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Performance Assessment of a Tractor Driver Whole Body Vibration Measuring System

Iman Ahmadi

Department of Agronomy, Khorasgan (Isfahan) Branch, Islamic Azad University, Isfahan, Iran

Abstract: Long term exposure of tractor driver to vibrations induced by agricultural machinery operations may lead to health problems. Therefore it is valuable to obtain the range of frequencies transmitted to tractor driver while performing farm operations, hence in the present study, in order to record tractor driver whole body vibrations, fabrication and evaluation of an inexpensive tractor vibration measuring system was considered. According to the results of this study, testing the system in static and dynamic conditions approved the system performance. Furthermore, the value of S_{ed} indexes of plowing with moldboard and rotary plows were 0.35 MPa and 0.4 MPa respectively. Based on the criterion of USAARL, since these values were lower than 0.65 MPa, the severity category of operation with the examined plows were graded in the class of 3; which means that the health hazard associated with these operations were marginal. Moreover, dominant frequencies transmitted to driver seat were in the range of 0-3 Hz.

Key words: Equivalent Daily Stress Index · Frequency Domain · ISO 2631 Standard · Matlab Software · Three Axis Accelerometer · Whole Body Vibration

INTRODUCTION

Passes of vehicles over irregularities of the road surface and presence of offset mass on rotating axes of these machines, cause mechanical vibrations [1, 2]. Furthermore, since the majority of light weight agricultural tractors (below 150 hp) haven't any conventional suspension system, these machines transmit vibrations to the driver more than the vehicles with suspension system [3, 4]. Long term exposure of tractor driver to these vibrations may lead to driver back pain and other health problems. Researchers reported the more prevalence of vibration-induced health problems, especially back pain, in tractor drivers compared to drivers of other vehicles. However all of the transmitted frequencies caused by tractor vibrations have not the same effect on driver health. Researchers concluded that the frequency range of (0,12) Hz has more effect on health of humans [5]. Therefore it is valuable to categorize tractors performing different agricultural operations based on the range of frequencies transmitted to tractor driver. Since the first step toward this goal is achieved by measurement of transmitted vibrations to driver, in this study in order to record tractor driver whole body vibrations, fabrication and evaluation of an inexpensive tractor vibration measuring system was considered. After checking the system performance, this system was installed on a tractor plowing with moldboard and rotary plows with a constant forward speed and the time domain tractor driver whole body vibrations were recorded. Finally, in order to extract the frequency range that the tractor driver was exposed to, the conversion of vibrations from time domain to frequency domain utilizing the code writing environment of the Matlab software was carried out.

MATERIALS AND METHODS

Hardware of Vibration Data Acquisition System: The vibration sensor utilized in this study was of the type of micro-electro-mechanical-system (MEMS sensor), with the capability of simultaneous measurement of the exposed accelerations in x, y and z directions. Working range of the sensor was ±3g but the data acquisition system was so designed to save acceleration data in the

Corresponding Author: Iman Ahamdi, Department of Agronomy, Collage of agriculture, Islamic azad university, Isfahan (Khurasgan) Branch, Isfahan, Iran. Tel: +989132220935.

range of ±3. Therefore in order to obtain real accelerations, measured data should be multiplied by the ravitational acceleration of the earth i.e. $g = 9.81\frac{m}{s^2}$ Moreover, system sampling frequency was 10Hz. With regard to ISO 2631 standard, the sensor was attached to tractor driver seat in such a way that the x axis direction was toward the front of tractor, y axis toward the left of tractor and z axis toward the top of tractor. With this sensor layout, longitudinal, transverse and vertical vibrations of the sensor were measured as functions of time; and stored in a 2 GB non-volatile memory as three separate text files in order to be utilized later for post processing of the data. The processing unit of the system was an Atmega 128 microcontroller, which was responsible for reading the sensor outputs and writing them to the system memory as three separate text files.

Checking the System Performance in Static Mode: The system performance in static mode can be checked, if the sensor is so located on a non rotating surface that the direction of z axis of the sensor aligns with the vertical line to the ground. In this condition, because the gravity acceleration (vertically downward) is the only acceleration which affects the sensor, if the system output for z axis is -1 (i.e. -g) and for x and y axes are 0, the accurate performance of the system in static mode will be checked.

Checking the System Performance in Dynamic Mode: For this purpose the sensor was so installed on a circular disk that the direction of the x axis of the sensor aligns with the radius of disk. Then, outputs of the system were recorded when disk was rotated with the constant angular velocity of $(\frac{red}{sec})$. This procedure was repeated with different rotational radii ($r(m)$) of the rotating disk. In each case if the measured acceleration from the x axis output of the sensor was equal to the calculated acceleration utilizing the formula of $\frac{rw^2}{g}$ and outputs of the y and z axes of the sensor were equal to 0 and -1 respectively, accurate performance of the system in dynamic mode would be checked.

Calculation of a Useful Parameter for Vibration Assessment in Time Domain: There are several parameters in the literature which can be used with regard to this goal. One of them is S_{ed} which is the equivalent daily stress index defined as $S_{ed} = \sqrt[6]{\sum_{k=x,y,z} (m_k D_{kd})^6}$, where m_k are constants for x, y and z directions (m_x=0.015, m_y=0.035 and m_z=0.032) and D_{kd} is the average daily acceleration dose for each direction k, calculated as $D_{kd} = D_k \sqrt[6]{\frac{t_d}{t_m}}$, where, t_d is the duration of an average workday, t_m is the period of vibration sampling and D_k is the acceleration dose defined as $D_k = \sqrt[6]{\sum_{i=1}^{m} A_{ik}^6}$, where A_{ik} is the i^{th} peak of the acceleration in the k-direction (k=x,y,z) and m is the number of peaks in the measured signal [6]. This parameter was calculated utilizing the measured vibration time domain data obtained in this research. The required program for the calculation of this index was written in code writing environment of the Matlab software.

Conversion of Vibration from Time Domain to Frequency Domain: In this study, since the vibration is acquired in time domain, a conversion of time to frequency domain is needed in order to obtain useful information in frequency domain. This was done utilizing the FFT command of the signal processing toolbox of Matlab software. The required code written in code writing environment of the Matlab software is as follows:

```
a=[];                  % sampled data must be entered here
fs=10;                 % sampling frequency
dt=1/fs;
n=size(a,2);           % number of data
t=dt:dt:n*dt;          % time of sampling in seconds
b=fft(a);              % conversion of time domain to
                       frequency domain
B=abs(b)/(n/2);        % absolute normalized spectrum
freq=(0:79)/(n*dt);    % the largest frequency is 79/(n*dt)
                       Hz, it may be any other value
subplot(2,1,1);
plot(t,a);             % plotting the amplitude of vibration
                       as function of time
subplot(2,1,2);
plot(freq,B(2:81));    % plotting the amplitude of vibration
                       as function of frequency
```

Practical evaluation of the system was performed by installing the sensor of the system on the seat of an MF 285 tractor plowing with moldboard and rotary plows with forward speed of $4\frac{km}{hr}$ and the measured accelerations were analyzed.

RESULTS AND DISCUSSION

While the z axis of the sensor was directed upward, the z axis output of the system in static mode was -1 and the x and y axes outputs were 0. Testing the system with the sensor in upside down position, led to the unchanged outputs of the x and y axes, while the z axis output converted to +1. This result approves the system performance in static conditions. In dynamic conditions, the system outputs were recorded while the sensor-attached disk was rotated from 0 to $1.5\frac{rev}{s}$ with the step of $0.3\frac{rev}{s}$ and the rotation radius of the sensor was increased from 0 to 25 cm with the step of 5 cm. Then the recorded data were compared with the outputs calculated utilizing the formula of $\frac{rw^2}{g}$. As expected, the y and z axes outputs were approximately 0 and -1 respectively and graphical representation of the measured and calculated acceleration data of the x axis of the system is shown in Fig. 1.

Visual examination of Fig. 1 approves the system performance in dynamic mode. Statistical analysis of the data led to the standard deviation of the difference between measured and calculated data of 0.059772, which is in agreement with visual inspection of Fig. 1. Then with regard to the methodology of the ISO 2631 standard, sensor of the system was installed on an MF 285 tractor seat and vibration time histories of 50 seconds plowing with moldboard and rotary plows with the velocity of $4\frac{km}{hr}$ were recorded. The z axis outputs of the acquired data were shown in Fig. 2 (a and b).

The value of S_{ed} indexes of plowing with moldboard and rotary plows calculated utilizing frequency weighted acceleration data obtained from the acquired vibration time histories, using the methodology described by Rimell and Mansfield [7], were 0.35 MPa and 0.4 MPa respectively. Based on the criterion of U.S. Army Aero-medical Research Laboratory (USAARL) tabulated in Table 1, since these values are lower than 0.65 MPa, the Severity Category (SC) of operation with the examined plows are graded in the class of 3; which means that the health hazard associated with these operations are marginal.

Finally, utilizing the measured vibration time histories as input parameter of the conversion program from time domain to frequency domain and executing the program in the Matlab software environment, dominant frequencies of the vibration data were extracted. The obtained results are graphically shown in Fig. 2 (c,d). As shown in Fig. 2 (c,d), the dominant frequency range transmitted to tractor driver is (0,3) Hz, which is in agreement with the results of other researchers like Hostens *et al*. [4] that obtained this frequency range for whole body vibration of agricultural operations performed with the aid of tractor. However more peaks and wider amplitude band were observed in rotary plow spectrum,

Table 1: Health hazard severity categories of whole body vibration (WBV)

ISO 2631 standard		Health Hazard Assessment (HHA) AR 40-10 based on USAARL criterion
WBV Daily Exposure Limit (minutes)	Equivalent Daily Stress, S_{ed} (MPa)	Severity Category (SC)
<10	>0.95	1-Catastrophic
10-30	0.65-0.95	2-Critical
30-180	0.35-0.65	3-Marginal
>180	<0.35	4-Negligible

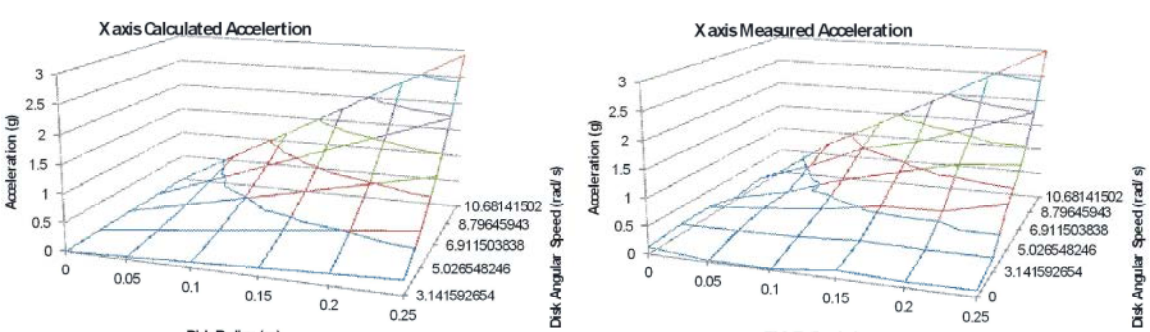

Fig. 1: Measured (right) and calculated (left) values of the x axis acceleration obtained by changing rotation speed and radius of the sensor-attached disk

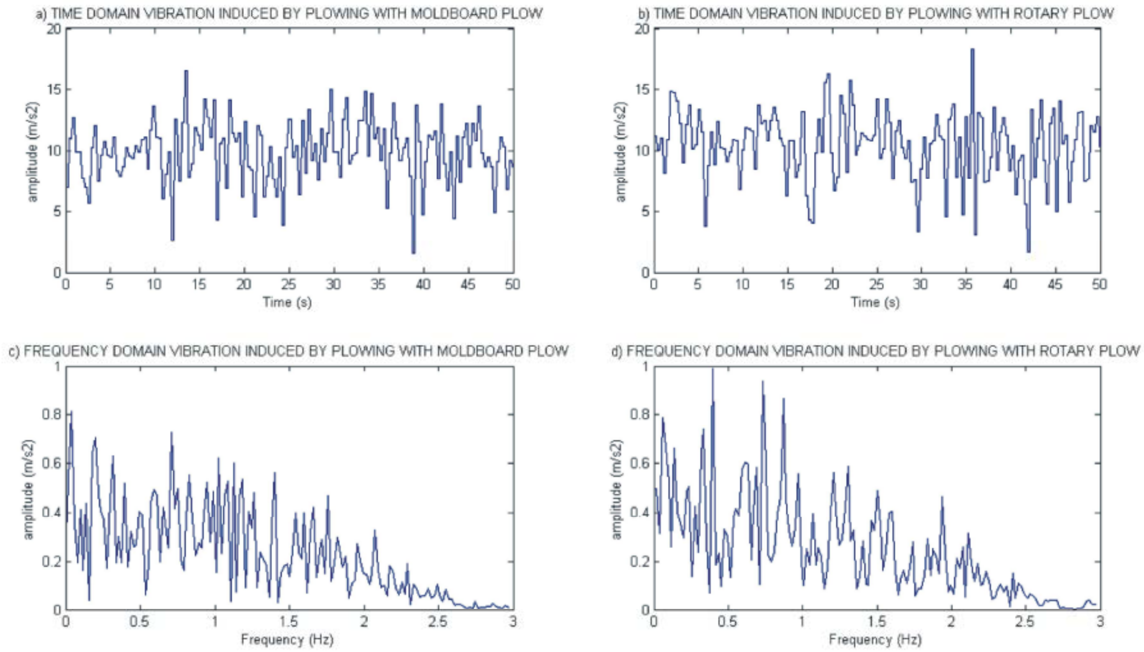

Fig. 2: Time histories (a,b) and frequency domains (c,d) of the z axis acceleration data obtained from plowing with moldboard and rotary plows

maybe because that the rotary plow is an active machine and receives tractor PTO power, which can transfer more frequencies to tractor due to the impacts of plow blades to the soil.

REFERENCES

1. Hostens, I. and H. Ramon, 2003. Descriptive analysis of combine cabin vibrations and their effect on the human body. Journal of Sound and Vibration, 266: 453-464.
2. Nguyen, V.N. and S. Inaba, 2011. Effects of tire inflation pressure and tractor velocity on dynamic wheel load and rear axle vibrations. Journal of Terramechanics, 48: 3-16.
3. Scarlett, A.J., J.S. Price and R.M. Stayner, 2007. Whole-body vibration: evaluation of emission and exposure levels arising from agricultural tractors. Jornal of Terramechanics, 44: 65-73.
4. Hostens, I., K. Deprez and H. Ramon, 2004. An improved design of air suspension for seats of mobile agricultural machines. Journal of Sound and Vibration, 276: 141-156.
5. Hostens, I. and H. Ramon, 2003. Descriptive analysis of combine cabin vibrations and their effect on the human body. Journal of Sound and Vibration, 266: 453-464.
6. Alem, N., 2005. Application of the new ISO 2631-5 to health hazard assessment of repeated shocks in U.S. army vehicles. Industrial Health, 43: 403-412.
7. Rimell, A.N. and N.J. Mansfield, 2007. Design of digital filters for frequency weightings required for risk assessment of workers exposed to vibration. Industrial Health, 45: 512-519.