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RESEARCH ARTICLE

Study of whole body and hand-arm vibration in a small tractor with implements

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Abstract

Mechanization is the main solution to increase work output and also to improve the timeliness of operations. In this regard, tractors are the major prime movers in Indian farms. The sale of tractors in the country was 894112 units in 2023, with exports of 97745 units. The vibration studies have been conducted for tractors of higher horsepower and power tillers, which showed that continuous operation may result in health problems to the operator. Labour shortage has triggered the use of machinery and a safe and comfortable workstation is necessary to improve and increase productivity. Hence, the study on the vibration level of small tractors will aid in reducing the risk of health hazards and in designing safety measures for the tractor operator. The whole body and hand harm vibration studies were conducted at selected speed levels using cultivator and rotavator with 20.13 kW Force tractor and 17.89 kW Kubota tractor. Instruments used to measure whole body and hand-arm vibration were B & K portable four-channel PULSE Multi-analyser 3560 C, Biometrics Data LOG (MWX8) and Accelerometer S2A-16G-MF. The whole body vibration was exceeding the exposure action value of 0.5 ms^2 and Exposure Limit Value of 1.15 ms^{-2} while operating the cultivator, but within the limits when operating the rotavator. The hand-arm vibration was within the Exposure Action Value of 2.5 ms^{-2} and Exposure Limit Value of 5 ms^{-2} for the force tractor. Similar results were obtained for the Kubota tractor; however, the vibration was less than that of the force tractor.

Keywords: accelerometer; frequency; root mean square; small tractor; vibration analysis

Introduction

Mechanization is the main solution to increase work output and also to improve the timeliness of operations. In this regard, tractors are the major prime movers in Indian farms. Sale of tractors in the country was 894112 units in 2023, with export of 97745 units (1). India is also expected to achieve the ambitious goal of doubling the farmers' income by 2030. The average size of the farmland shrunk by over 6 % during 2010-11 and 2015-16, with operative holding in the nation state dropping from 1.15 ha - 1.08 ha in 2010-11. With land holdings receiving less, the proportion of small and marginal holdings in the nation state has increased to 86.20 % of the entire operational holdings of around 126 million in 2015-16, as against 84.97 % in 2010-11 (2). There are many prime movers, most of them from developed countries, aiming to serve large farmers. But for the small and marginal farmers, small machinery will be more suitable. Small tractors are becoming popular nowadays. Though the tractor can be effectively used for field operations, the same should not create any health problems for the operator.

Vibration studies have been conducted for tractors of higher horsepower and power tillers, which showed that continuous operation may result in health problems to the operator (3, 4). Labour shortage has triggered the use of machinery and a safe and comfortable workstation is necessary to improve and increase productivity. Hence, the study on the vibration level of small tractors will aid in reducing the risk of health hazards and designing safety measures for the tractor operator.

Vibration generated from the engine, terrain surface and is transmitted on the workers' body in the seat, from the feet and to the hand arm system from the steering wheel (5). Exposure to whole-body vibration influences performance, comfort and harms to the worker when they are working the tractors for a lengthy duration. Vibration transmission to the human body should be minimized, as the body resonates within the 4-8 Hz range for the trunk and 4-5 Hz for the lumbar vertebrae, potentially causing discomfort or harm. However, the tractor's vibrations were observed in the 1-7 Hz range, which could lead to operator discomfort and potential health risks. Therefore, the investigation of vibration will be supportive in finding out the maximum operational time of a tractor before the occurrence of any health hazard (6).

Many studies have been conducted with respect to the vibration of the tractor during operation in static and dynamic modes. The vibration levels of agricultural tractors with and without a cabin were analyzed and reported that the vibrations in tractors with a cabin were lesser those in tractors without compartment cabin (7). The vibration analysis on the driver's seat of farm tractors during the tillage process was examined and found that the tractors played a key role in vibration development in the lateral axis and was followed by the equipment. The whole body vibration (WBV) transmitted to tractor drivers was analysed (8, 9). The results showed that the supreme transmissibility was detected in the first two frequency levels, 1-5Hz and 6-10 Hz. With short-term exposure to vibration in the 2-20 Hz range at 1 ms^{-2}, one can sense more symptoms such as chest pain, nausea, abdominal pain, loss of equilibrium, shortness of breath, muscle contractions, influence on speech, etc. and long-term exposure may cause saviour health issues. Some of the health effects are discussed here due to whole-body vibration. Spinal column disease and complaints are created because the lower back is more sensitive to a 4 to 12 Hz vibration range. Digestive system disease formed by stomach resonance movement is in the frequency range between 4 and 5 Hz. And cardiovascular system effects at frequencies below 20 Hz.

Next to tractors, power tillers were economic prime movers for small and medium farmers. But the energy spent to operate the power tiller and its limited use made people search for an alternative. Small tractors are becoming popular among farmers due to their low cost and suitability for small farm holdings. It has become a very good substitute for power tillers, where the drudgery to the human body will be significant. Also, the effect of operating the tractors with implements on the operator is not comprehensible. Exposure to whole body vibration combined with forced sitting posture may result in degeneration of the spine along with low back pain. The biomechanical parameters like ride vibration, body sitting posture, pressure distribution between the seat and the buttocks, thighs and the back support, control of posture during static and dynamic conditions play a vital role in increasing health hazards to the operator. A large number of vibration Studies have been conducted on higher HP tractors and power tillers. These studies showed that exposure to whole body vibration, hand-arm vibration and vibration in the leg causes health problems to the operator and reduces the productivity and efficiency of the tractor. This study aimed to assess vibration levels of small tractors in static mode and dynamic mode.

Tractor operators are exposed to whole-body vibration (WBV) through the seat and hand-arm vibration (HAV) through the steering wheel. Prolonged exposure is linked to back pain, fatigue and reduced neuromuscular control, increasing the risk of incidents during long field days. In addition, the excessive vibration degrades ride comfort and control, lowering sustainable operating speeds and field capacity. High vibration loads accelerate wear on seats, mounts, bearings and linkages. Hence, the study was undertaken to measure the whole body and hand-arm vibration which is transmitted through the seat and analyse the data to formulate a suitable system for the reduction of vibration transmitted during farm operation with a tractor.

Materials and Methods

The present study was conducted at the farm, Tamil Nadu Agricultural University, Coimbatore-3. The whole body and hand harm vibration studies were conducted at selected speed levels using cultivator and rotavator with the 20.13 kW power of the Force tractor and 17.89 kW power of the Kubota tractor. A triaxial accelerometer was mounted on the seat pan (between the operator and the seat cushion) to capture vibrations transmitted to the operator's body. For HAV, a triaxial accelerometer was securely attached to the steering wheel rim or grip area to record vibrations transmitted through the hands and arms. These accelerometers were connected to a data acquisition system (DAQ) or portable vibration meter capable of sampling at high frequency and storing time-domain signals. A signal conditioner was often used to filter and amplify the accelerometer output and software was applied to perform frequency weighting (as per ISO 2631-1 for WBV and ISO 5349-1 for HAV) and compute exposure metrics such as RMS acceleration, vibration dose value (VDV) and daily exposure during the study period.

Whole body vibration

WBV is assessed at the points where the body comes into contact with the vibration source. In the case of seated individuals, this typically requires placing accelerometers on the seat surface directly under the ischial tuberosities. Additionally, vibration measurements were taken at the seat back-between the backrest and the occupant's back-as well as at the feet and hands (10). The hand-transmitted vibration is the one transmitted from the steering to the operator's hand and hence it was measured at the operator's hand steering interface. In hand-operated tillers and tractors, handle vibrations primarily result from the reciprocating movement of key mechanical components (11). There are three International standards for whole-body vibration assessment (10, 12). Human exposure to vibration is influenced by numerous factors, which can be categorized as intrinsic (individual-related) and extrinsic (vibration-related). Since intrinsic factors can vary over time, an activity that feels uncomfortable at one moment might go unnoticed at another by the same person. Extrinsic factors include the vibration's intensity (RMS acceleration), frequency and exposure duration. Hence, the existing standards were restricted to the extrinsic variables.

Effects of whole body vibration on human health

Measurement of WBV was concerned with health, comfort, perception and motion sickness. Exposure to whole-body vibration (WBV) can lead to various health effects, including responses to periodic, random and transient vibrations that impact comfort, perception and overall well-being during work. Oscillatory motion may also contribute to kinetosis (motion sickness). While not all effects of WBV cause direct injury or health damage, they can interfere with task performance, affect sensory perception and hinder information processing. Some WBV effects are frequency-dependent, as certain body parts may resonate at specific vibration frequencies. Individuals exposed to vibrations in the 1-30 Hz range often struggle to maintain proper posture. Additionally, some adverse outcomes may arise from the cumulative effect of vibrations across a spectrum of frequencies, leading to issues like imbalance and impaired coordination, etc.

Furthermore, discomfort was directly related to the vibration frequency. Discomfort generally rises as the duration of vibration exposure increases. This relationship was represented by the 'fourth power' formula, commonly expressed as the root-mean-quad (RMQ) or vibration dose value (VDV). Random vibration and multiple-axis vibration produce more discomfort. Vibrations at or below 1 Hz can trigger motion sickness, leading to symptoms such as nausea, dizziness and vomiting, which may impair the safe operation of vehicles. These effects are most severe within the frequency range of approximately 0.125 to 0.25 Hz. Research indicates provides a clear assessment method for all three axes, how they can be integrated and to which postures the final evaluation is shown in Fig. 1 (10).

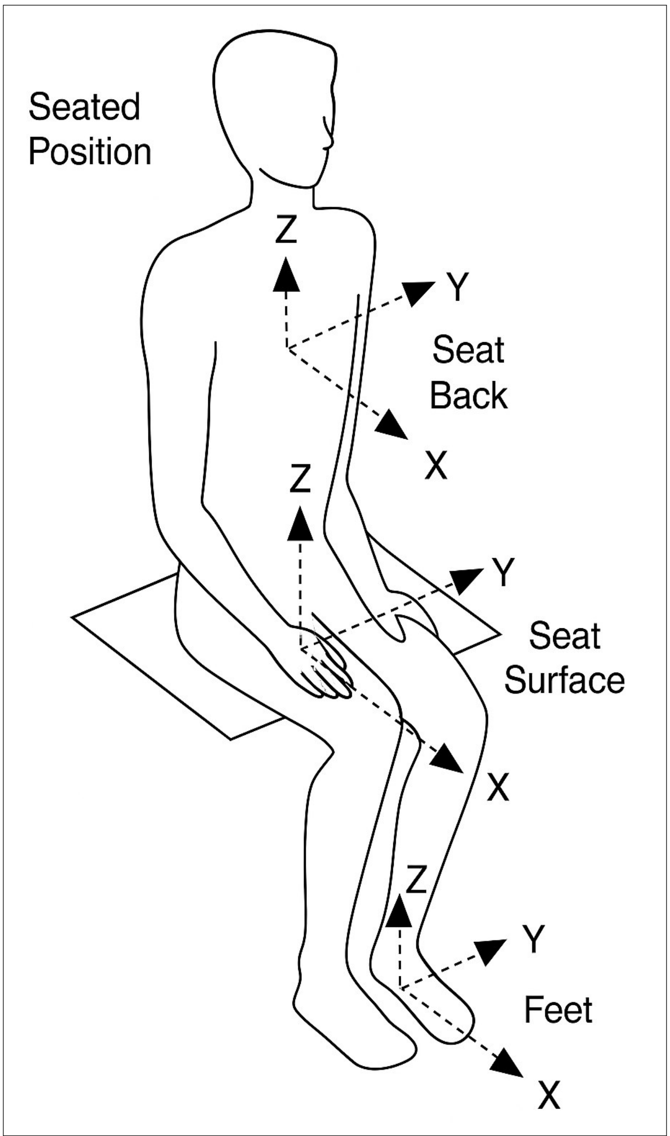

Fig. 1. Vibration through the body in sitting position (17).

Instruments

Instruments used to measure whole body and hand-arm vibration were B & K portable four-channel PULSE Multi-analyser 3560 C, Biometrics DataLOG (MWX8) and Accelerometer S2A-16G-MF.

Measurement of whole-body vibration

Where vibration enters the body from a rigid surface (e.g. floor or hard seat), it was adequate to measure the movement of the surfaces close to the primary contact areas between the body and the surface (e.g. within 100 mm of the centre of this area) (12). When vibration was transmitted to the body through a flexible or cushioned material (such as a seat cushion or sofa), it was essential to place the transducer between the individual and the main contact areas of the surface. The mounting should not significantly affect the pressure distribution on the surface of the resilient material. Ride vibrations were measured by a triaxial accelerometer.

The tri-axial accelerometer was positioned on the operator's seat at the interface between the operator and the seat to measure ISO-weighted RMS acceleration levels along three perpendicular axes: vertical (az), longitudinal (ax) and lateral (ay) (10). The vibration-measuring device was equipped with a frequency-weighted electronic network, covering a frequency range of 1-80 Hz, ensuring that its vibration response closely matched that of the human body. It delivered an average normalized ride vibration over a test period of 60 s. The measurement was made beneath the ischial tuborisities.

Frequency weighting by the one-third octave bandwidth method

All the measured acceleration values obtained from the instrument were frequency weighted and represented in a one-third octave bandwidth method, as shown in Fig. 2. This was the common method of representing the whole body vibration spectrum. In this method, each vibration type recording would be analyzed into one-third octave component accelerations for the given centre frequencies. The r.m.s. values of each component shall be averaged over the duration specified for the measurement.

Assessment of whole body vibration

According to the Indian standards, the whole body vibration algorithms were implemented (10).

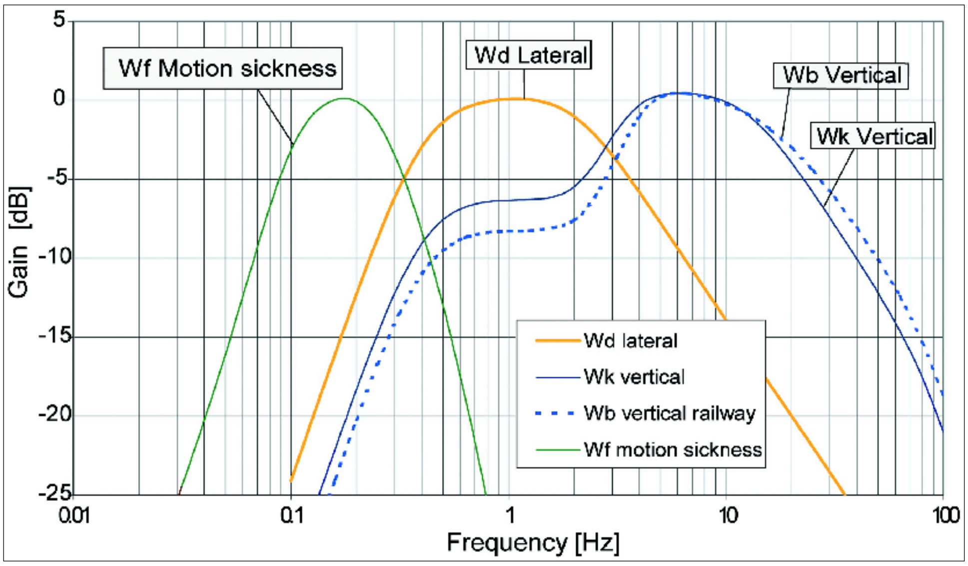

Fig. 2. Frequency weightings.

Likely subjective reactions

The rough estimates of the expected responses to different levels of frequency-weighted RMS acceleration are furnished in Table 1 (12). The likely reaction of the subjects was determined by following the Table below.

Table 1. Likely reaction of the subjects to the whole body vibration

S. No.	Acceleration (ms^{-2})	Likely reaction of the subjects
1.	< 0.315	Not uncomfortable
2.	0.315-0.630	A little uncomfortable
3.	0.5-1.0	fairly uncomfortable
4.	0.8-1.6	Uncomfortable
5.	1.25-2.5	Very uncomfortable
6.	> 2.0	Extremely uncomfortable

Measurement of hand-transmitted vibration

Hand-arm vibration (HAV) is the vibration entering the body through the hand. It may be through one hand or both hands and the vibration will be transmitted to the shoulder. Studies showed that vibration can impact both the biomechanical function and muscle activity of the hand-arm system. The hand-arm system was particularly sensitive to vibrations in the lower frequency range (13). The hand-transmitted vibration very much influences the biological effect of the hand based on the method of working, proficiency and climatic conditions (14). The most serious vibration was obtained in the x-direction, when testing a walking tractor in static condition with engine speed of 3000 rpm (15). Hand-transmitted vibration was measured at the steering grip level, as shown in Fig. 3 (16, 17).

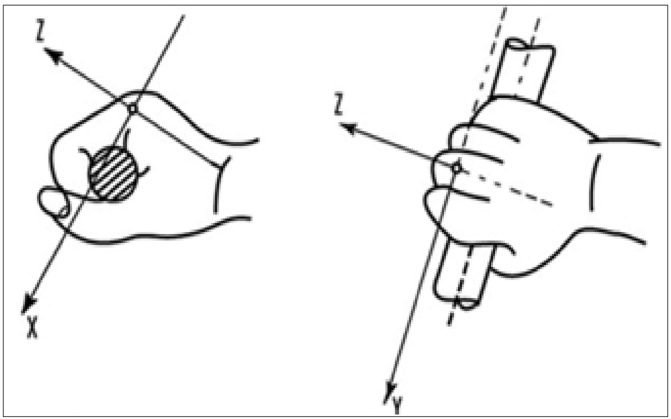

Fig. 3. Basicentric coordinate system for measurement of hand-transmitted vibration.

Fig. 4. Vibration studies of tractor (1) in the field with implements.

Small tractors with attachments

Force (OX) and Kubota small tractors were used to measure the whole body and hand-arm vibration with the spring tyne cultivator and rotovator that are available at the research station. The vibration levels were measured at selected operating speeds. The following observations were recorded during the investigation. Whole body vibration in terms of frequency weighted acceleration and hand transmitted vibration in terms of frequency weighted acceleration.

Results and Discussion

The fields located at the Tamil Nadu Agricultural University were used for trials. The temperature and the RH were recorded every day during the field measurements. The average temperature was 26 °C and the RH was 59 %. For the whole body vibration, the vibration transmitted from the tractor seat was evaluated as per the guidelines of Indian standards (10, 12). The hand-arm vibration was evaluated as per the guidelines of the Indian standards (14).

Vibration characteristics of the Force tractor in the field with an implement

The vibration characteristics of the tractors were studied in the field by operating the cultivator at selected speeds of operation. The r.m.s weighted acceleration was measured on the seat interface. Vibration studies of a tractor in the field with implements are shown in Fig. 4 (1). The acceleration levels in the three axes, x, y and z directions, were measured and are depicted in Fig. 5. The results revealed that the vibration was increased with an increase in tractor operating speed. The vibration was maximum at the Y axis for whole body and hand-arm vibrations. The vibration in the z -axis, where the human body has a resonance frequency of 4-8 Hz, was low at all the operating speeds. Vibration in the Y axis was more in the frequency range (1-2 Hz), which increased the total (sum) vibration. The vibration was in the frequency range of 1-8 Hz, with maximum vibration in the frequency range of 1-2 Hz along the Y axis. The likely reaction of the subject was extremely uncomfortable while operating the cultivator whereas it was not uncomfortable while operating a rotavator.

Vibration characteristics of the Kubota tractor in the field with an implement

The vibration characteristics of the tractors were studied in the field by operating the cultivator with a selected speed of operation, as shown in Fig. 6. The r.m.s weighted acceleration was measured on the seat interface. The acceleration levels in the three axes, x, y and z directions were measured and are

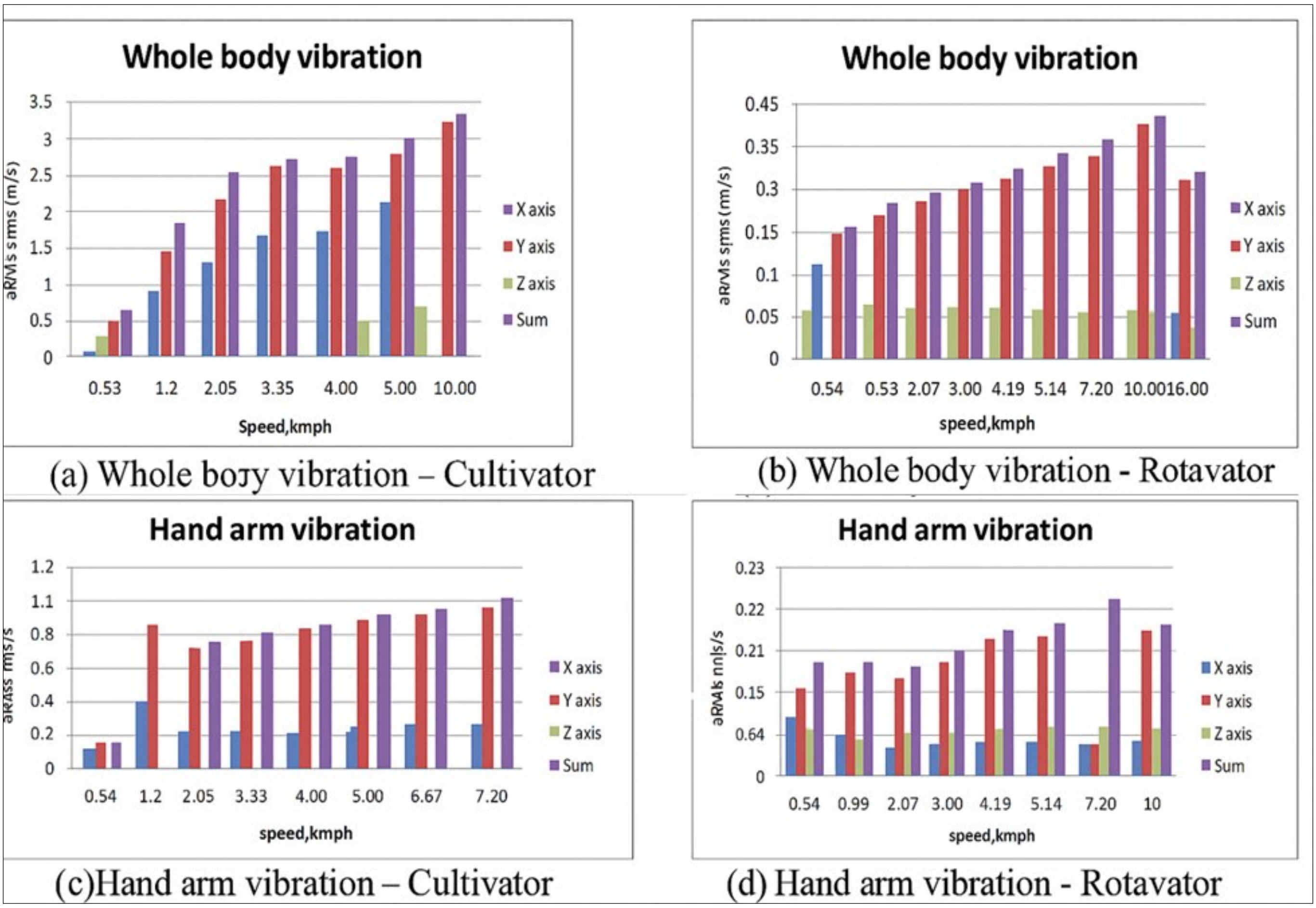

Fig. 5. RMS levels with respect to speed (Force tractor).

Fig. 6. Vibration studies of tractor (2) in the field with implements.

depicted in Fig. 7. From the result, it was found that the vibration increased with an increase in speed. As it was for the Force tractor, the spatial roughness of the field was tested faster, shifting excitation to higher frequencies and increasing input energy to the tractor-seat system. But the magnitude of vibration was less in the Kubota tractor due to lower transmissibility. The vibration was maximum at the Y axis for WB and HA vibrations. The WBV was in the frequency range of 2-6 Hz. The vibration in the z-axis, where the human body has a resonance frequency of 4-8 Hz, was low at all the speeds of operation. The vibration in the Y axis was more in the frequency range of 2-6 Hz. As the implements, like cultivators, create uneven pulling forces on the tractor, especially side-to-side. This excites the tractor body and seat laterally (Y-axis). The 2-6 Hz range matches the natural vibration response of the tractor-soil system, so the lateral shaking was amplified. Hence, the total vibration value increased most in this axis and frequency band, which increased the total (sum) vibration. Hand-arm vibration in the frequency range of 6-10 Hz was more along the Y axis. The steering wheel and linkage parts naturally vibrate in the mid-frequency band (6-20 Hz). The arms and shoulders of the driver also resonate around 6-10 Hz, which makes side-to-side (Y-axis) steering vibrations feel stronger. The likely reaction of the subject was extremely uncomfortable while operating the cultivator where whereas it was a little uncomfortable while operating a rotavator. Since the cultivator produces jerky, irregular draft forces, which excite strong side-to-side oscillations in the sensitive 2-6 Hz range for whole-body vibration. The human body is highly sensitive to discomfort in this range, so the driver feels extremely uncomfortable. However, the rotavator produces smoother, continuous forces with less lateral impact, so vibrations were lower and the discomfort was only a little.

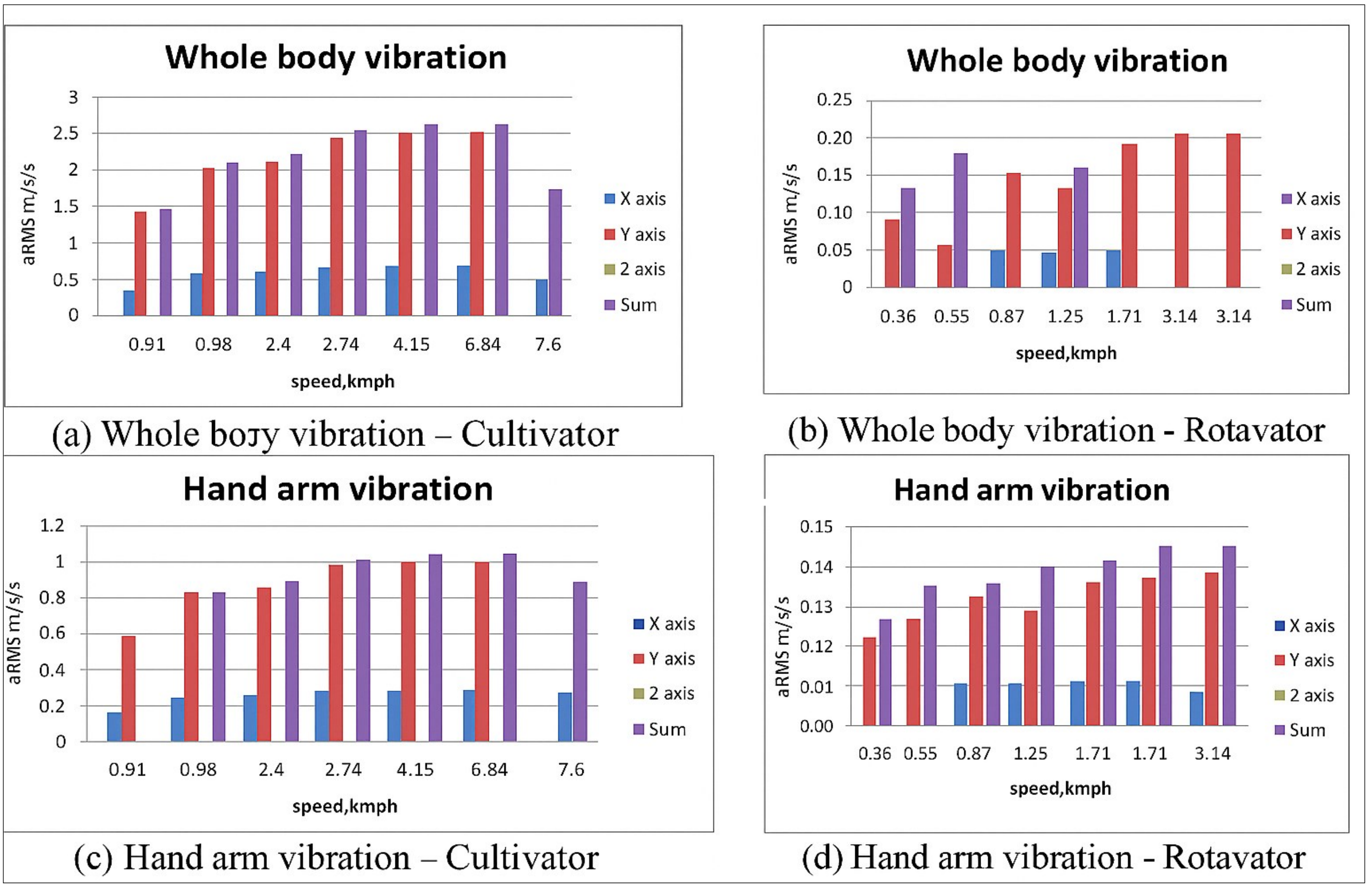

Fig. 7. RMS levels with respect to speed (Kubota tractor).

Conclusion

The vibration studies were conducted using cultivator and rotavator with the Force tractor (20.13 kW) and Kubota tractor (17.89 kW). Comparison of the test results with higher hp tractors showed that the vibration transmitted depends on the terrain conditions, weight of the tractor, tractor implement system, type of implement, speed of operation, etc. The vibration was found to be lower in the case of higher hp tractors, the reason being more weight, stability. As there was a limitation on the seats, vibration isolators may reduce vibration to a certain extent.

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Authors' contributions

AS, PV and RK have contributed equally to the conception, design and execution of this research study. All authors have read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare no conflict of interest.

Ethical issues: None

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