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Assessment of hand-transmitted vibration in self propelled vertical conveyor reaper

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■ **ABSTRACT :** The self propelled vertical conveyor reaper is commonly used for harvesting wheat, rice etc. It has become a main or the sole of mechanical power source on small and medium size farms in India. The operators of VCR are exposed to a high level of vibration arising from single cylinder engine during field operations. The vibration from the VCR is transmitted from handle to hands, arms and shoulders. The detrimental effect of the prolonged exposure to hand-transmitted vibration on the operators has been known for a long time. In the present study, experiments were conducted to assess the vibration extent in VCR for two operational conditions *i.e.* transportation on bitumen road and wheat harvesting operation. The vibrations were measured at engine speed 2200 and 2800 rpm. In this study it was found that the vibration magnitudes decreased with increase in engine speed from 2200 to 2800 rpm in both operational conditions. The highest vibration values were observed in x-direction. The maximum frequency-weighted vibration acceleration (rms) in x-direction was 18.76 and 22.8 ms^{-2} in transportation and wheat harvesting. One third octave band frequency spectra were also obtained. The peak acceleration appeared around 50 Hz for both transportation and wheat harvesting at engine speed 2200 and 2800 rpm. The average 8 hour exposure time for occurrence of white finger syndrome was 1.16 and 0.93 years at transportation and wheat harvesting operation.

■ **KEY WORDS :** VCR, Engine speed, Wheat harvesting, Vibrations, White finger syndrome

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The presence of a large number of small holding has rendered the self propelled vertical conveyor reaper (VCR) to be suitable farm power source in view of its compact size, versatility and cost.Self-propelled vertical conveyor reapers are used in developing countries for harvesting of rice, wheat etc.The demand of VCR is 4000-5000 per year (Mehta *et al.,* 2014). In VCR, one of the major safety concerns has been to a high intensity of hand-transmitted vibration. Hand-transmitted vibration of the VCR is very severe as the handle grip is a cantilever beam, and the power is obtained from a single cylinder diesel engine (Ying *et al.,* 1998). The hand-transmitted vibration is transmitted to the hands, arms and shoulders resulting in discomfort to the operator and an early fatigue to the operator. Such fatigue experienced over a period of months and years may cause physical, physiological and musculoskeletal disorders (Waersted and Westgaard, 1991 and Buckle, 1997). The detrimental effect of the prolonged exposure to hand-transmitted vibration on the operators have been known for a long time and the occupational health disorder are referred to as “vibration induced white finger” (VWF) or “hand-arm vibration syndrome” (HAVS). The walking type VCR is controlled and operated by human beings. The operator has to guide the machine by walking behind it. He is exposed to extreme environmental conditions like temperature, humidity, noise and high level of vibration arising from the dynamic interaction between the element and the working medium while performing harvesting operation.The symptom which includes effects on peripheral circulation, the peripheral nerves or the musculoskeletal system has also been recognized as important occupational disease. Therefore, there was need to measure the level of vibration of VCR considering the effect of long term use of machine. The experiment was conducted in Department of Farm Machinery and Power Engineering, CTAE, MPUAT, Udaipur.

METHODOLOGY

Self propelled vertical conveyor reaper (VCR):

A 5hpVardaan-2FD walk behind self propelled vertical conveyor reaper (Fig. A) manufactured in India and commonly used by the farmer was selected for study. The VCR was powered with single cylinder four-stroke, air-cooled diesel engine. The power of the engine was transmitted to the transmission box with the help of V-belt and pulley. From the transmission box power was transmitted to ground wheels and the reaping bevel box. Then again from the reaping bevel box power was transmitted to crank pin and pitman shaft to drive the cutter bar assembly. Two levers had given, one for engaging and disengaging the drive of the engine and another one for engaging and disengaging the movement of cutter bar assembly. The specifications of VCR are given in the Table A.

Fig. A : Self propelled vertical conveyor reaper (VCR)

Table A : Specifications of self-propelled Vertical Conveyor Reaper (VCR)

Parameters	Specifications
Engine model	Greaves-5520
Type	Single cylinder, four stroke, air-cooled, diesel engine
Rated power, kW	3.7
Rated engine speed, rpm	3000
Number of forward speed	One
Number of reverse speed	One
Specific fuel consumption, g $kW^{-1}h^{-1}$	299
Fuel tank capacity, l	4.00
Weight of engine, kg	46
Net weight of VCR, kg	230
Power transmission system	Engine to main drive pulley through belt and V-pulley
Width of cutter bar, mm	1200
Speed of cutter bar, strokes min^{-1}	1326
Stroke length, mm	73
Type of wheel	Pneumatic
Inflation pressure, kg/cm^2	0.25
Tyre size	5.00 × 12

Instrumentation:

A SVAN 958, four channel vibration analyzer was used in this study (Fig. B). SVAN 958 analyzes the frequency range from 0.5 Hz to 20 kHz. Each of four channels work simultaneously with independently configured input (transducer type), filters, and RMS detector time-constants. The digital signal processor can perform advanced frequency analysis simultaneously to the meter mode for real-time four-channel 1/1 octave or 1/3 octave analysis including statistical calculations, real-time four-channel FFT analysis including cross spectra, and sound intensity measurements. Vibration analyzing fulfils requirements according to ISO-5349 (2001) and ISO-2631-1 (1997). The vibration analyzer has 17.8 ms^{-2} and 316 ms^{-2} two measuring ranges. A four-pin cable makes a connection between the accelerometer and the vibration analyzer. The data stored in the vibration analyzer was downloaded on a personal computer at the end of the experiment for further analysis.

An adapter was used for attachment of transducer

Fig. B : Vibration analyzer

to measure the vibration intensity of hand-arm system. The adapter was made up of the aluminum alloy. A light weight tri-axial accelerometer was fixed by a stud in the adapter to measure hand-arm vibration. The design of the adapter was such that the accelerometer should lie in between the index and middle finger. The total weight of the adapter including the accelerometer was 28.8 g. The adapter was mounted according to the ISO-5349 (2001) on the handle bar of the VCR with the help of the thread. After mounting, the adapter should act as an integral part of the VCR, so that it can sense the actual vibration levels as of the handle of the VCR and there should not be any vibration dampening in between the adapter and handle. The adapter was mounted on the right hand handle bar of the VCR.

To measure the vibration magnitude, one tri-axial accelerometer (Manufacturer-SVAN, Model- SV 3023 M2) of 12 mm × 18 mm × 9 mm and weight 4.02 g was used to measure vibration magnitude. The accelerometer was fixed by a stud in the adapter. The position of hand on the handle bar (Fig. C) was such that it followed the directions according to the ISO standard.

Tasks:

One subject was selected to operate a self propelled walking type vertical conveyor reaper and performs two

Fig. C : Position of hand on the handle with accelerometer

operations, namely transportation on bitumen road (Fig. D) and wheat harvesting (Fig. E). The VCR was operated at two different engine speeds (2200 and 2800 rpm) during the operations. The average forward speed of the machine at engine speeds 2200 and 2800 rpm were 2.02 and 2.57 km/h during transportation and 1.83 and 2.34 km/h during wheat harvesting, respectively. The engine speeds were achieved at the different accelerator lever positions.

In transportation operation the experiments were conducted on bitumen road of Department of Farm Machinery and Power Engineering, CTAE, MPUAT, Udaipur during the period February to March, 2015. The

Fig. D : Measurement of HTV of VCR in transportation on bitumen road

Fig. E : Measurement of HTV of VCR in wheat harvesting operation

road was dry and level with medium surface finish. There was no cutter bar movement of VCR. The Average dry bulb temperature, relative humidity and wind velocity during the experiment were 30^0 C, 27 per cent and 1.5 ms^{-1}, respectively. In wheat harvesting operation the experiments were conducted in farmers filed at Kanpur, near to Udaipur during the period April to May, 2015. The variety of crop was Raj-4120 and the moisture content of crop was 34.7per cent (db). The field was dry and undulated. The Average dry bulb temperature, relative humidity and wind velocity during the experiment were 38^0 C, 20 per cent and 2.3 ms^{-1}, respectively. The average soil moisture content and bulk density before operation were 14.8 per cent (db) and 1.64 g/cc, respectively.

Vibration measurement:

Direction of operation:

It is known that the vibration entering the hand contains contributions from all three measurement directions. Therefore, the measurement should preferably be made for all three directions simultaneously. Fig. F illustrate an anatomical and basicentric coordinate system for measurement of hand transmitted vibration exposure as defined in ISO 5349-a(2001). The coordinate system will then define as: z-axis is defined as the longitudinal axis of the third metacarpal bone and is oriented positively towards the distal end of the finger. The x-axis passes through origin, is perpendicular to the z-axis and is positive in the forward direction when the hand is in normal anatomical position (palm facing forwards). The y-axis is perpendicular to the other two axes and positive in the direction towards the fifth finger (thumb). In practice the basicentric coordinate system is used. The system is generally rotated in the y-z plane so that y-axis is parallel to the handle axis.

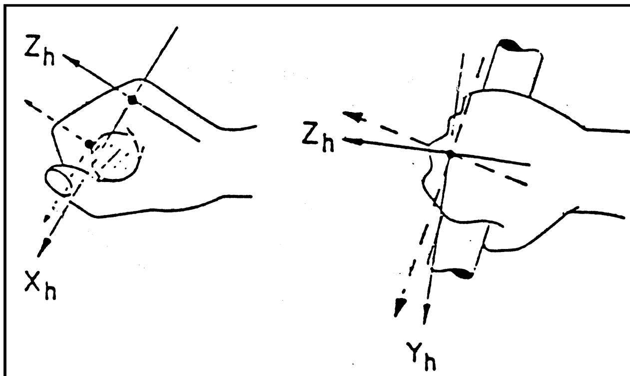

Fig. F : Coordinate system for hand

Magnitude of vibration:

When the human body is in contact with a vibrating mechanical device, it is displaced about its contact position (Sanders and McCormic, 1993). Displacement is therefore one parameter which can be used to describe the magnitude of a vibration. Although displacement, velocity and acceleration can be used for quantifying the vibration severity. Human response to vibration is highly dependent on the frequency of the vibration. As per the ISO 5349(2001) recommendations, the most important quantity used to describe the magnitude of vibration transmitted to the operator's hands is root mean square (rms) frequency weighted acceleration in ms^{-2} expressed as

$$a_{hw} = \left[\sum_{j=1}^{n} (W_h a_{hj})^2 \right]^{\frac{1}{2}} \qquad (1)$$

where

a_{hw} = Root mean square (rms) frequency weighted acceleration

W_h =Weighting factor for j^{th} one-third octave band

a_{hj} = rms acceleration measured in one-third octave band used in ms^{-2}

n = Number of frequencies used in the octave band

The weighted value should be determined over the eight octave bands (*i.e.* n=8) from 8 to 1000 Hz or over the 24 one third octave bands (*i.e.* n=24) from 6.3 to 1250 Hz. The one- third octave band is very common and is adopted in the ISO 5349 (2001). The sensitivity of body to different frequencies is different, so weighting factor for different frequency bands are defined in ISO 5349-a (2001). It is clear from the table that the hand-arm vibration is more sensitive to the frequency range of 6.3 to 31.5 Hz.

Vector sum of the frequency weighted acceleration (Vibration total values) in three axes represents the acute effects better than does the weighted acceleration in the main axis alone. This is the vibration total value a_{hv} and it is defined as the rms of the three component values given below:

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

where

a_{hv}=total rms weighted acceleration at the handle in ms^{-2}

a_{hwx}=rms weighted acceleration in x-axis in ms^{-2}

a_{hwy}= rms weighted acceleration in y-axis in ms^{-2}

a_{hwz}=rms weighted acceleration in z-axis in ms^{-2}

Therefore the vector sum of vibration intensity is virtually independent of the orientation of the coordinate system.

The daily vibration exposure in terms of 8-h energy equivalent was derived from the magnitude of the vibration (vibration total value) and daily exposure duration. In order to facilitate comparison between daily exposures of different durations, the daily vibration exposure were expressed in terms of 8-h energy equivalent frequency-weighted vibration total value, a_{hv} as shown in the eq. 2 as follows:

$$A(8) = a_{hv}\sqrt{\frac{T}{T_0}} \qquad (3)$$

where

A (8) = Daily vibration exposure in terms of 8-h energy equivalent, in ms^{-2}

T = Total daily duration exposure to the vibration a_{hv} (h or sec)

a_{hv} = Vibration total value in ms^{-2}

T_0 = Reference duration of 8 h (28,800 sec)

The following formula was used to estimate exposure duration for finger blanching in 10 per cent of exposed persons as given in ISO-5349 (2001).

$$D_y = 31.8\ [A(8)]^{-1.06} \qquad (4)$$

where

D_y = The group mean total (life time) exposure duration, in years.

A (8) = Daily vibration exposure in terms of 8-h energy equivalent, in ms^{-2}

Assessment of vibration magnitudes during different selected operational condition:

The vibration measurements and analysis were carried. The handle adapter was rigidly fixed on the right side of the VCR by thread. The accelerometer was mounted on the adapter with the help of a stud to measure the vibration intensity at the handle. The handle adapter was fixed such that the inclination of the metacarpus bone, when the hand grasped the grip, was 45^0 to the vertical (Fig. G). The accelerometer mounted on the adapter was tightly secured to avoid any relative motion between the measuring point and the accelerometer. A single subject was used to operate the VCR throughout the experiment. The vibration acceleration was recorded in ms^{-2} at different operating condition with three replications. The buffer step setting was taken as 60 sec and three replications were taken for each set of readings.

Fig. G : Measurement of vibration magnitudes

RESULTS AND DISCUSSION

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

Frequency weighted rms acceleration in different directions:

The hand-transmitted vibration for all the three axes as defined in ISO 5349 (2001) was measured and recorded (eq. 1) in field operations *viz.,* transportation and wheat harvesting for x, y and z direction (Table 1).

Table 1 : Frequency weighted rms acceleration values of hand-transmitted vibration at handle

Operational condition	Engine speed (rpm)	Vibration magnitude in rms acceleration (ms^{-2})		
		x-axis	y-axis	z-axis
Transportation	2200	18.76	6.01	11.46
	2800	8.9	5.07	7.88
Wheat harvesting	2200	22.8	9.6	13.33
	2800	12.43	6.91	10.8

It is evident from the Table 1 that in both operations, vibration magnitudes were higher in the x-direction and lower in the y-direction. It is also clear from the Table 1 that the vibrations were higher in wheat harvesting for all three directions as compare transportation. This was due to undulated field condition and cutter bar movement. In wheat harvesting, the magnitudes in x-direction varied from 22.8 to 12.43 ms^{-2} at engine speed 2200 to 2800 rpm which is higher than transportation. In y and z direction, the hand-transmitted vibration were ranges from 9.6 to 6.91 ms^{-2} and 13.33 to 10.8 ms^{-2}, respectively in wheat harvesting.

Vibration total values:

The total vibration values (ms^{-2}) calculated as shown in eq. (2). It can be seen from the Fig. 1 that the vibration magnitude were maximum at engine speed 2200 rpm as compared to 2800 rpm which depicts that the vibration magnitudes decreases with increase inengine speedin both transportation and wheat harvesting operation. This was due to balance or stable of inertial forces of single cylinder engine in higher engine speed. The similar results were reported by Bahareh *et al.* (2013).

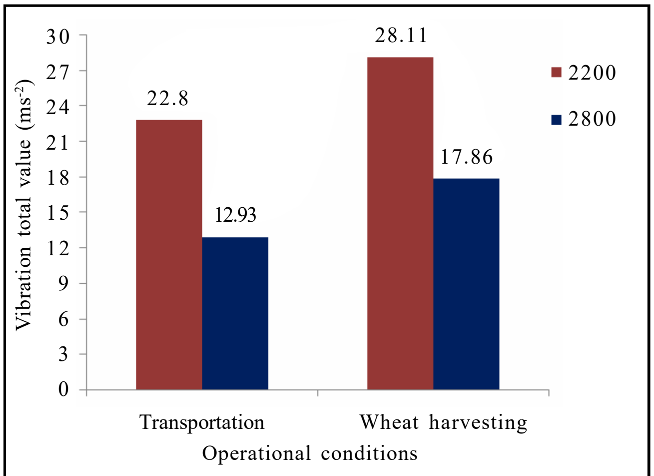

Fig. 1 : Vibration magnitudes

As evident from the Fig. 1 that the observed vibration magnitudes at 2200 rpm were 22.8 and 28.11 ms^{-2} in transportation and wheat harvesting, respectively. Whereas at 2800 rpm, the vibration magnitudes were 12.93 and 17.86 ms^{-2}, respectively.

The analysis of variance of the vibration magnitudes is presented in ANOVA Table 2. The F-value was significant for operational condition and speed at one per cent level of probability also F-value was significant for the interaction of operational condition and speed at five per cent of probability.

One third octave band analysis:

Frequency spectra were obtained for all three axes in both transportation and wheat harvesting without anti-vibration measures. The vibration magnitudes were obtained over a frequency range of 6.3 to 1250 Hz. Fig. 2 shows the one third octave band frequency spectra for wheat harvesting operation at 2200 rpm. The vibration magnitudes were concentrating over a frequency range of 0-200 Hz. Ying *et al.* (1998) also reported the similar trends. They found that most vibrations were concentrated in the frequency range of 0-200 Hz and

Table 2 : ANOVA for vibration magnitudes without anti-vibration measures

Source of variation	D.F	SS	MSS	F-value	S.E.±	CD (P=0.05)
Replication	2	0.009	0.0043	0.182	0.0774	0.2679
Operational condition	1	78.79	78.79	3286.62**	0.0632	0.2187
Speed	1	303.91	303.91	12676.23**	0.0632	0.2187
Operational condition * Speed	1	0.114	0.114	4.75*	0.0894	0.3094
Error	6	0.144	0.023	1.0	0.0774	0.2679

* and ** indicates of significance of values at P=0.05 and 0.01, respectively level of probability

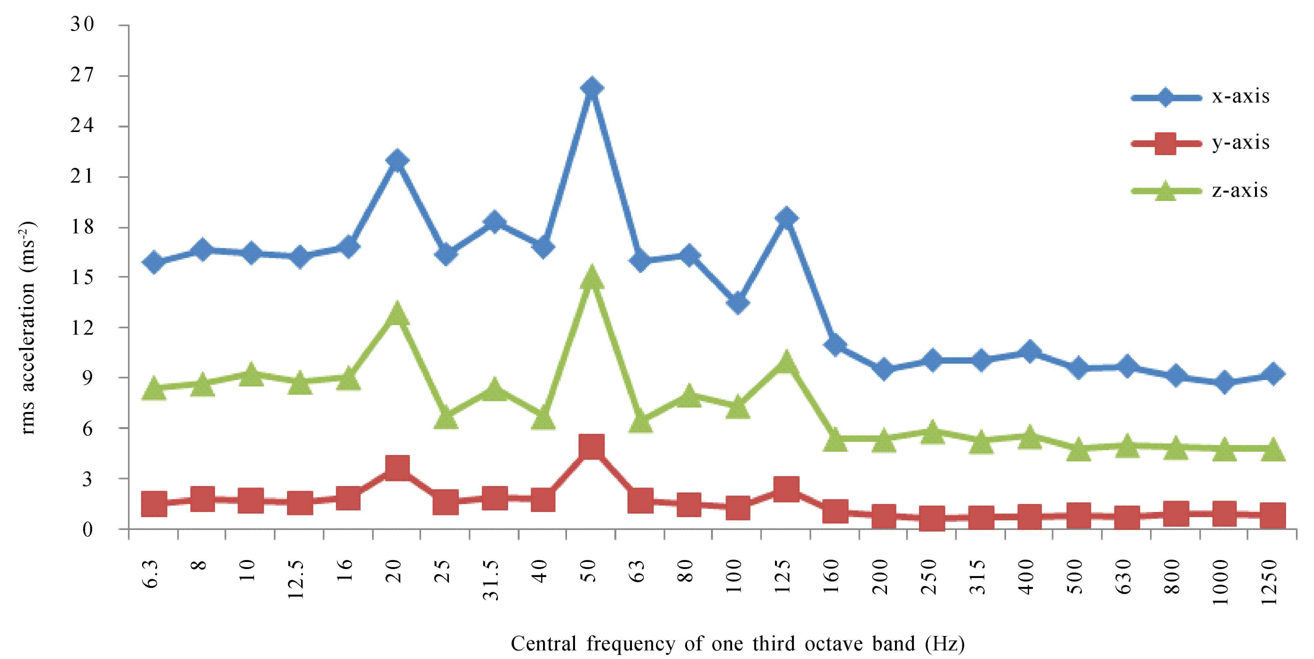

Fig. 1 : Vibration magnitudes of x, y and z directions at 2200 rpm in wheat harvesting

most serious vibration occurs in x-direction.

In one third octave band frequency spectra, the peak acceleration appeared around 50 Hz for both transportation and wheat harvesting at engine speed 2200 and 2800 rpm. Goglia *et al.* (2006) also reported the similar range of frequency for peak accelerations.

However as per ISO 5349-a (2001), the hand-transmitted vibration is more sensitive to the frequency range of 6.3 to 31.5 Hz. The second peak acceleration was obtained at frequency of 20 Hz which causes the more detrimental effect on operators. This may be because of the engine in VCR was the major source of excitation of vibration, its different moving parts vibrate at different frequencies depending on their own degree of freedom and natural frequencies which contribute to further vibration of the whole system. This interference of the vibration makes the vibration of the whole system rather complex and this might possibly be the reason for the appearance of several predominant frequencies.

Assessment of exposure time for white finger syndrome:

The vibration total values were highest at engine speed 2200 rpm for both transportation and wheat harvesting. The exposure limit for 10 per cent of operators as prescribed in ISO 5349 (2001) to have white finger syndrome was calculated as shown in eq. 4. The exposure limit occurrence of white finger for 8-h daily use of self propelled VCR was 0.93 to 1.16 years in transportation and wheat harvesting. The lower exposure limit predicts the heavy vibrations in VCR.

Conclusion:

– The vibration magnitudes decreased with increase in the engine speed from 2200 to 2800 rpm for all three directions in both transportation and wheat harvesting.

– The maximum vibration values were obtained in x-direction for both operational conditions. Higher values of x-direction vibration were major contributor in total vibration value.

– The vibration total values were highest in wheat harvesting. The magnitudes varied from 28.11 to 17.86 ms^{-2} with engine speed from 2200 to 2800 rpm.

– In one third octave band frequency spectra, the peak acceleration appeared around 50 Hz for both transportation and wheat harvesting at engine speed 2200 and 2800 rpm.

– Due to heavy vibration the exposure limit for occurrence of white finger for 8-h daily use of self propelled VCR was less.

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