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OCCUPATIONAL RIDE COMFORT OF TRACTOR DRIVERS UNDER THE EXPOSURE OF WHOLE BODY VIBRATION DURING HARROWING

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ABSTRACT

The study focused to investigate occupational ride comfort level among Indian tractor drivers during harrowing operation. Randomsample of ten (10) male tractor drivers with mean age 24.2±3.65 years, weight 74.3±8.43 kg, height 1.558±0.01 meter and body mass index30.48±3.39 Kg/m^{2}is selected for the present study. A total of 120 experimental runs are carried out with varying input conditions like sitting body postures and speed levels. It is observed that 90% of vibration dose value (VDV) exposures values in without backrest posture (P2) and 70% in with backrest posture (P1)found to exceeding the recommended exposure action value (EAV) at 7.6 m/s along vertical (z) axis as per ISO 2631-1 (1997). The daily dose (VDV_{exp})values are beyond the recommended exposure action value among all the experimental runs. Moreover, the majority of the VDV_{exp}(90%) are above exposure limit value (ELV).The daily equivalent static compression dose (S_{ed} (8)) response indicted moderate probability of an adverse health affect in posture P1 at 5.4 m/s, while 70% having high probability of adverse health affects in posture P2 at 7.6 m/s. The Fast Fourier Transformation (FFT) response at seat base provided dominant frequencies of 10 Hz and 12 Hz at 5.4 m/s and 7.6 m/s speed levels along vertical (z) axis. It is concluded that sitting postures and speed levels have significant influence on tractor ride comfort. The exposure levels could be severe for human health with a major risk to lumber spine. The dominant frequencies may cause discomfort to various body parts due to their existing natural frequencies. Hence, tractor driving occupation needs more ergonomic enhancements in order to improve ridecomfort of drivers.

INTRODUCTION

Modernization of agricultural sector has influenced manual labour as well as characteristics of work load [1]. In developing countries like India, around 3 million population are having tractors with an average growth of 0.25 million tractors per year in current scenario. However, India has been considered as largest manufacturer of tractor and its implements worldwide [2]. Nowadays, Indian agricultural activities are largely dependent upon tractor for being a major source of power. It is well known that tractor drivers have to work under the exposure of vibrations arising by tyre-terrain interactions as well as high frequency induced by tractor- machinery such as engine, gear train and other accessories [3]. Generally, human body attenuates most of vibrating frequencies but a range of 1-20 Hz frequencies are considered very critical to body. These frequencies can influence spinal column, internal organs and tissues, pelvis due to existing natural frequencies of human body which may result into resonance if interact with similar external frequency [4]. A long term exposure under the whole body vibration along with awkward sitting postures are two major contributors towards musculoskeletal issues among professional drivers [5]. Usually, tractor driving occupations is allied with a high risk of causing musculoskeletal disorders especially to back region of tractor drivers [6]. Vibration exposure at tractor seat is considered quite complex to analyze ride behavior particularly for off-road operations. The vibrations in such conditions are caused by a number of different components and lead to generate multi-degree of freedom mechanism [7,8]. Such vibrating frequencies may have adverse effect on driver due to existence of natural frequencies of human body. In developed countries, tractors have been designed by either providing suspension system or suspended cabs in order to limit vibration exposures. Hence, tractor drivers are much comfortable with seats of such tractors [9]. Yet, tractors in developing countries like India are unsuspended and used without cabs due to excessive cost. Seat is well thought to be an essential part of machinery among all the tractor components due human-machine interactions which largely affects comfort of tractor drivers. Tractor seats could have prominent improvement in cushioning and suspension which may result into better comfortable design.

Although, Tractorization has increased production rate along with reduction of human labour but still there are ergonomic inadequacies in tractors [10,11]. More or less, agricultural mechanization has increased occupational health hazards as well as musculoskeletal disorders which may lead to impaired work performance among tractor drivers. As Indian tractor drivers have not received much attention towards their occupation due to unawareness of such health related issues. Therefore, present study aimed to investigate occupational ride comfort of tractor drivers while performing harrowing operation.

II. MATERIAL AND METHODS

A 2017 model 40.25 KW tractor 'T' of weight 2055 kg with power steering and double clutch mechanism has been selected for present study. The tractor has three cylinder engine, wheel base 2045 mm and tyre dimension was 6.0×16 (front) and 14.9×28 (rear) with negligible wear and tear of lugs. Tractor was mounted by an 8×8 disc harrow of weight 332 kg for performing harrowing operation. A process of data recording/processing and analyzation has been summarized in the form of flow chart

(Figure: 1). A brief explanation of every step is explained under sub-headings.

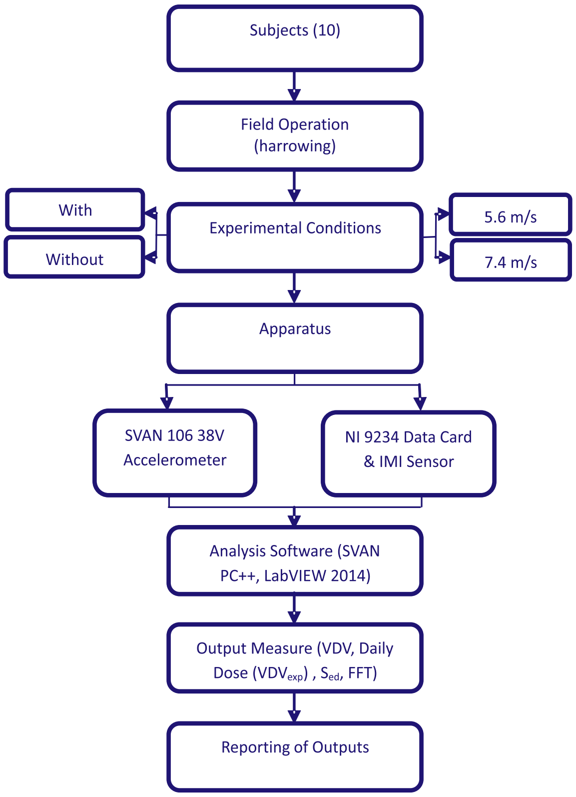

Figure 1: Summary of Data Processing and Analyzation

A. Subjects

A random sample of ten healthy male tractor drivers with mean age 24.2±3.65 years, weight 74.3±8.43 Kg, height 1.558±0.01 meter and body mass index 30.48±3.39 Kg/m^2 were included for present study. The selected subjects have at least an experience of 5 years in tractor driving. None of the subject has reported for any sensitive towards exposure to shock and vibrations. The purpose of study was already explained to subjects before start of experimentation.

B. Experimental Details

The experimental includes speed S1 & S2 (5.6 m/s & 7.4 m/s) and sitting postures P1 & P2 (with & with back rest) as independent parameters. The tractor was driven at 3/4th rated speed to maintain speed levels under allexperimentation conditions. The subjects were instructed to maintain postures (Figure: 2) as per their comfort and no apparatus has been used for posture measurements [12].

(P1) (P2)

Figure 2: Representation of Sitting Posture with (P1) and without Backrest (P2)

Experimental design was planned by using 'one factor at a time (OFAT)' full factorial technique. A total of 120 experimental trials were designed with three replications and each run last long for 60 seconds. The field area selected for experimentation was 4046.86 m^2 and soil lies under sandy category. Every subject performed preliminary experimental trials prior to final experimentation. The data of preliminary experiments was not incorporated in this study.

C. Instrumentation/Software and Algorithms

A tri-axial seat pad accelerometer (SV 38V) has been mounted on tractor seat for assessing whole body vibration exposures along fore-and-aft (x), lateral (y) and vertical (z) axes simultaneously. The data was acquired by SVAN 106 human vibration monitor having in built weighting filters (W_d for x, y axes and W_k for z axis) with a sampling rate of 6 kHz. The data was processed by SVANPC++ software to evaluate vibration dose value (VDV), daily dose (VDV_{exp}) and daily equivalent static compression dose (S_{ed}). The mathematical terminologies of these measures are as following:

$$VDV = \left\{\int_0^T [a_w(t)]^4\right\}^{1/4} \quad (1)[13]$$

VDV: Vibration dose value (ms$^{-1.75}$); $a_w(t)$: Weighted RMS acceleration (ms^{-2}); T: Measurement duration (seconds)

$$VDV_{exp} = \left[VDV^4_{exp,x} + VDV^4_{exp,y} + VDV^4_{exp,z}\right]^{1/4} \quad (2)[13]$$

$VDV_{exp,x,y,z}$ Daily dose value along x, y and z axes respectively;

$$VDV_{exp,x} = 1.4 \times VDV_x \left[\frac{T_{expose}}{T_{measure}}\right]^{1/4} \quad (2a)$$

$$VDV_{exp,y} = 1.4 \times VDV_y \left[\frac{T_{expose}}{T_{measure}}\right]^{1/4} \quad (2b)$$

$$VDV_{exp,z} = VDV_z \left[\frac{T_{expose}}{T_{measure}}\right]^{1/4} \quad (2c)$$

Multiplication factor for x and y axis is 1.4 and 1 for z axis.

$$S_{ed}(8) = [(m_k D_k(8))^6]^{1/6} \quad (3)\ [14]$$

$S_{ed}(8)$: Daily equivalent static compression (MPa)
$m_k = m_x$=0.015MPa, m_y = 0.035MPa, m_z= 0.032MPa

$$D_k(8) = D_k \left[\frac{480\ minutes}{measurement\ time}\right]^{1/6} \quad (3a)$$

$D_k(8)$: Average daily dose (MPa)

$$D_k = [\Sigma_i A_{ik}^6]^6 \quad (3b)$$

D_k : Acceleration dose (MPa); A_{ik}: highest peak of the axis (x, y and z); both positive and negative direction peaks are considered for x and y axes. For z axis, positive peak is only considered.

Figure 3:Apparatus/Instruments of Experimental Setup

Consequently, an IEPE-IMI uniaxial 2-pin accelerometer of 100mV/g having sampling rate of 15 kHz was mounted near to seat. The BNC termination was connected to a four channel NI 9234 vibration card of ±5V and 51.2 kS/s/channel. This setup (Figure: 3) was associated with LabVIEW 2014 software to get fast fourier transformation (FFT) response of exposure levels.

III. RESULTS AND DISCUSSION

A. Vibration Dose Value (VDV) Exposure

the vibration responses of subjects has been measured in terms of vibration dose values along fore-and-aft (x), lateral (y) and vertical (z) axes under both the selected postures as well as speed levels as mentioned in figures 4 & 5.

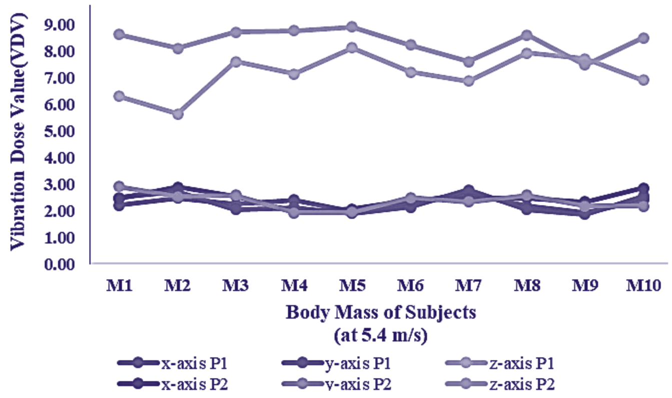

Figure 4: Whole Body Vibration Response of Subjects at 5.4 m/s

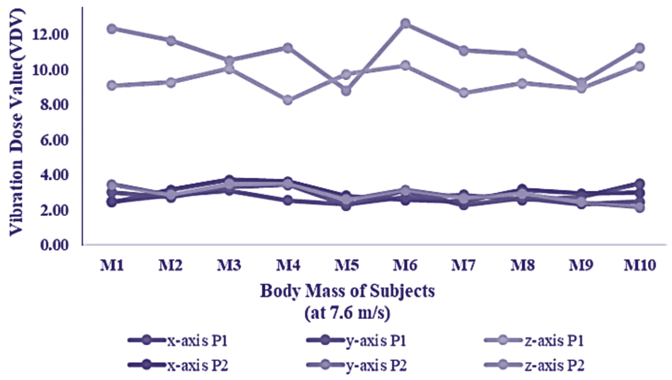

Figure 5: Whole Body Vibration Response of Subjects at 5.4 m/s

It has been observed that VDV exposure values were below the ISO 2631 1, 1997 exposure limit values at both postures and speeds. Consequently, z-axis was dominant among all the experimental conditions. However, majority of VDV responses were found to be approaching ISO recommended action value (9.1ms-1.75) under posture P2 at 5.4 m/s. Although, ninety (90) percent of VDV exposures values under posture P2 and seventy (70) percent under posture P1 were exceeding ISO exposure action values at 7.6 m/s.

B. Daily Dose Value (VDV_{exp}) of Subjects

Whole body vibration exposure levels were evaluated in the form of daily dose value as shown in Figure 6. Subjects with different body masses perform experimental runs with respect to speed as well as postural conditions. Eighty percent of the subjects showed higher dose value in posture P2 as compared to P1 at 5.4 m/s. However, seventy percent of subjects exhibit opposite trend i.e. VDV_{exp} in posture P1 has been found higher as compared to P2 at 7.6 m/s. Besides, VDVexp was increasing while moving from 5.4 m/s to 7.6 m/s speed levels under both postural conditions respectively. Similar trend of increasing vibration response values were observed while increasing speed levels [15]. Consequently, VDV_{exp} were exceeding ISO 2631 1, 1997 recommended exposure action value (EAV≥9.1 $ms^{-1.75}$) among all the experimental runs. Rather, 90 percent of VDVexp were beyond exposure limit value (ELV≥21$ms^{-1.75}$). Such exposure levels may cause degradation of human health and effects work performance [16, 17].

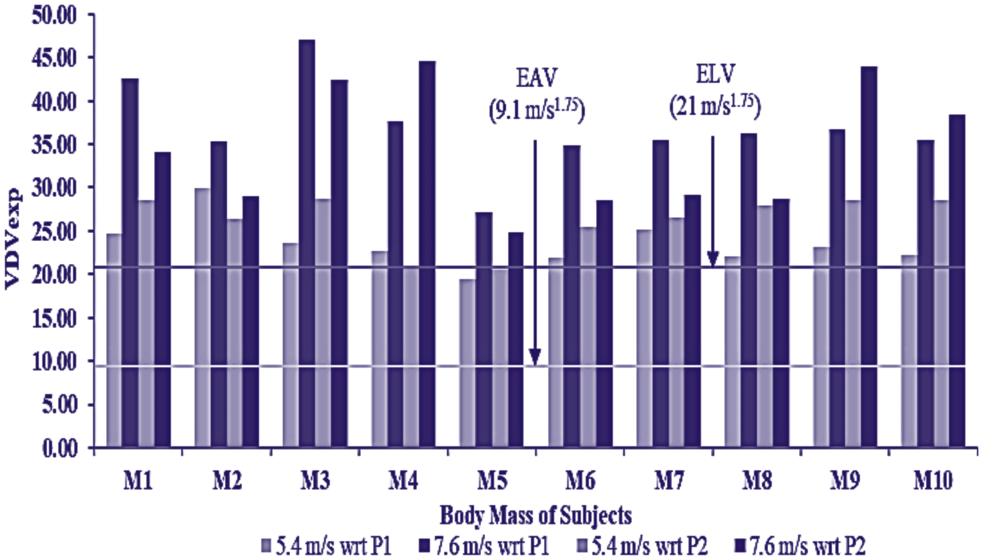

Figure 6: VDV of Subjects at Varying Speed and Posture Conditions

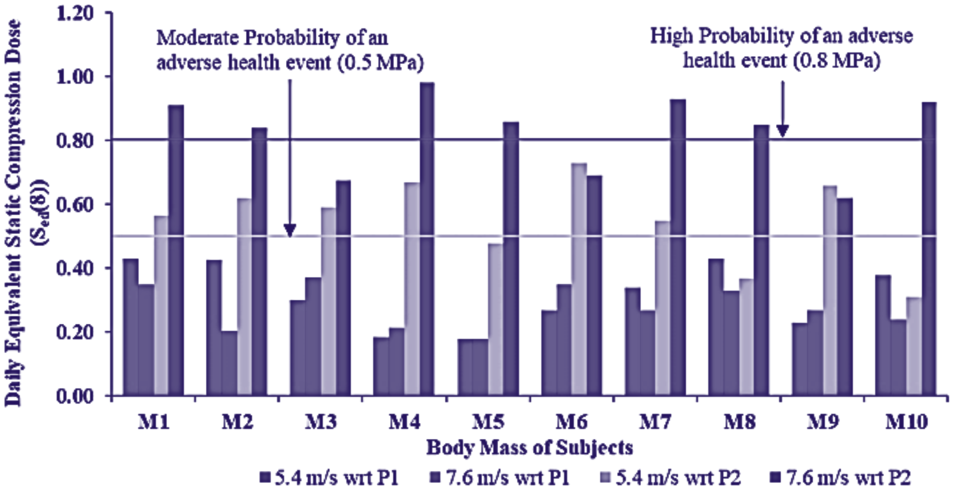

Figure 7: VDV_{exp} of Subjects at Varying Speed and Posture Conditions

C. Daily Equivalent Static Compression Dose (S_{ed} (8))

Afterwards, daily equivalent static compression dose (S_{ed}(8)) has been evaluated to measure the compressive forces on lumber spine while exposed under WBV exposures(figure 7). Moreover, it could also lead to cause various health issues in addition to these compressive forces [16]. As shown in Figure, S_{ed}(8) found to be under the ISO 2631 5, 2004 limit values under sitting posture without back rest (P1) at both speed levels. Whereas, seventy percent of subjects were exceeding S_{ed}(8) for moderate probability (S_{ed}>0.5 MPa) of an adverse health effect under with back rest posture (P2) at 5.4 m/s, while seventy percent were on higher probability (S_{ed}>0.8 MPa) of adverse health effect under posture P2 at 7.6 m/s. It has been revealed that S_{ed}(8) exposure may cause negative impact on human health especially lumber spine whether exceeding moderate or higher probability limits of adverse health effect [14]. As there could be formation of shear forces along lateral as well as anterior-posterior directions [17].

D. Fast Fourier Analysis of Seat Vibrations

Vibration signals were analyzed at seat levels by evaluating FFT responses at both speed levels. Vibration amplitude has been measured for duration of sixty (60) seconds as shown in Figure 8&9. The maximum vibration amplitude (A_{max}) has been evaluated as 0.55 m/s^2& 0.51 m/s^2 at 5.4 m/s & 7.6 m/s speed levels respectively.

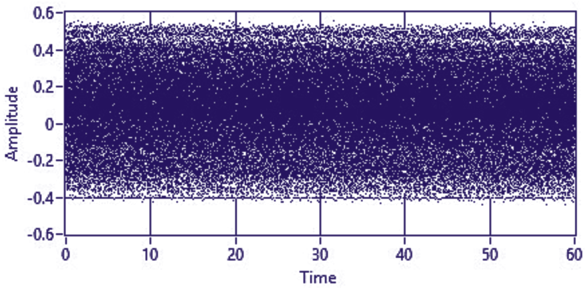

Figure 8: Time-Amplitude Response of Vibrations at 5.4 m/s

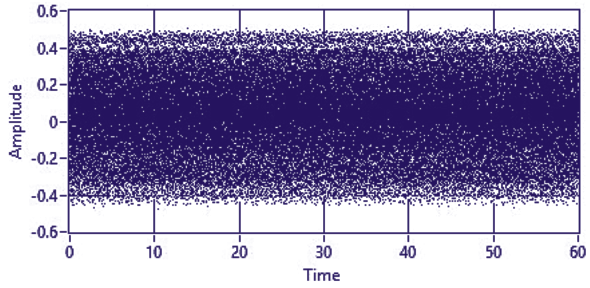

Figure 9: Time-Amplitude Response of Vibrations at 7.6 m/s

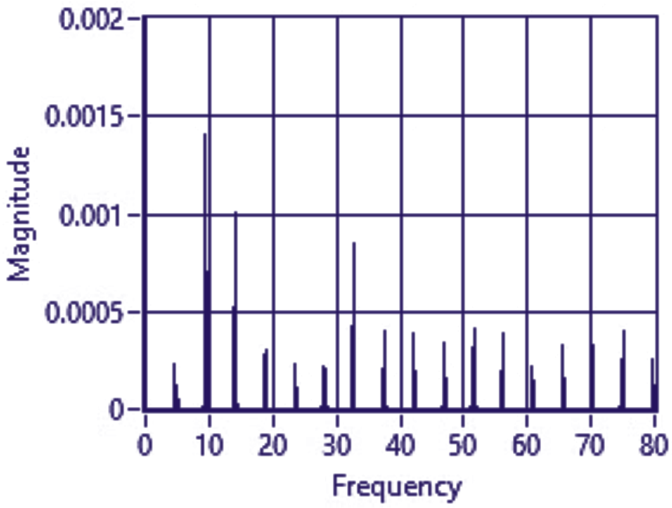

Figure 10: Frequency-Magnitude Response of Vibration levels at 5.4 m/s

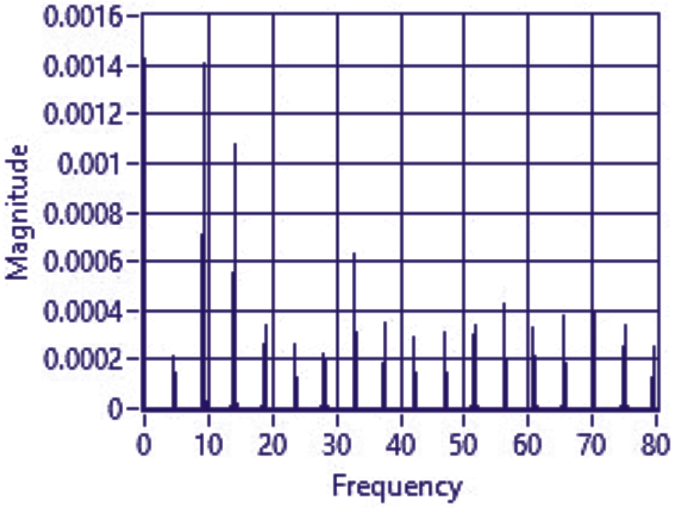

Figure 11: Frequency-Magnitude Response of Vibration levels at 7.6 m/s

Furthermore, dominant frequencies have been examined on evaluated time-amplitude data for both speed levels. As shown in Figure 10 & 11, the dominant frequencies of 10 Hz and 12 Hz were found common at 5.4 m/s and 7.6 m/s speed levels. However, such frequencies come under the category of low frequencies (1-20 Hz) and human body has been considered very sensitive towards such frequencies [18]. Moreover, it may influence ride comfort and ultimately diminishes work performance capacity [19].

IV. CONCLUSIONS

Following conclusions are drawn from present study:

Majority of VDV exposure levels under both the postures have been exceeding ISO 2631 1, 1997 recommended exposure values at 7.6 m/s. Consequently, daily dose values are also higher than ISO exposure action limit (EAV≥9.1 $ms^{-1.75}$) for all experiments while 90% found to be beyond exposure limit value (ELV≥21 $ms^{-1.75}$). The $S_{ed}(8)$ of majority of subjects indicated moderate (S_{ed}>0.5 MPa) to high (S_{ed}>0.8 MPa) probability of adverse health effect on lumber spine region.FFT analysis of seat base exhibited dominant frequencies of 10 Hz and 12 Hz and human body is very sensitive to such low frequencies due to existence of natural frequencies. Hence, tractors need more designing enhancements and suitable rest pauses might be designed in order to improve driving comfort by limiting such occupational vibration levels

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