Handle grips for reducing hand-transmitted vibration in hand tractor

K. N. Dewangan[1], V. K. Tewari[2]

(1. *Department of Agricultural Engineering, North Eastern Regional Institute of Science and Technology, Nirjuli* – 791 109, *Arunachal Pradesh, India*;

2. *Department of Agricultural and Food Engineering, Indian Institute of Technology, Kharagpur* – 721 302, *West Bengal, India*)

Abstract: The operators of hand tractors experience high levels of hand-transmitted vibration which cause early fatigue. Two different designs of handle grips made of foam rubber (HG_1) and styrene butadiene rubber (HG_2) were selected for the study. They were evaluated for reducing vibration with regard to their performance as per ISO 5349 (2001) and subjective feeling of comfort during actual field operations involving rota-tilling, rota-puddling and transportation. Ten experienced hand tractor operators were chosen for the study. Data were collected at three levels of forward speed, i.e. 1.11, 1.71 and 2.31 m/s during transportation and 0.30, 0.45 and 0.63 m/s during rota-tilling and rota-puddling. The data collection included frequency-weighted vibration acceleration in Root Mean Square (rms), frequency spectrum of vibration acceleration and subjective response. The results indicated that the handle grip made of foam rubber (HG_1) and styrene butadiene rubber (HG_2) could reduce frequency-weighted vibration acceleration (rms) by about 11% and 5%, respectively, from the existing handle grip. The characteristics of the handle grips were found to vary considerably below 40 Hz. Maximum reduction of vibration acceleration (rms) was in the frequency range from 20.0 to 31.5 Hz by handle grip HG_1. Average reduction of frequency-weighted vibration acceleration (rms) was highest in the X-axis, i.e. perpendicular to the palm surface area. Handle grip made of foam rubber was most preferred by all the subjects over the existing handle grip of the hand tractor.

Keywords: frequency-weighted vibration acceleration, frequency spectrum, subjective response, discomfort, field operation

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1 Introduction

In developing countries, hand tractor (also known as a power tiller or walking tractor or garden tractor or single-axle tractor) is used by small and medium category of farmers. They are particularly suitable for small and medium size fields where conventional four wheel tractors are either difficult or uneconomical to use. In India, the hand tractors are used for land preparation under dry and wet land conditions. Though the machines have many advantages, their acceptance among farmers has been very slow for many reasons. This can be seen by the population of hand tractors and tractors in India. In 2005-2006, the population of hand tractor was 0.181 million whereas number of tractor was 3.819 million and their share was 1.6% and 33.4%, respectively of the total mechanical power (Singh, 2006).

One of the major reasons for low adoption of hand tractors is the drudgery involved in its operation. The operator is exposed to extreme environmental conditions, like temperature, humidity, noise and vibration. Operators of the hand tractor are exposed to high levels of vibration (Salokhe, et al., 1995; Ying, et al., 1998; Tewari, et al., 2004; Dewangan and Tewari, 2009). Excessive vibration felt at the handle grip is observed as one of the major reasons for not being popular in field operation of hand tractor. Vibration in addition to force applied by the operator to maneuver the hand operator increases fatigue. Such fatigue stretched over a period of months

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Corresponding author's email: prof.vktewari@gmail.com, kndewangan2001@yahoo.co.in

and years may cause physical, physiological and health problems in the long run (Waersted and Westgaard, 1991). The various disorders associated with exposure to vibration are vascular, neurological, musculoskeletal and articular. The term 'hand-arm' vibration syndrome (HAVS) is used collectively for the different symptoms of disorder (Griffin, 1996).

Resilient/elastomeric materials are water resistant, cost-effective and maintenance free. They are available with different density and hardness. These materials are used in handles on hand-held and hand-guided machinery. Elastomeric materials reduce vibration, therefore, Ying et al. (1998); Tewari and Dewangan (2009) have used isolators made of elastomeric material to reduce hand-transmitted vibration in hand tractor. Elastomeric materials can also be used as device for vibration reduction in the handle grip. Ragni (1994) observed that by inserting rubber, i.e. one of the elastomeric materials, sleeves on the handle of small tillage tools attenuated vibrations up to 35% on an Italian made walking tractor. Björing et al. (1999) have used foam rubber to reduce handle vibration in hand drilling machinery. Handle grips used in the present design of the hand tractors in India are hard, which is not only a poor vibration isolator but it also causes discomfort to the operators. Fellows and Freivalds (1991) have also observed that the rigid and hard handle surface is source of discomfort to many users. This discomfort includes painful blistering and a reduction in both the efficiency of the work and the consumer's satisfaction with the tool. They used foam rubber to increase comfort in the garden hand tools.

Thus, a suitable handle grips provided in the hand tractor may not only reduce magnitude of hand-transmitted vibration and increase comfort but it will also increase the work output of the operator. It was therefore decided to conduct a study with the objectives: (1) To study the effect of handle grip on reduction of hand-transmitted vibration; (2) To study the operator's response on the handle grip with regard to comfort.

2 Materials and methods

The study was done to reduce hand-transmitted vibration with a view to enhance the work output of the operators during field operation of the hand tractor. For these purpose two types of handle grips were selected. The experiments were conducted at three forward speeds for three most commonly performed operations, namely, transportation on a tarmacadam road, rota-tilling (dry soil condition) and rota-puddling (wet soil condition).

2.1 Subjects

Ten representative male subjects were chosen for this study. Average values (±standard deviation) of physical characteristics, i.e. age, stature and body weight of the operators were (28.3±6.9) years, (1665±45) mm and (57.9±10.1) kg, respectively. It was ensured that they were healthy with no physical ailment. The operators selected had more than five years experience of operating the hand tractor for rota-tilling, rota-puddling and transportation. The operators were made acquainted with experimental protocol and their consent was obtained to enlist their full cooperation.

2.2 Tasks

The subjects were required to operate the hand tractor and perform three operations namely, transportation on tarmacadam road, rota-tilling in untilled field and rota-puddling in field with 5 cm standing water. The hand tractor was operated at three gears (H_1, H_2 and H_3) during transportation and at three gears (L_1, L_2 and L_3) during rota-tilling and rota-puddling at about three-quarter of rated engine speed, i.e., 1,500 r/min. The average forward speed of hand tractor was 1.11, 1.71 and 2.31 m/s in H_1, H_2 and H_3 gears, respectively, and 0.30, 0.45 and 0.63 m/s in L_1, L_2 and L_3 gears, respectively. The rotor speed of about 162 r/min was maintained.

2.3 Equipment and accessories

A 6.7 kW hand tractor manufactured in India and commonly used by the farmers was selected for the study. Isolator (engine mounting and handle isolator) recommended by Tewari and Dewangan (2009) was used in the hand tractor. The specifications of the hand tractor are given in Table 1. The hand tractor was fitted with a 600 mm long rotor having 18 tilling blades. C-type tines for rota-tilling and L-type for rota-puddling were fitted on the shaft of the rotor. For the transport operation, a 2-wheel trailer was attached to the chassis of the hand tractor. The total weight on the trailer was about 1 ton including the weight of the operator. The total weight of the hand tractor with full fuel tank and radiator, and lubricating oil was 510 kg. The hand tractor without optional front weights and tire ballast was put in proper test condition before conducting the tests. The recommended tire pressure of 147 kPa was maintained in pneumatic wheels of the hand tractor during transportation and rota-tilling. Length, width and depth of the trade were 11.0, 2.5 and 1.5 cm, respectively. Spacing between two successive trades was 14.5 cm. Lug type iron wheels were used during rota-puddling operation. Dimension of the lug was 18 cm in length and 21.5 cm in width. Spacing between two successive lugs was 28 cm.

Table 1 Important specifications of the hand tractor

Engine model and type	Kamco Kubota, KMB 200, Single cylinder, four-stroke, water cooled, horizontal diesel engine
Swept volume, cc	744
Rated power, kW	6.7 kW at 2,000 r/min
Number of speeds	6 forward, 2 reverse
Rated speed range, m/s	0.42–3.37 forward, 0.36–1.34 reverse
Number of rotavator speeds	2
Speed of rotavator tines at engine speed of 2000 r/min, r/min	315 high, 215 low
Dry weight of engine, kg	145
Weight of hand tractor with full fuel tank, radiator and lubricating oils, kg	510
Tyre type, mm	Lugged rubber/steel wheel
Tyre size (pheumatic), mm	152.4×305
Tyre inflation pressure, kPa	147
Wheel size (steel), mm	792
Width of tilling, mm	600
Number of tines	18

Other accessories employed during the study were handle adapter, light weight tri-axial accelerometer (356A22, PCB, USA), 3-channel signal conditioner (Indo Computers and Controls, India), and 8-channel data acquisition and analysis system (Indo Computers and Controls, India).

2.4 Handle grip

Handle grips made of either plastic or rubber are used in the machines. In the power tiller, hard rubber is used. Since the soft material absorbs vibration, therefore, two handle grips made of soft rubber were randomly selected (Figure 1). Two types of handle grips were designated as HG_1 and HG_2. These handle grips are commercially available in Indian market. HG_1 was made of foam rubber and HG_2 was made of styrene butadiene rubber. Thickness of the isolating materials on the handle grips were 4 and 3 mm by HG_1 and HG_2, respectively.

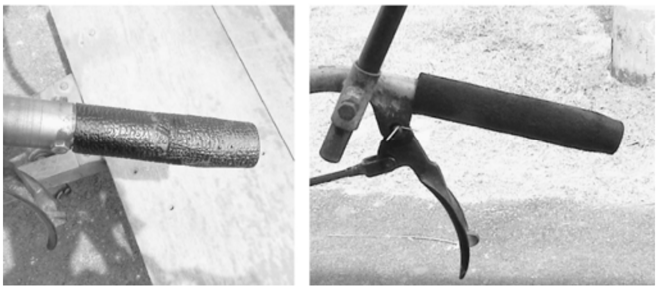

Figure 1 Two types of handle grips used in the study

2.5 Field layout experiment

The experiment on hand-transmitted vibration was conducted in split-split-plot design where different operations were taken as main-plot, different handle grips as sub-plot and speed of operation as the sub-sub-plot. The operators were taken as replications. In order to increase accuracy, three trials were conducted with each operator for each of the above conditions and the mean value of these trials was taken as the representative value for that replication. The treatments were randomized in order to minimize the effects of variation in the soil and environmental conditions.

The surface condition of tarmacadam road was dry and level with medium surface finish. Rota-tilling and rota-puddling were conducted under clay loam soil (55% clay, 30% silt and 15% sand) at the Research Farm of the Department of Agricultural and Food Engineering, Indian Institute of Technology Kharagpur, India. Average soil moisture content, bulk density and weed intensity in the experimental plots were 14.6% (db), 1.63 g/cm^3 and 18 g/m^2 (db), respectively. Depth of operation during rota-tilling and rota-puddling operation was fixed at about 10 cm. For depth control, a rear wheel was used during rota-tilling operation and a tailskid was used during rota-puddling operation.

All the trials were conducted between 9:00 to 12:00 and 15:00 to 17:00 during the month of September to December. The observed variations in the mean dry bulb temperature, relative humidity and wind velocity during the tests were 20.01-30.06℃, 11.0%-29.0%, and 0.42-1.01 m/s, respectively.

2.6 Data collection

For measuring vibration acceleration at the handle grip of the hand tractor during actual operation, the accelerometer was mounted on a hand adapter and the hand adapter was fixed on the right side of the handle grip of the hand tractor by nylon clamps (Figure 2). The recommendation of ISO 5349-1 (2001) was followed for orientation of the measurement axes (Figure 3). The inclination of the metacarpus bone, when the hand grasped the grip, was 45° to the vertical (Figure 2). The schematic diagram of the experimental set up for measuring vibration acceleration is shown in Figure 4.

One of the selected subjects for the experiment was asked to operate the hand tractor (already started and engine throttle position set at three quarters of rated engine speed by another person). The vibration acceleration at various gear settings at the handle grip was recorded in the data acquisition system for the trial distance of 30 m. The experiment was repeated for all the ten operators with three operations, i.e., transportation, rota-tilling and rota-puddling. The entire experiment was replicated three times. The data stored in the data acquisition system were downloaded in a personal computer at the end of experiment for analysis.

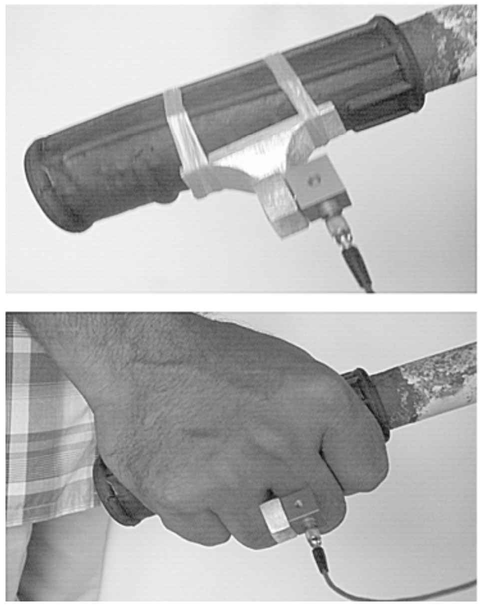

Figure 2 Mounting of accelerometer and hand adapter on existing handle grip of the hand tractor

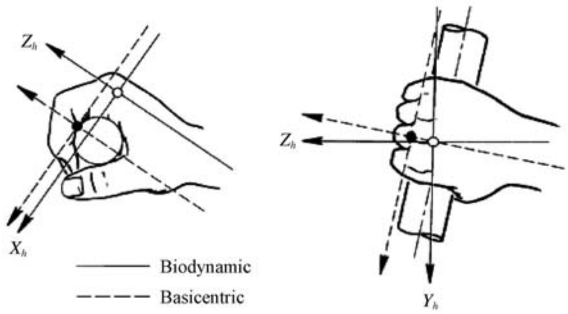

Figure 3 Anatomical and basicentric coordinate system for hand

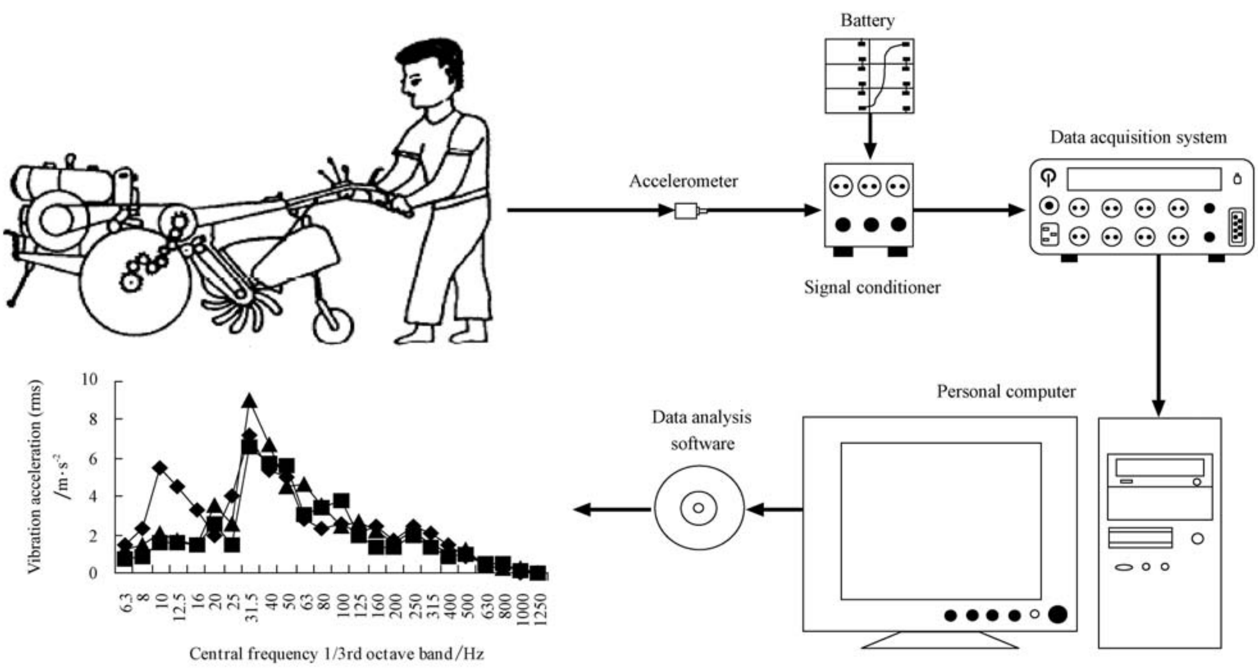

Figure 4 Schematic diagram of the experimental setup for measuring hand-transmitted vibration

At the end, the subject was asked to take rest until he felt normal again and ready for the next bout of work. The operator was asked to operate the hand tractor at the 2nd gear for duration of 30 min. After the work, the general discomfort rating in 10-point scale was asked for the performance evaluation of the handle grips. This scale is generally used for assessment of chair comfort /discomfort (Griffin, 1996). The experiment was repeated for all the ten subjects with three operations, i.e., transportation, rota-tilling and rota-puddling.

2.7 Data analysis

A real-time frequency analyser was used to obtain fast Fourier transform (FFT) analysis of the data in 1/3rd octave bands centred from 6.3 to 1,250 Hz. Frequency-weighted root mean square (rms) values of vibration acceleration (a_{hwx}, a_{hwy}, and a_{hwz}) were calculated according to the weighting factors as suggested in ISO 5349. Frequency-weighted vibration acceleration is calculated as

$$a_{h,w} = \left[\sum_{j=1}^{n} (k_j\, a_{h,j})^2 \right]^{1/2} \tag{1}$$

Where: k_j is the weighting factor for the j^{th} octave; $a_{h,j}$ is the rms acceleration measured in octave bands used in m/s^2; n is the number of octave band and its value is 24 in 1/3rd octave band.

From frequency-weighted vibration acceleration (rms) of three axes, vibration total value (a_{hv}) was calculated for each subject. Vibration total value may be determined as (ISO 5349-1, 2001)

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

Where: a_{hv} is the total rms acceleration at the handle in m/s^2; a_{hwx}, a_{hwy} and a_{hwz} are the frequency-weighted vibration acceleration (rms) in the X_h-, Y_h- and Z_h-axes respectively in m/s^2.

Average of three trials of a subject was calculated. Average of vibration acceleration of all the ten subjects was calculated, which represented vibration exposure during operation of the hand tractor. The vibration acceleration measured after installation of handle grips (HG_1 and HG_2) was subtracted from vibration acceleration measured in the hand tractor with existing handle grip to get the reduction in vibration acceleration. Vibration reduction was also calculated for spectrum of vibration acceleration in frequency range from 6.3 to 1,250 Hz.

Analysis of variance (ANOVA) was calculated to obtain the effect of speed of operation and type of handle grips on reduction of frequency-weighted vibration acceleration (rms) during transportation, rota-tilling and rota-puddling.

3 Results and discussion

3.1 Effect of speed of operation on vibration reduction

Table 2 shows frequency-weighted vibration acceleration (rms) at the handle grip during transportation, rota-tilling and rota-puddling. It can be seen that frequency-weighted vibration acceleration (rms) during transportation varied from 5.39 to 7.68 m/s^2 with increase in speed of operation from 1.11 to 2.31 m/s when the existing handle grip was installed on the hand tractor. In the same condition of the hand tractor, vibration acceleration varied from 3.72 to 4.94 m/s^2 during rota-tilling and 4.84 to 5.99 m/s^2 during rota-puddling at forward speed of operation from 0.30 to 0.63 m/s. When the handle grip HG_1 (foam rubber) was installed on the hand tractor, frequency-weighted vibration acceleration (rms) varied from 4.82 to 6.85 m/s^2 with increase in speed of operation from 1.11 to 2.31 m/s during transportation and 3.25 to 4.32 m/s^2 and 4.34 to 5.34 m/s^2 with increase in speed of operation from 0.30 to 0.63 m/s during rota-tilling and rota-puddling, respectively. Frequency-weighted vibration acceleration (rms) varied from 5.13 to 7.30 m/s^2 during transportation at forward speed of operation from 1.11 to 2.31 m/s, when handle grip HG_2 (styrene butadiene rubber) was used. In the same condition of the hand tractor, vibration acceleration varied from 3.52 to 4.65 m/s^2 during rota-tilling and 4.60 to 5.68 m/s^2 during rota-puddling at forward speed of operation from 0.30 to 0.63 m/s.

Table 2 Mean and SD (standard deviation) of frequency-weighted vibration acceleration (rms) in m/s^2 with handle grips (existing, HG_1 and HG_2) and reduction of vibration during transportation on tarmacadam road, rota-tilling in dry land and rota-puddling in wet land

Particulars	Forward speed /m • s^{-1}	Frequency-weighted vibration/m • s^{-2}						Reduction in vibration/%	
		Existing handle grip		Handle grip, HG_1		Handle grip, HG_2			
		Mean	SD	Mean	SD	Mean	SD	HG_1	HG_2
Transportation	1.11	5.39	0.48	4.82	0.51	5.13	0.50	10.57	4.82
	1.71	6.50	0.56	5.80	0.46	6.18	0.65	10.77	4.92
	2.31	7.68	0.67	6.85	0.42	7.30	0.58	10.87	4.95
Rota-tilling	0.30	3.72	0.86	3.25	0.32	3.52	0.35	12.63	5.38
	0.45	4.45	0.85	3.89	0.36	4.21	0.43	12.60	5.40
	0.63	4.94	0.77	4.32	0.45	4.65	0.47	12.56	5.87
Rota-puddling	0.30	4.84	0.46	4.34	0.53	4.60	0.57	10.34	4.96
	0.45	5.38	0.50	4.81	0.58	5.11	0.60	10.60	4.95
	0.63	5.99	0.68	5.34	0.64	5.68	0.65	10.85	5.22

Figures 5 and 6 show the effects of handle grip at different speeds on frequency-weighted vibration acceleration in rms during transportation, and rota-tilling and rota-puddling, respectively. It is clear that the increase in speed of operation has a significant (p<0.01) effect on vibration reduction (Table 3). Reduction of vibration acceleration increased from 0.57 to 0.84 m/s^2 (10.57% to 10.87%) by handle grip, HG_1 and 0.26 to 0.38 m/s^2 (4.82% to 4.95%) by HG_2 with increase in speed of operation from 1.11 to 2.31 m/s during transportation. Reduction of vibration acceleration was 0.47 to 0.62 m/s^2 (12.63% to 12.56%) by HG_1 and 0.20 to 0.29 m/s^2 (5.38% to 5.87%) by HG_2 with increase in speed of operation from 0.30 to 0.63 m/s, respectively during rota-tilling. However, at the same speed, reduction of vibration was 0.50-0.65 m/s^2 (10.34% to 10.85%) by HG_1 and 0.24-0.31 m/s^2 (4.96% to 5.22%) by HG_2, respectively during rota-puddling. Frequency-weighted vibration reduction was maximal during rota-tilling operation and minimal during rota-puddling operation. Average reduction of vibration was 12.60% to 5.55% by HG_1 and HG_2, respectively during rota-tilling, 10.74% and 4.90% by HG_1 and HG_2 respectively during transportation and 10.60% to 5.55% HG_1 and HG_2, respectively during rota-puddling. Vibration reduction was more by HG_1 as compared to HG_2 during entire experiment and there is significant (p<0.01) difference in reduction of vibration acceleration between two handle grips, i.e., HG_1 and HG_2 (Table 3). Interaction between speed of operation and handle grip was significantly (p<0.01) different during transportation only. This shows the non-linear characteristics of handle grips.

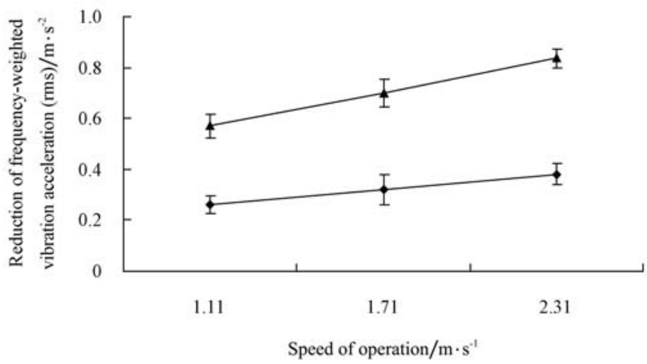

Figure 5 Reduction of frequency-weighted acceleration in rms of different handle grips during transportation

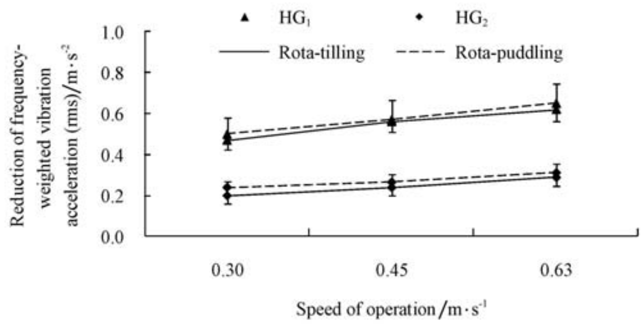

Figure 6 Reduction of frequency-weighted vibration acceleration in rms of different handle grips

Table 3 Analysis of variance (ANOVA) for the effect of forward speed of operation and handle grips on reduction in frequency-weighted vibration acceleration in rms

Sl. No.	Source of variation	Degree of freedom	Sum of square	Mean square	Calculated F	Tabular F	
						5%	1%
	Transportation						
1	Replication	9	0.04	0.00	2.31	2.46	3.60
	Speed (S)	2	0.30	0.15	84.86**	3.55	6.01
	Handle grips (HG)	1	2.04	2.04	1157.98**	4.06	7.23
	S X HG	2	0.03	0.02	9.61**	3.21	5.11
	Rota-tilling						
2	Replication	9	0.02	0.00	1.00	2.46	3.60
	Speed (S)	2	0.14	0.07	33.67**	3.55	6.01
	Handle grips (HG)	1	1.44	1.44	697.29**	4.06	7.23
	S X HG	2	0.01	0.01	2.82	3.21	5.11
	Rota-puddling						
3	Replication	9	0.06	0.01	1.34	2.46	3.60
	Speed (S)	2	0.12	0.06	13.11**	3.55	6.01
	Handle grips (HG)	1	1.38	1.38	291.26**	4.06	7.23
	S X HG	2	0.02	0.01	1.61	3.21	5.11

Note: * Significant (p<0.05), ** Significant (p<0.01).

Reduction of vibration in the present study may be due to two reasons. First, handle grips were made of foam rubber. Foam rubber reduces vibration. Björing et al. (1999) reported that foam rubber attenuates vibrations of about 15%. Less attenuation of vibration in present study might be due to variation in characteristics of foam rubber. However, Radwin and Haney (1996) have observed that compressible/resilient materials on the handle have reduced vibration but not significantly. Second, foam rubber is soft material. When soft material is used as handle grip, the operator has the sense of loss of control during handling of the machine. So the operator grips the handle tightly. The handle of the hand tractor is cantilever beam, therefore, increase in grip force might have reduced hand-transmitted vibration at the handle (Ying, et al., 1998). Increase in reduction of vibration in absolute value with increase in speed of operation may be due to higher vibration acceleration at higher speed. But vibration reduction in percent with increase in speed of operation was more or less constant.

3.2 Vibration reduction in different directions

Figure 7 illustrates the characteristics of different handle grips on frequency-weighted vibration acceleration (rms) in all the three orthogonal axes during transportation at 1.11 m/s. It can be seen that vibration was reduced from 4.26 to 3.73 m/s^2, i.e., about 12.3% with handle grip HG_1 in the dominant X-axis (perpendicular to the second metacarpus bone of the hand), which is dominant direction of vibration. However, in the same direction, vibration was reduced to 3.97 m/s^2, i.e., about 7.3% with handle grip HG_2. The highest reduction of vibration in the X-axis may be due to higher level of vibration in the X-axis and higher grip force. The operators use a palm grip while operating the hand tractor and sometimes they lift the rear portion of hand tractor. The direction of pulling/pushing force applied by the operators is normal to their palm, which corresponds to the X-axis of vibration. Ying et al. (1998); Tewari and Dewangan (2009) also observed that an anti-vibration device mounted on walking tractor resulted in the highest vibration reduction along the X-axis. Furthermore, vibration reduction characteristics of a rubber depend on its elastic stiffness and damping coefficient which determines the transmissibility characteristics of the rubber. But the isolation characteristic under dynamic conditions varies with the amplitude and frequency of excitation. Foam rubber and styrene butadiene rubber may have different stiffness and damping coefficient. Vibration acceleration in all the three directions is different; therefore, vibration reduction by both the handle grips in various axes (direction) might be different.

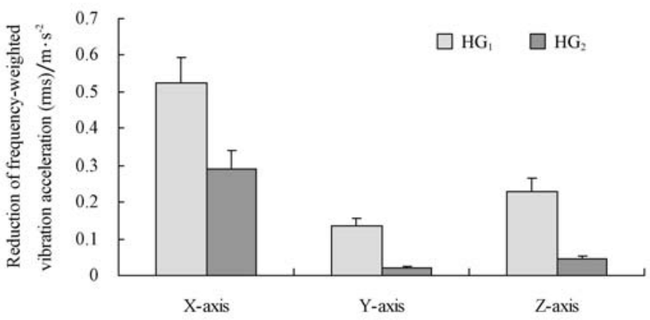

Figure 7 Effects of different handle grips on reduction of frequency-weighted vibration acceleration in rms at various axes during transportation at 1.11 m/s

Vibration reduction was minimum in the Y-axis (parallel to the longitudinal axis of the grip). Similar trend of vibration reduction was seen at different speeds and the other two operations, i.e., rota-tilling and rota-puddling.

3.3 Frequency spectrum of vibration acceleration

The effect of handle grips on the frequency-weighted vibration acceleration in rms at 1/3rd octave bands having centre frequencies from 6.3 to 1,250 Hz is shown in Figure 8. It can be seen that the performance of handle grips varied considerably below 40 Hz and there was negligible vibration reduction in the frequency range from 63 to 1,250 Hz. Furthermore, they had a tendency to amplify vibration in the frequency range of 8.0 to 12.5 Hz by handle grip, HG_1 and 25 to 100 Hz by HG_2. The weighting factor of the vibration is very high at lower frequency and it is very low at high frequencies. Since amplification of vibration at lower frequency is low as compared to reduction of vibration at middle frequency, therefore reduction of frequency-weighted vibration was high by handle grip HG_1. Though, vibration was reduced at lower frequency but reduction was small therefore, reduction of frequency-weighted vibration acceleration was less by handle grip HG_2 as compared to HG_1. Vibration reduction was maximum by handle grip, HG_1 in the frequency range from 20.0 to 31.5 Hz. Björing et al. (1999) also observed the highest reduction in vibration at 31.5 Hz on power hand drill. The foam rubber handle attenuated this frequency better than the hard rubber and also compared with the handle without rubber cover.

Similar trend of vibration reduction was seen at different speed and other two operations, i.e., rota-tilling and rota-puddling.

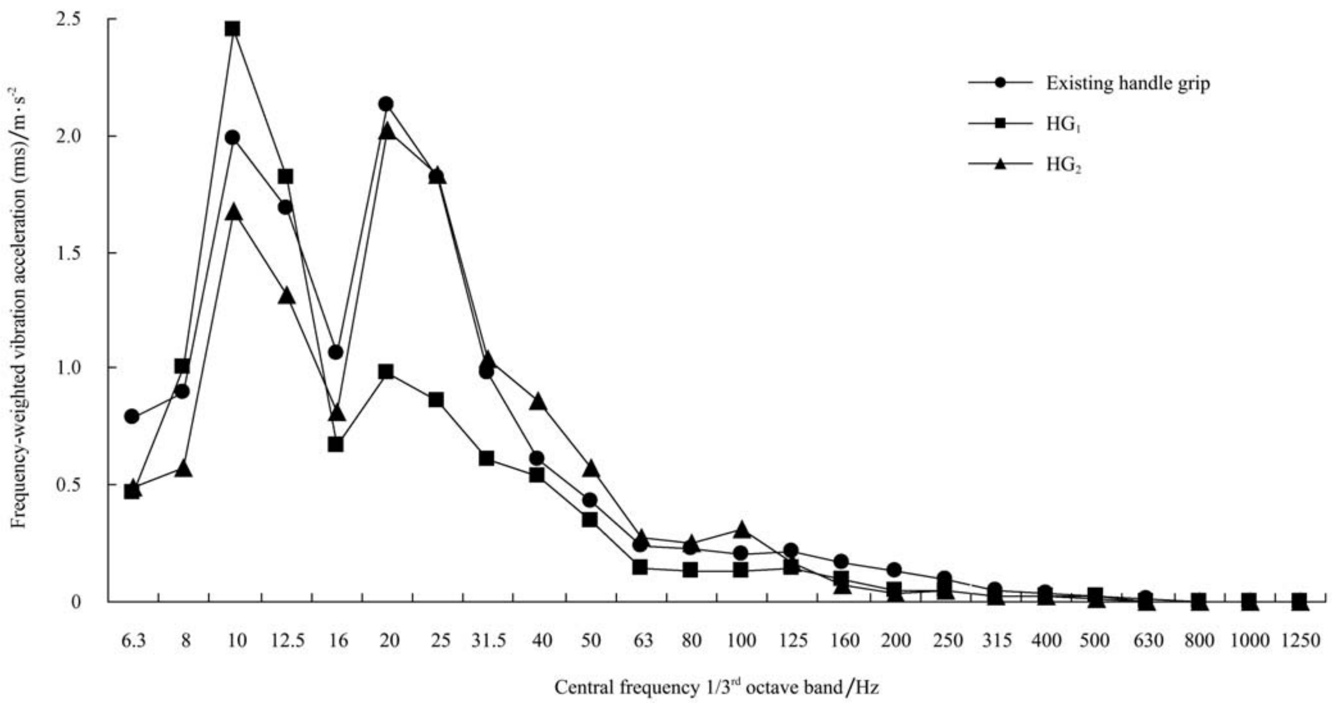

Figure 8 Frequency-weighted vibration acceleration in rms at 1/3rd octave band during roto-tilling operation at 0.30 m/s

3.4 Subjective rating

Mean discomfort rating of the selected handle grips are given in Figure 9. It was observed that handle grip, HG_1 was rated to give the lowest discomfort with 2.3, 2.6 and 2.7 with standard deviation of 0.39, 0.25 and 0.28 during transportation, rota-tilling and rota-puddling operation, respectively. It was also preferred by the subjects for handle grip as compared to the existing handle grip of hand tractor. Soft material is easier on the hand. It distributes the surface pressure more evenly in the hand compared with an incompressible material. The increased uniformity of the force distribution for the foam grips may have contributed to their increased preference for the foam grip. It should be noted that the subjects generally prefer the uniform distribution of contact force. This seems reasonable, since any highly localized forces should correlate well with friction blister formation (Fellows and Freivalds, 1991). Foam rubber is preferable covering material in the handle from ergonomics point of view (Björing, et al., 1999). It is often recommended that the handle surface should be smooth and slightly compressible (Mital and Kilbom, 1992). Björing et al. (1999) also reported that most of the operator ranked foam rubber as the most comfortable and the hardest rubber handle as the least comfortable.

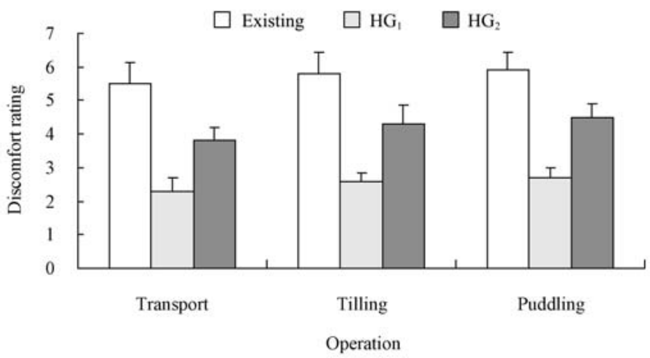

Figure 9 Discomfort rating of the handle grips during various operations

4 Conclusions

The following major conclusions can be drawn from the present investigation.

1) Frequency-weighted vibration acceleration (rms) reduction was maximal during rota-tilling operation and minimal during rota-puddling operation. Average reduction of vibration was 12.60% to 5.55% by handle grips, HG_1 and HG_2, respectively during rota-tilling, 10.74% and 4.90% by HG_1 and HG_2, respectively during transportation and 10.60% to 5.55% by HG_1 and HG_2, respectively during rota-puddling;

2) Average reduction of frequency-weighted vibration acceleration (rms) in the X-axis was the highest;

3) Handle grip made of foam rubber was preferred by all the subjects over the existing handle grip of the hand tractor.

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