



Experimental study of vibration exposure of tractor occupant subjected to whole body vibration

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Abstract - Exposure to vibrations has become an indispensable part of daily life for the human beings. The daily commute of humans makes them prone to the vibrations experienced in the buses, trains, trucks and other heavy vehicles. Being continuously exposed to vibrations in one form or the other could cause a variety of health issues. Human vibrations can be pleasant or unpleasant depending on the situation where the exposure is observed. Health issues associated with the vibrations could be discomfort, fatigue and a number of physical and nervous disorders (low back pain as well as long term health degradation) due to regular and long-term vibration exposure. Degeneration of the lumbar spine with long-term exposure to whole-body vibration is also observed. The exposure of human body to the vibrations exceeding a certain limit that is given by the International Standard Organisation (ISO) for the prescribed duration may be hazardous to the health of the human body. The measurements of whole body vibration are commonly expressed in terms of the frequency weighted acceleration (measured on the vibrating surface which is in contact with the body) and is measured with the help of a Seat Pad Accelerometer. In the present study, the human response to the whole body vibration generated by tractors is studied by performing experiments under different road profiles and results are used to check with the standards set by the ISO to show whether the vibration exposure is within the safe limit or not.

Keywords - Exposure Limit; Seat Pad Accelerometer; Tractor vibration; Vibration Exposure.

I. INTRODUCTION

Vibration is a "to and fro" motion of a body about its mean position. It is highly preferable or deeply unpleasant for the humans depending on the situation of the exposure [1]. The vibration experienced by the human body can be called as human vibration. This human vibration can be classified as either Whole Body Vibration or Hand Arm Vibration depending on how the vibration is transmitted to the human body. When the vibration is transmitted to the body through supporting surface like back and buttocks, it's called as Whole

Body Vibration [2]. When the vibration transmission is through the hand and the arm it is called the Hand Arm Vibration.

It was shown by Ghuman Kuljit [3] that this exposure to the vibration for a prolonged period of time causes a number of musculoskeletal disorders like Ischemic Lumbago which is condition causing a pain in the lower back region of the spine and degeneration of the lumbar spine. He stated that the physical problems became more severe when exposed to the Whole Body Vibration (WHB) encountered in the heavy vehicles, agricultural vehicles, moving bed machinery and trailers. The risk associated with the vibration exposure to the human body increases with the duration of the vibration exposure [3]. One such heavy vehicle discussed by Bongers et al., is a forklift used for lifting heavy objects. Bongers et al., showed that the operators who are involved in operating the crane for more than five years suffered from physical issues such as fatigue, backbone disorders, degeneration of the vertebral disc and nervous issues like reduction in tactile sensitivity and tingling sensation and decrease in the ability to perform precise motor movements thereby confirming the proportionality of the duration of exposure to the degree of health effects. He also stated that there is strong association between the age of the operators and the vibration risks [4]. The health risk of the whole body vibration also depends upon the posture of the operators during the vibration exposure. This was stated by Bovenzi and Betta [5] in his investigation on postural stresses which an operator is subjected to in the driving conditions. Cann et al., [6] conducted a study on transport truck operators to determine which truck characteristics influence the level of whole body vibration exposure. Various variables were considered like road condition, truck type, driver experience, and truck mileage and seat type. It was found that road condition was a significant predictor of the frequency weighted acceleration in all the three direction showing that the health risks due to the WBV is seriously associated with the road conditions in which the vehicle is operated [7]. Ji-Geng Yan [7] studied the effects of

the vibration induced by motor vehicle and found that prolonged vibration exposure results in chronic brain edema and shrunken neurons which can be strongly associated with the neural function impairment. Usually the measurement of the vibration and its quantification is done as per the standard ISO 2631 – 1 for vehicles [7].

ISO 2631 - 1 states the procedure for measuring vibration exposure and also provides the endurance limit in the form of duration of the vibration exposure for the human being which is shown in the figure 1 [8].

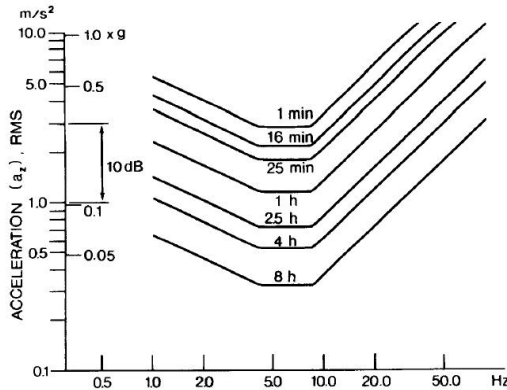


Fig. 1, The range of human endurance against vertical acceleration for Z-axis by different duration ISO 2631 [17]

Owing to serious health issues that are associated with the exposure to the whole body vibration, various steps were taken to investigate the human being’s exposure to whole body vibration and also to study its effects on human beings with the aim of reducing the health hazards that are associated with the whole body vibrations. Exposure to the Whole body vibration can be reduced by various methods.

One such method is providing a proper cushioning in the operator’s seat. Musa Marul et al., [9] tried using three different cushion material wool, sponge and cotton on the driver seat of a tractor setup and studied the extent to which the vibration is transmitted to the human body in each case. It was concluded that the wool cushion provided with the better isolation when compared to the other two [9]. Xiaoxu Ji et al. [10] proposed four different seat/cushion combinations and developed a neural network algorithm to identify the vibration attenuation properties of each seating conditions by implementing them in some forestry and mining vehicles. It was found that air inflated cushion has better vibration attenuation properties of the seat thereby reducing the health risks associated with the whole body vibration exposure [10].

Other way of reducing the health risks associated with the whole body vibration is to alter the suspension parameters of the vehicles by either modelling it mathematically or numerically such that the vibration transmitted to the body is attenuated or reduced. Zehsaz et al., [11] conducted a study whose main objective is to reduce the vibrations that is transmitted to the tractor’s cabin. Initially the vertical acceleration of the driver’s cabin is measured experimentally and it was used as the dynamic input to the finite element model of the tractor’s cabin. Finally by using an iterative

technique the suspension parameters are optimised and it was found that there was a significant improvement in terms of comfort and reduced fatigue [11]. Gunston et al. [12] tried to model the suspension seats whose dynamic behaviour was measured experimentally in the laboratory. The two different models were lumped parameter model which shows the response of the individual components of the seat and the Bouc–Wen model which has a nonlinear degree of freedom. Both of these models were stimulated by providing the dynamic inputs and the results were compared against the measured values. It was concluded that the lumped parameter model for the development of the suspension seat design [12]. These models can then be used to alter the suspension parameters to reduce the health risks associated with the whole body vibration. Cho-Chung Liang et al. [13] investigated on various lumped parameter models of the seated humans without back rest which are exposed to the vertical vibrations. The study [13] involved validating and synthesising the data of various models with different degree of freedom from published literature. Based on the correlation between the analytical and experimental results it was found that a four degree of freedom model was a best fit to the test results thereby making it a recommended model for studying the biodynamic response of the seated humans subjected to the whole body vibration [13].

The studies and investigations have been carried out by mathematically modelling the human and vehicle and analysing the model using experimental setup and very less focus is made on the experimentation in different road profiles. Hence this paper focuses on carrying out experiments on the vibration exposure of the Tractor occupants on different road conditions. The result of the experimental analysis is then used to check for the exposure limit of the human body by comparing against the standard ISO 2631.

II. MATERIAL AND METHODS

A. Experimental Test and Instrumentation

TABLE I. Technical Specification of Mahindra MKM-NST 575 DI Tractor

Maximum Power	33.556 kW @ 1900 rpm
Engine	Model: MDI2500 Type: Four Stroke Direct Injection Water Cooled Cylinders: 4
Transmission	Sliding Mesh Eight speed Gear Box with eight forward speeds and two reverse speeds
Wheel and Tyre Size	Front: 6.0 x 16” Rear: 13.6 x 28”
Dimensions and Mass	Wheel Base: 1910mm Mass (with fuel, oil and water): 1870kg

The study of the vibration exposure of human beings involves an experiment to determine the values of the vibration experienced by the driver in a tractor.

The experiment involves the proper selection of the instrument for measuring vibration according to ISO 2631, and measurement of the vibration and analysis.

- i. Tractor: The experiment is performed with a Mahindra MKM-NST 575 DI tractor, the specification of which is listed in the table 1. The road conditions for the test consist of both rough and smooth conditions. The rough condition signifies the use of a field with and without plough.



Fig. 2, Tractor Used for Experimentation

- ii. Instrumentation: The instrument involves a seat pad accelerometer comprising of a Tri-axial accelerometer mounted in a rubber pad which is placed on the seat on which the driver sits. The sensitivity of the accelerometer is 100mV/g ($\pm 5\%$) with a range of $\pm 60g$. The values are taken from the Human Vibration Meter (HVM – VM30-HAWB). The vibration is measured in terms of acceleration using the seat pad accelerometer and is obtained from the vibration meter.



Fig. 3, Seat Pad Accelerometer

- iii. Measurement and Data Extraction: The data of the measured vibration are stored in the vibration meter which can be extracted later. This gives the mean value of the readings observed. The experiment is performed as per ISO 2631 and the readings are used to identify the safe limit of

vibration after which the tractor occupant is subjected to health related issues.

III. THEORY

A. Experimental Analysis

The experimental analysis is performed according to ISO 2631 [17] by using a seat pad accelerometer by placing it on the driver's seat of the tractor. This ensures the measurement of the maximum amplitude of vibration that is transferred to the human body. The figure 5 shows the experimental set-up used. The seat pad accelerometer is placed on the Tractor's seat on which the driver is seated. The location is determined as per the ISO 2631 which states that:

“Transducers shall be located so as to indicate the vibration at the interface between the human body and the source of its vibration”



Fig. 4, Human Vibration Meter



Fig. 5, Experimental Setup

The prime focus is that human vibration is accurately measured so that an assessment can be made of:

- a. The discomfort produced by the vibration and
- b. The possible danger involved in being exposed to the vibration

The exposure to vibration is mainly due to the fact that if people are over-protected it could impose limitations on their

freedom of movement, resulting in reduced efficiency, but over-exposure to vibrations can cause accidents in the short term and/ or physical damage after a long-term exposure. This stresses the importance on the analysis of the vibrations that the human is exposed.

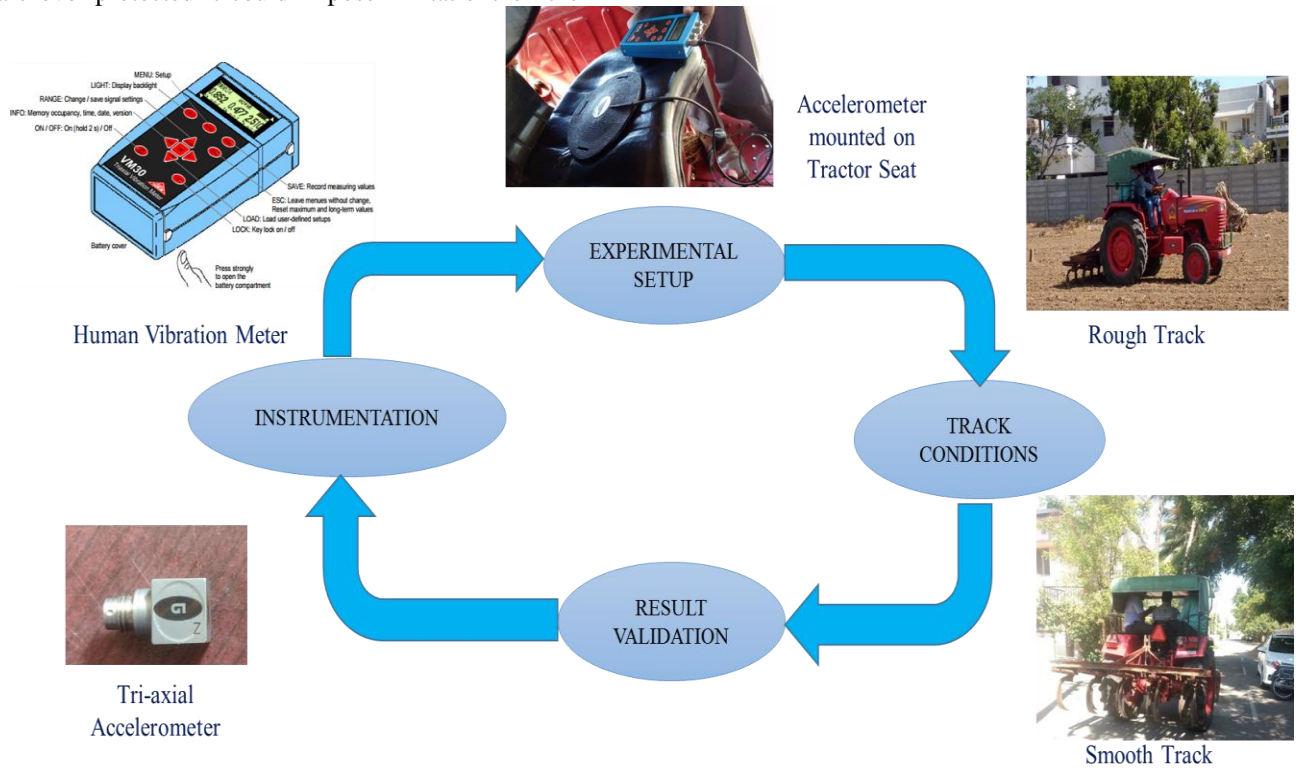


Fig. 6, Schematic of the Experimental Analysis

The accuracy of human vibration measured depends on the analysis and recording equipment used. The transducer which is used for vibration measurements is the piezoelectric accelerometer, exhibits better all-round characteristics and stability than any other type of vibration transducer, and its response is linear through the frequency range of interest.

TABLE II. Whole Body Vibration Limit

Exposure Action Value	0.5 ms ⁻²
Exposure Limit Value	1.15 ms ⁻²

The whole body vibration is mainly caused by the vibration transmitted from the vehicle to the body through the seat. For this purpose a seat transducer - a tri-axial seat pad accelerometer placed into a rubber pad is used which can be positioned at the excitation point without disturbing the original position of the person or reducing his/her comfort. To measure vibrations transmitted to a vehicle driver, the driver may either sit on the transducer or strap it onto his back. The measurement was made for a duration 120 seconds to ensure reasonable statistical precision and the mean values of the readings were taken. ISO 2631 - Evaluation of human exposure

to whole body vibration is used to identify the range in which the vibration should lie which is provided in table 2.

For whole-body vibration interval RMS is measured for each coordinate direction though the prime focus is on the z-direction, in which the vibration is transmitted to the human body. The vibration measurements are noted from the VM30-HAWB which provides the mean value of the vibration during the time period of measurement. The test parameters are tabulated below:

TABLE III. Test Parameters

Instrument Used	VM30-HAWB
Accelerometer	KB103SV-100 for whole-body measurement (10mV/ms ⁻²)
Frequency	10 Hz – 1250 Hz
Duration	120 seconds
Machine	Mahindra MKM-NST 575 DI tractor



Fig. 7, Tractor Operating on an Agricultural Field (Rough Track) with Plough

The track used for measurement was selected to simulate the working conditions of the tractor. The two track conditions used were (a) Rough track (Agricultural Field) with/ without plough and (b) Smooth track (Plain road) without plough.



Fig. 8, Tractor Operating on an Agricultural Field (Rough Track) without Plough

The figures 7 and 8 show the operation of the tractor with and without plough on a rough track - agricultural field. The figure 9 shows the operation of the tractor under smooth conditions. The tests were performed on the same driver to ensure the uniformity of the readings measured. The results obtained were compared with the ISO standard chart to determine the duration of exposure and the inferences are discussed in the subsequent section.

IV. RESULTS AND DISCUSSIONS

A. Experimental Results

The tables 4, 5 and 6 represent the peak RMS acceleration value obtained during the experiment using a seat pad accelerometer and human vibration meter. The RMS acceleration value were measured under three different road conditions for around 120 seconds – Tractor running on rough

track with and without plough and tractor running on smooth track without plough. Under each of the track condition, the tractor is operated at three different speeds.

The X, Y, Z represents the RMS acceleration along three different directions. However the acceleration along the Z direction is considered as it is the primary source vibration transmitted to the lumbar region. It can be seen from the table 4, 5 and 6 that the RMS acceleration in Z direction is much higher when the tractor is operated with plough rather than without plough. This means that health risks associated with the vibration generated by tractor is much higher when it is operated with plough. Another important thing that can be observed here is that when the engine RPM is increased under the same gear, the RMS value of the acceleration in the Z direction also increases. Thus the vibration transmitted to the human body also increases. At higher gear however the speed of the vehicle increases, hence the frequency of encountering the bumps in the track increases. This in turn increases the transmission of vibration to the human body. The results of the experiment performed are compared with the exposure limit stated by the standards ISO 2631.



Fig. 9, Tractor Operating on a Smooth Track without Plough

Table 4 gives the acceleration values experienced by the human when the tractor is operated on a rough track with plough. The plough or the rotavator forms a significant part of the tractors’ operation solving the prime purpose in the agricultural lands. The values obtained from the vibration meter are tabulated and it has been graphically represented in the figure 10.

TABLE IV. Acceleration Values on Rough Track with Plough

Rough Track, With Plough, Duration:120 s	
At 1000 rpm, 1 st gear	
Interval RMS (A(T)) in m/s ²	X = 0.1 m/s ²
	Y = 0.5 m/s ²
	Z = 0.3 m/s ²
At 1100 rpm, 1 st gear	
Interval RMS (A(T)) in m/s ²	X = 0.2 m/s ²
	Y = 0.3 m/s ²
	Z = 0.3 m/s ²
At 1000 rpm, 2 nd gear	
Interval RMS (A(T)) in m/s ²	X = 0.3 m/s ²

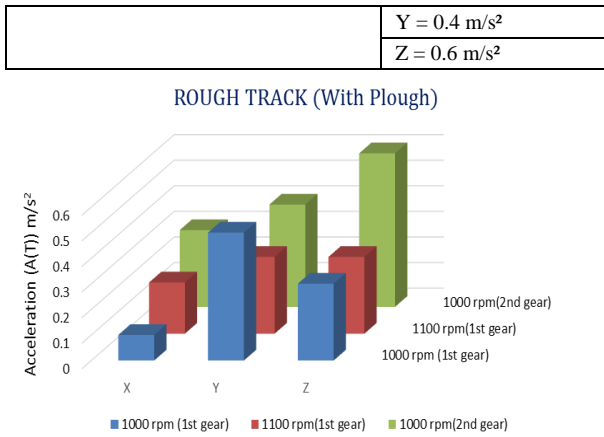


Fig. 10, Graph Comparing Acceleration Values for X, Y, Z Axes for Rough Track with Plough

Table 5 shows the acceleration values for the operation of the tractor in a rough track without plough. It can be observed that the values are significantly decreased in comparison with that observed with the plough. This helps in concluding that the rotavator plays a significant role in contributing to the vibration. The values are graphically represented in the figure 11.

TABLE V. Acceleration Values on Rough Track without Plough

Rough Track, Without Plough, Duration :120 s	
At 1000 rpm, 1 st gear	
Interval RMS (A(T)) in m/s ²	X = 0.1 m/s ²
	Y = 0.3 m/s ²
	Z = 0.2 m/s ²
At 1100 rpm, 1 st gear	
Interval RMS (A(T)) in m/s ²	X = 0.1 m/s ²
	Y = 0.5 m/s ²
	Z = 0.2 m/s ²
At 1000 rpm, 2 nd gear	
Interval RMS (A(T)) in m/s ²	X = 0.2 m/s ²
	Y = 0.5 m/s ²
	Z = 0.4 m/s ²

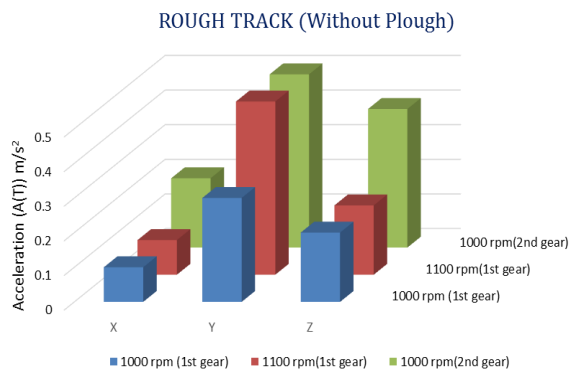


Fig. 11, Graph Comparing Acceleration Values for X, Y, Z Axes for Rough Track without Plough

The acceleration values observed during the operation of the tractor in a smooth track without plough are shown in the table 6. It is seen that the z axis acceleration increases when compared with the previous two cases. This is due to negative

correlation of the road profile with that of the vibration profile which reduces the vibration amplitude in the case of the rough track which is a random observation. A change in the road profile could increase or decrease the amplitude. Figure 12 gives the graphical representation of the values in the table.

TABLE VI. Acceleration Values on Smooth Track without Plough

Smooth Track, Without Plough, Duration :120s	
At 1000 rpm, 1 st gear	
Interval RMS (A(T)) in m/s ²	X = 0.2 m/s ²
	Y = 0.5 m/s ²
	Z = 0.3 m/s ²
At 1200 rpm, 2 nd gear	
Interval RMS (A(T)) in m/s ²	X = 0.2 m/s ²
	Y = 0.3 m/s ²
	Z = 0.7 m/s ²
At 1000 rpm, 3 rd gear	
Interval RMS (A(T)) in m/s ²	X = 0.3 m/s ²
	Y = 0.6 m/s ²
	Z = 0.7 m/s ²

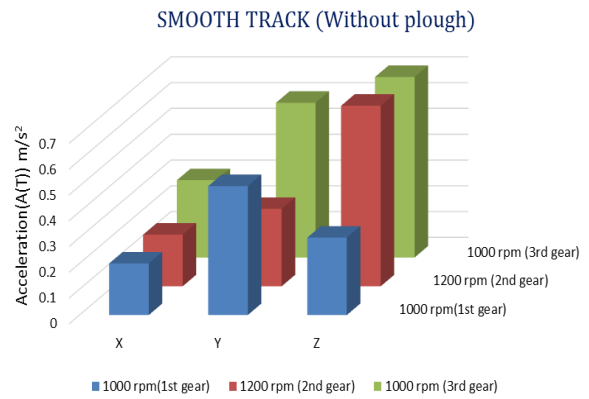


Fig. 12, Graph Comparing Acceleration Values for X, Y, Z Axes for Smooth Track without Plough

V. CONCLUSIONS

In this study, the experimental analysis of the vibrations experienced by a tractor occupant is carried out. The experiments conducted are in accordance to the standards mentioned in ISO 2631. The experiment shows that the road profile plays a significant role in affecting the vibration transmitted. Also it is observed that the rotavator used in ploughing the agricultural fields is also a significant factor to induce increased vibration amplitude affecting the operating person in the long run. Also the amplitude of vibration increases with the speed in the smooth tracks where the amplitude is observed to be greater than that obtained in the field conditions.

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