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ERGONOMIC ASPECTS AND EVALUATION OF VIBRATION IN THE OPERATING POSITION OF AGRICULTURAL TRACTORS

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Summary: *Human beings are exposed to vibrations arising from different sources of excitation. These vibrations are considered disturbances and can interfere with physical integrity and the ability to perform certain work functions. These disturbances are known to cause undesirable effects on human health, therefore assessments and possible vibration controls are necessary. Furthermore, the discomfort caused by vibrations is also directly linked to human fatigue. There are several vibration analyzes that can be done and among them is the whole body vibration analysis. It is known that the human body has different natural frequencies and since the frequency of the exciting source coincides with these natural frequencies of the body, there is an amplification of movement. Based on the risks to which the human body is exposed, the search for improvements in comfort and safety for operators is constant in the automobile industry, which also includes agricultural vehicles. In this study, vibration analyzes are obtained using a portable device used for whole-body vibration analyses. The tractors were subjected to vibrations arising from an unpaved track with severe irregularities and different gears. Measurements were carried out using a three-dimensional accelerometer directly on the operator's seat. Statistical analysis tools were adopted in order to obtain coherent results in accordance with standards. Bearing in mind the risks of vibration on occupational health, the main objective of this work was to analyze the whole-body vibration of two agricultural tractors and verify, together with European Community standards, whether the levels are acceptable. Based on the acceleration values identified in these analyses, possible improvements can be adopted in order to reduce exposure to vibration.*

Keywords: Ergonomics, Whole body vibration, Statistical analyses, Occupational health

1. INTRODUCTION

The level of comfort is a very important item and must be considered when it comes not only to passenger vehicles, but also to any environment that exposes the human body to vibrations. Any and all vehicles including aircraft, cars, trucks, tractors and elevators can expose humans to mechanical vibrations. According to Rao (2009), any movement that is repeated after an interval of time is called vibration or oscillation. According to Maia and Silva (1997), vibrations or dynamic movement are inherent to life in general. Although humanity considers as unpleasant and unwanted phenomena to cause such undesirable consequences as discomfort, noise, malfunction, wear, fatigue and even destruction. All structures are in fact three-dimensional bodies, and each point of such a body, unless contained, can move along three perpendicular directions (x, y and z) to each other (CRAIG, 1981). Therefore, the human body feels these vibrations in the same directions as the structure to which it is in contact.

Occupational vibration is one of the study segments in the area of ergonomics recognized as a high-risk factor to which the worker is exposed (PINHO et al., 2014a). According to the International Ergonomics Association, "ergonomy (or Human Factors) is the scientific discipline that studies the interactions between humans and other system elements, and the profession that applies theories, principles, data and methods, to design that aims to optimize human well-being and global systems performance." In this way, the level of comfort is linked to the reduction of vibrations that are directly linked to ergonomic aspects. Nietiedt et al. (2012) report that the ergonomic analysis of the operating station of agricultural tractors is essential for the protection and comfort of the operator. Franchini (2007) and Oliveira et al. (2011), evaluated the transmissibility frequencies in this area, with the aim of improving the vibration absorption elements. According to Debiasi, Schlosser and Dornelles (2004), operating tractors imposes great physical and mental stress, which justifies the continuous search for improving the comfort of the workplace, otherwise its performance and safety could be compromised. The most commonly reported symptoms, as the vibration level and exposure time increased, were back disorders or pain and signs of degeneration of the vertebrae and intervertebral discs and disc herniation (WIKSTRÖM; KJELLBERG; LANDSTRÖM, 1994). The study of vibration in tractors in the agricultural mechanization process directly contributes to improving the designs of these equipment, aiming at operator comfort during the workday (PINHO et al., 2014b).

Cunha, Duarte and Souza (2012) report that in past decades little attention was paid to workers' health problems arising from noise and vibrations generated by tractors. Also in this study, the exposure levels obtained in the noise and vibration analyzes on the two agricultural tractors were compared with the limits acceptable by the standard. Therefore, it became clear that these vibrations can compromise worker health. It is established in the ISO 2631-1 standard of 1997 that the comfort limit, in the case of vibrations, is between the frequencies of 1 to 80 Hz (INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, 1997). Pinho et al. (2014a) evaluated 36 tractors and identified that the highest frequencies are respectively in the vertical, longitudinal and transverse positions.

According to (TIEMESSEN; HULSHOF; FRINGS-DRESEN, 2007), the factors that had a positive effect (reduction of vibration) were: type of seat; cabin and seat suspension; weight, posture and driver experience; driving speed; track conditions; cabin location; type, tires, load and maintenance of the vehicle.

Marsili et al. (2002) state that the reduction of vibration in tractors through suspension systems can allow an increase of more than 50% in the operator's exposure time. Currently, most manufacturers are incorporating systems to reduce vibration in agricultural tractors (SCARLETT; PRICE; STAYNER, 2007). FMO (1974) states that old machines have higher rates of vibration than modern ones, due to the natural wear factor. In addition to high rates of vibration due to component wear, older agricultural equipment was equipped with antiquated vibration isolation devices. These factors indicate flaws in relation to ergonomics and safety in projects.

For Rossi, Santos and Silva (2011), ergonomics tends to harmonize the process of executing a given task, reconciling the machine with the man, using aspects such as anthropometry, psychology, environment, biomechanics and human physiology, respecting the characteristics of the man for his benefit.

In view of the ergonomic aspects discussed, it is possible to correctly propose the application of ergonomics in a project.

2. METHODOLOGY

For the analyzes presented in this article, the software R version 3.2.2 (Copyright 2015 The R Foundation for Statistical Computing) was used, which uses a language and an integrated development environment for statistical and graphical calculations (VENABLES et al., 2002). Vibration measurement was performed on each axis separately and a sum vector was considered. According to the European standard ISO 2631-97, the value of the largest axis must be adopted, as shown in Table 1.

Table 1: Results x, y and z axis

General data					
	Axle x	Axle y	Axle z	Sum	Units
Aeq(k)	5,78	3,52	3,48	—	m/s^2

Where Aeq(k) is already standardized as a full-body assessment, where the x, y and z axes are multiplied by the factors 1.4, 1.4 and 1, respectively. To define the Aeq values as shown in Equation 1.

$$Aeq = \sqrt{\frac{a_1{}^2 t_1 + a_2{}^2 t_2 + \ldots a_n{}^2 t_n}{t_1 + t_2 \ldots t_n}} \quad (1)$$

Being, Aeq the equivalent acceleration, an, the value of the vibration obtained and tn the exposure time to the acceleration obtained in an. With this value, the normalized acceleration value is calculated for an 8-hour working day (A(8)), according to Equation 2.

$$A(8) = Aeq \sqrt{\frac{T}{T_0}}$$

Where, T is the daily duration of exposure and T0 is the time corresponding to the duration of 8 hours in seconds(s).

3. EXPERIMENTAL PROCEDURE

This section addresses the list of equipment used experimentally, properties of the machines involved in the project and test methodology. The materials and equipment necessary to carry out the proposed experimental procedures required the use of:

- 02 agricultural tractors
- 01 seat sensor with three-dimensional accelerometer
- HVM100 signal acquisition module (Larson Davis, Depew, NY, USA)
- Blaze software for reading signals

The agricultural machines that were used for vibration analyzes are: Massey Ferguson 290 (1981) and Ford 6610 (1989) tractors. For convenience in this work, they will be called Tractor A and Tractor B, respectively. The routine for data acquisition in the field was carried out using the HVM100 module and the three-dimensional sensor on the seats of agricultural machines, as shown in Figures 1-a and 1-b.

(a) (b)

Figure 1: Fixing the accelerometers according to the NHO09-2013 standard on the seat of Tractor A (a) and Tractor B (b).

Some parameters to consider in relation to the unpaved runway where the experimental tests were carried out:

- 25m of unpaved track.
- 3% slope.

The test routines took place with 1 min samples for each gear, as shown in Tables 2 and 3. In order to simulate a work situation that includes short breaks, the tractors started moving 15 seconds after starting the readings on the HVM100 module . The tractors remained moving along the track until the sampling time of 1 min had completed.

able 2: Tractor A Results

Sample	Observation
A1S	Single gear 1
A2S	Single gear 2
A2R	Reduced gear 2
A3R	Reduced gear 3
A4R	Reduced gear 4

Table 3: Identification of tests - Tractor B

Sample	Observation
B1S	Single gear 1
B2S	Single gear 2
B2R	Reduced gear 2
B3R	Reduced gear 3
B4R	Reduced gear 4

Figures 2-a and 2-b show the test carried out in the field where it is possible to check the rods that demarcate the beginning and end of the test track, which totaled 25 meters. It is noteworthy that for these tests the operators were the researchers themselves.

(a) (b)

Figure 2: Experimental test track with details of Tractor A (a) and Tractor B (b).

3.1 Characteristics of Tractors

Tractor A - working at 1700 rpm.

- Ballast: front (front and radial), rear (radial and water).

- Seats: poor condition.

Tractor B – working at 1700 rpm.

- Ballast: front (radial and Supertatu front blade), rear (radial and water).

- Seats: good condition.

The speed scales adopted were equivalent to the manufacturer's manual.

4. RESULTS

4.1 Statistical analysis of data

From the acquisition of data collected in the field, they were transferred to the BLAZE software to be processed and analyzed in the R program. Using the statistical tools ANOVA (CARNERO et al., 2010) and Tukey test (WIJAYA; LUNDBERG, 2012) applied to the "Sum" data, which represents the vector sum of the acceleration of the three axes (x, y and z) for each reading, provided in each test performed. The experimental test provided 60 "Sum" readings of the accelerations for each test, thus allowing the application of the aforementioned tools.

Initially, a comparative analysis was carried out between the "Sum" values of tractors A and B, as shown in Figure 3.

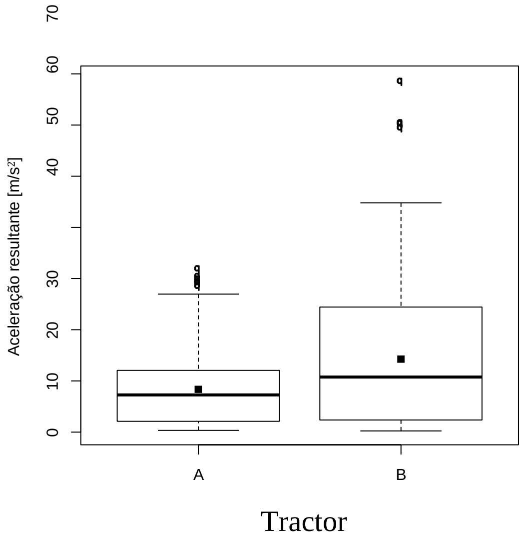

Figure 3: Comparison of the resulting acceleration between tractors A and B.

After comparing the tractors, a comparison was made between each test of each tractor, as shown in Figures 4 and 5. The tests carried out on tractor A, as shown in Figure 4, presented averages very close to 6 m/s2 for reduced gears and of 12 m/s2 for single gears, expected results, since the speed reached with single gears are greater than those achieved with reduced gears. The significant difference between the test means was confirmed with the ANOVA test, which resulted in a p-value of $5.07 * 10^{-12}$, also less than 0.05.

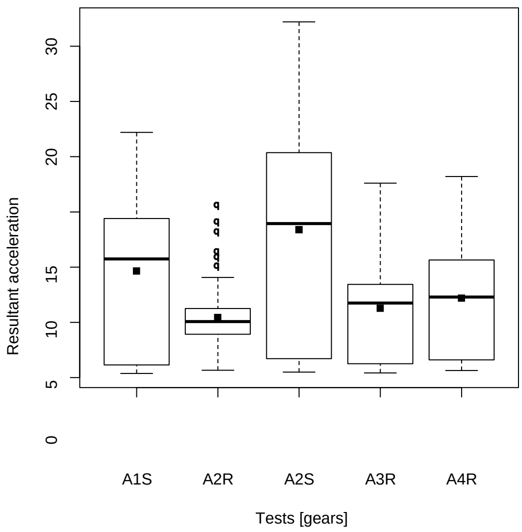

Figure 4: Comparison of the resulting acceleration between tests (gears) of tractor A.

As for the Tractor B tests, as shown in Figure 5, as they have a greater dispersion of values, the pattern is not repeated and a large difference was found in the means of each test. However, the tests with reduced gear also showed lower averages, from 5 to 12 m/s2, than those verified in simple gears, from 18 to 28 m/s2. The greatest difference between the tests also had an influence on the ANOVA test, which resulted in a p-value of $2.2 * 10^{-16}$, lower than that found in the Tractor A test, and also lower than 0.05.

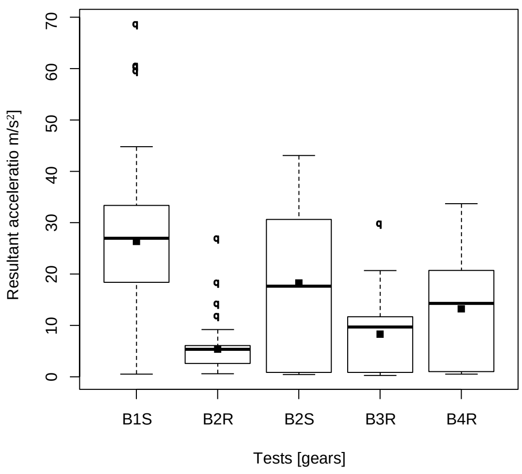

Figure 5: Comparison of the resulting acceleration between tests (gears) of tractor B.

The assessments made in this work were based on the assessment of whole-body vibration, in accordance with European Community criteria. The VDV value represents the vibration dose value and the A(8) value defines the exposure limit for an 8-hour day. Directive 2002/44/EC 25.6.02 - annex B, establishes that the criteria for exposure to vibration are:

- A(8) = 0.5 m/s^2 ou 9,1 VDV - (Action level)
- A(8) = 1.15 m/s^2 ou 21,0 VDV - (Exposure limit)

According to ISO 2631-1 (1997), the vibration dose value (VDV) was used because there are significant peaks or shocks. Table 4 presents the VDV values for tractors A and B according to each gear, with the F value representing the

Tukey test for a 95% confidence interval. In this analysis it is verified that the vibration dose values of Tractor B are higher than those of Tractor A in all gears. Despite the high values, the 2R, 3R and 4R gears of Tractor A present values that are within the exposure limit.

Considering the A(8) values presented in Table 5, it is noted that all acceleration values are above the accepted exposure limit, contradicting some of the VDV results. Therefore, in these cases the VDV values will be considered, due to the presence of significant peaks or shocks.

Table 4: VDV Tractor

	Test				
	1S	2S	2R	3R	4R
A	22,40	34,60	19,20	18,40	19,40
B	95,00	66,80	28,40	33,60	41,30
F = 0,059					

Table 5: A(8) m/s^2

Tractor	Test				
	1S	2S	2R	3R	4R
A	7,42	10,60	4,53	4,94	5,96
B	27,10	14,30	5,40	8,51	12,40
F = 0,129					

4.2 Discussions

From the results it is observed that the vibrations found were significantly different in all tests. This is due to the fact that the tests are carried out in different gears, some of which are reduced. For the testing of both tractors, A and B, exposure limit A(8) is well above the limit imposed at the discretion of the European Community. In this way, the VDV behaved in the same way, showing marked values and well above those predicted for the limit, which would be 21.0 VDV. Therefore, prolonged use of this equipment can cause illness, especially in the lower back, of operators (WIKSTRÖM; KJELLBERG; LANDSTRÖM, 1994).

When comparing the tractors, it was found that Tractor B presented worse results in terms of vibration, even though it was newer than Tractor A, contrary to what FMO (1974) reports. However, it can be concluded that other factors, according to Tiemessen, Hulshof and Frings-Dresen (2007), may have led to this difference in favor of Tractor A, including the suspension of the seat and cabin, the loading and maintenance of the vehicle and the fact that Tractor B is equipped with a front loader. This difference between tractor results corroborates the study by Vanerkar et al. (2008), demonstrating that the level of vibration does not depend exclusively on the working terrain of the agricultural machine, but also on the condition and maintenance of the machine.

Another factor pointed out by Tiemessen, Hulshof and Frings-Dresen (2007) that was found to be directly related to the level of perceived vibration was driving speed, since simple gears, with higher speeds, presented greater vibration than reduced gears, with lower speed, for both tractors. Therefore, one of the proposals to reduce the vibration perceived by the operator would be to reduce the working speed.

5. CONCLUSION

It is concluded that for the operation of these machines, considering that they are old-fashioned when analyzing the ergonomic variable (vibration), it is suggested that intervals between operations be studied (TIEMESSEN; HULSHOF; FRINGS-DRESEN, 2007). These intervals are defined with the aim of adapting the work without harming the operator's health. Another solution would be to use seats with a higher level of vibration absorption, or in more extreme cases, the acquisition of more modern equipment.

Such adjustments may be necessary mainly on small and medium-sized properties, which, according to ANFAVEA (2010), still have older machines in operation, with it being found that 59% of tractors in Brazil are 10 to 20 years old and 37% are older. 20 years of use, which is the reality verified in this study.

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