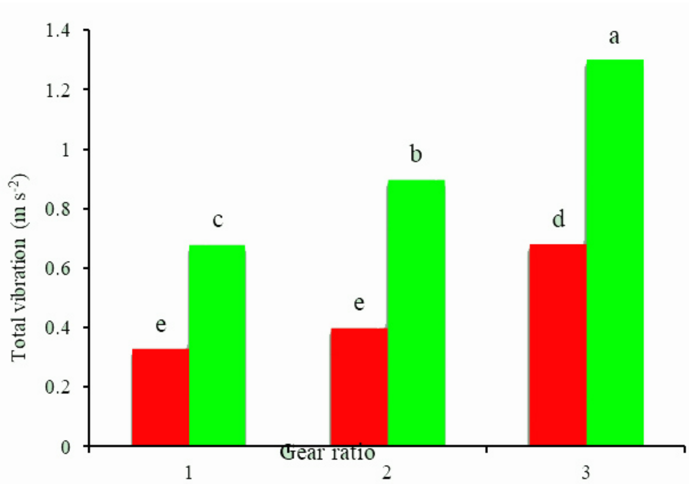

Figure 7 The effects of gear ratio and road interactions on the total tractor seat vibration. Different letters show significant difference at 1% probability level

It can be seen that in the 1st and 2nd gear ratios, while the tractor traveled on the asphalt road, there was not a significant difference between the corresponding total vibrations, whereas in other gear ratios, during traveling on the asphalt and dirt road the results showed a significant difference at 1% probability level. The results also showed that the total tractor seat vibration increased by shifting gear from 1st to 3rd while traveling on different road surfaces. Moreover, the total vibration emitted from the tractor seat while traveling on dirt was higher than that of asphalt road. This can be due to increasing of tractor vibration caused by change of traveling speed and road surface. These results are similar to those reported by Kabir et al. (2017), Ahmadian et al. (2014), and Taghizadeh-Alisaraei et al. (2007).

The allowable exposure time of driver of ITM475 Tractor in different engine rotational speeds and gear ratios while traveling on asphalt and dirt roads has been given in Table 6. According to the acceptable model of work in Iran offered by the technical committee of the country's occupational health organization, 8 h of work per day and 40 h work per week are considered as daily working time. Besides, the results given in Table 5, 3rd gear ratio with engine rotational speed of 1000 rpm and in the 2nd and 3rd gear ratio with engine rotational speed of 1500 and 2000 rpm on dirt road and in the 3rd gear ratio with engine rotational speed of 2000 rpm on asphalt road, the tractor driver is allowed to drive less than 8 h per day. In other engine rotational speeds and gear ratios, there is not limitation for 8 h driving per day. In addition, according to the results obtained for the driver allowable exposure time to vibrations, there can be stated that the effect of reducing engine rotational speed on the increase of the driver allowable exposure time to vibration is more than that of shifting gear.

Table 5 The allowable exposure time of driver of ITM 475 Tractor

Engine rotational speed (rpm)	Road	Gear ratio	Allowable exposure time (h)	Allowable exposure care limit (h)
1000	Asphalt	1	894.46	127.39
		2	298.73	41.69
		3	98.35	13.44
	Dirt	1	60.48	8.19
		2	22.16	2.94
		3	3.34	0.42
1500	Asphalt	1	261.61	36.41
		2	133.13	18.30
		3	37.54	5.04
	Dirt	1	18.08	2.03
		2	6.94	0.90
		3	1.79	0.22
2000	Asphalt	1	97.27	13.29
		2	63.23	8.57
		3	4.12	0.53
	Dirt	1	8.44	1.10
		2	2.92	0.37
		3	1.16	0.14

The exposure care limits to ITM 475 seat vibration at different engine rotational speeds and gear ratios while traveling of the tractor on asphalt and dirt roads have been shown in Table 5. The care limit is a range of exposure times within which vibration takes place without any risk. Thus, the results given in Table 5 indicate that the length of this range is smaller on dirt road than that of asphalt road and this is due to the effects of the surface and topography of a dirt road in comparison with asphalt road. Moreover, the effect of reducing engine rotational speed on the increase in the range of the healthy time is more than that of shifting gear.

Comparing the rate of the total vibration with the data given in Table 3, the responses of the tractor driver to the vibration exerted to the body were analyzed and the results have been illustrated in Table 6.

Table 6 The responses of driver of ITM 475 Tractor to the whole body vibration

Engine rotational speed (rpm)	Road	Gear ratio	Human response
1000	Asphalt	1	Comfortable
		2	A little uncomfortable
		3	A little uncomfortable
	Dirt	1	A little uncomfortable
		2	Almost uncomfortable
		3	Uncomfortable
1500	Asphalt	1	A little uncomfortable
		2	A little uncomfortable
		3	A little uncomfortable
	Dirt	1	Almost uncomfortable
		2	Almost uncomfortable
		3	Uncomfortable
2000	Asphalt	1	A little uncomfortable
		2	A little uncomfortable
		3	Uncomfortable
	Dirt	1	Almost uncomfortable
		2	Uncomfortable
		3	very uncomfortable

According to the obtained information, it can be concluded that the effect of reducing engine rotational speed on the decrease in the total amount of the vibration emitted by the tractor seat and improvement of the driver's comfort was higher than that of shifting gear. It can also be observed that the driver's comfort level was more critical (more at risk) when the tractor traveled on dirt than that of asphalt road. These results are similar to those reported by Kabir et al. (2014) and Jahanbakhshi et al. (2016).

4 Conclusion

In this study, the total vibration exerted to the driver body, the allowable exposure time, the care limit, and the driver responses to the vibrations of ITM 475 were investigated according to the ISO 2631-1 international vibration standard. The results of variance analysis showed that the effects of the investigated main factors such as engine rotational speed, gear ratio, and road and their interactions on the whole body vibration in X, Y, Z directions and total vibration (resultant of the three directions) were significant at 1% probability level. Increasing of engine rotational speed from 1000 to 2000 RPM and gear ratio from 1st to 3rd, caused to increase whole body vibration and thus reduce the allowable exposure time. The minimum amount of whole body vibration on asphalt road occurred at 1000 rpm and gear ratio of 1st which was 0.23 m s^{-2}. The maximum whole body vibration and thus the minimum exposure time and the care limit on dirt road took placed at engine rotational speed of 2000 rpm and 3rd gear ratio with amounts of 1.49 m s^{-2}, 1.16 h and 0.14 h, respectively. It was found that ITM 475 driver is allowed to drive the tractor fewer than 8 h per day in a few number of the evaluated conditions. The driver’s response to tractor vibration was classified from comfortable to very uncomfortable situation. The whole body vibrations of the tested tractor on dirt road have been higher than those of asphalt road for all engine rotational speeds and gear ratios. It is suggested that drivers consider lower engine rotational speeds and gear ratios for driving the tractor on dirt road. It is suggested to design, construct and evaluate a cabin or a new seat for the tractor to decrease the amount of vibration and increase allowable exposer time and care limit.

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