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# VIBRATION ANALYSIS DURING THE OPERATION OF A TRACTOR WITH AGRICULTURAL IMPLEMENTS

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***Abstract.*** *Vibration is one of the most important variables to be understood and interpreted in the design and improvement of machines. Tractors have proved to be extremely important for certain tasks such as transport and power supply in the use of agricultural machinery and implements. The vibration that is emitted by the tractors and other mechanical equipment, which propagates in the body of the operator, can cause lesions which can be qualified as occupational diseases. The present work had as objective to measure and analyze the vibration that is transmitted to the operators of agricultural tractors in the field operating conditions. For this, an agricultural tractor was used, with different feed rate speeds coupled to an agricultural brush cutter. The experimental data obtained were analyzed using Blaze software and statistically manipulated. Subsequently, the results were analyzed according to current regulation. The results obtained showed that the vibration levels, in low rotation, are in accordance with what is recommended in the norm for an 8-hour workday. For the tests in high rotation, the vibration levels presented were worrisome, since they do not allow exposure to these levels for 8 hours of work. Therefore, it is recommended to place a new seat, with a higher level of vibration absorption, thus allowing the reduction of occupational vibration to the operator.*

***Keywords:*** *vibration, ergonomics, tractors.*

## 1. INTRODUCTION

Agricultural mechanization has become increasingly widespread, with the main objective of reducing input costs and increasing agricultural production. Aiming at the optimization and feasibility of agricultural productivity, it has been an alternative to the small and medium producer (Kumar *et al*., 2016; Verma; Tripathi, 2015). With the increase of mechanization in agriculture, the number of accidents in this field increases, generating a concern for the health of the operators that work in this sector, mainly because they are exposed to high-risk health activities due to ergonomic problems found in agricultural machines, such as vibration (Santos *et al*., 2014).

Vibration is characterized as a physical disturbance that occurs in machines, and its nature varies according to the dynamic characteristics of the system and the elements that make up the machine. Its effect on the human body depends mainly on frequency, magnitude, direction, contact area and exposure time (Baad, Qaimi, 2016).

In this way, it is noticed that the analysis of the vibration in tractors is of fundamental importance to understand and to comprehend the risks that the users of this type of equipment are subject to. In the design of agricultural machinery, performance and productivity have always been prioritized in comparison to the comfort and safety of the operators and, therefore, the workers are subject to the conditions of the machines (Nagahama *et al*., 2012). The same is true for the design of machinery in general, which until recently had as its main objective the maximization of the efficiency of the machinery associated to the lowest cost, not taking into account the human factor. However, with the increase of the work safety standards, there is a tendency to improve the ergonomic and safety conditions of workers, aiming to favor working conditions, reducing the level of fatigue in which the operator is exposed to, reducing the risk of accidents and, consequently, increasing work productivity and quality (Alves, 2011).

Human exposure to vibration can be classified as Full Body Vibration (FBV) Vibration in Hands and Arms. For the vibration that affects the whole body, the most harmful frequency range is between 0.5 and 80 Hz. This type of vibration is mainly present in transportation systems such as trains, cars, buses, etc. (Gomes, Savionek, 2014). And when applied throughout the body can cause resonance in the viscera, in addition to damaging the muscles and spine (Ximenes, 2006).

Ergonomics studies the adaptation of machines to humans and its main objective is to modify the work environment to adapt the activity in it. That is, to assist in machine design in order to accommodate natural variability, associating it with human performance, achieving the general purpose of the system with safety and productivity (Hassall, 2015).

Nipun *et al.* (2017), when conducting a research with industrial workers, where the main focus was to analyze the ergonomic risks in the execution of construction tasks, welding, among others carried out in the industrial sector, affirm that, during long periods of time, the sustained physical work causes injuries to workers, which in turn, damages workers and causes a drop in productivity, since the work posture exposed the worker to a high level of ergonomic risk.

For the evaluation of the vibration which reaches the operator of a particular machine, the International Organization for Standardization standards, ISO 2631 (1978) and ISO 5349 (2001), which have a guide for the assessment of human exposure to whole body vibration and vibration in the hands and arms, respectively, were used. In Brazil, NHO 09 (2013) and NHO 10 (2013) were developed based on ISO 2631 (1978) and ISO 5349 (2001) standards, with a focus on risk prevention and control. The present work uses ISO 2631 (1978) and NHO 09 (2013) as the basis for whole body vibration.

According to ISO 2631 (1978), there are four physical factors of prime importance in determining the human response to vibration: intensity, frequency, direction and vibration duration (exposure time). And the human body can receive vibration in three different ways, reaching the whole body or substantial parts of it, vibrations transmitted by supporting surfaces, such as feet, buttocks and back, and finally those that affect specific parts of the body such as hands, head and legs. The orthogonal coordinate system for studies of the magnitude effect in different directions of the human body for whole body vibration is presented in Fig 1.

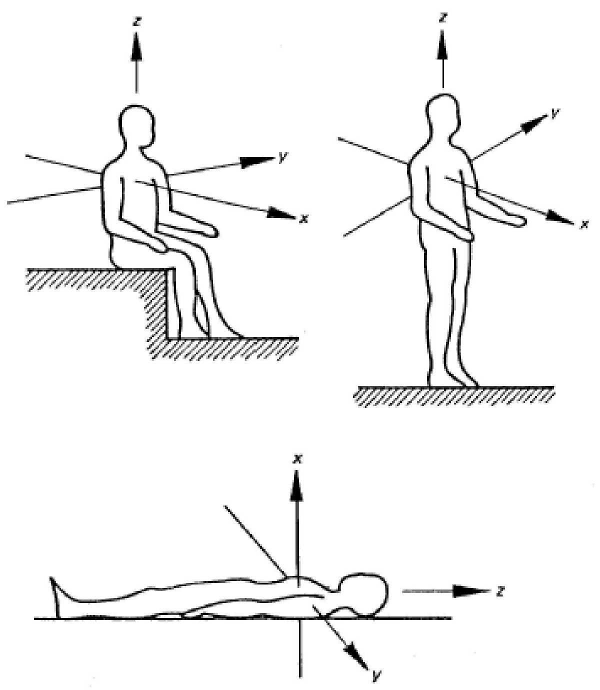


Figure 1. Directions of positions for measuring full body vibration
Source: ISO 2631(1978)

It is noteworthy that the direction of movement is of paramount importance when analyzing the vibration in the whole body because the human body reacts to the vibrations in different forms for each axis, these being, longitudinal along the z axis, referring to the vertebral and transverse column, axes x or y, acting on upper limbs or through the thorax (Nietiedt *et al.*, 2012).

Therefore, when studying the vibration in agricultural tractors, it contributes to the improvement of projects of this equipment, aiming for the operator's comfort during work (Pinho *et al.*, 2014).

In addition to the vibration influence, tractor operators are also subject to limitations and adversities such as: noise, dust, temperature, humidity, illumination, and others because of the machinery and the work environment (Schlosser *et al*., 2002).

Knowing this, this work had the purpose of analyzing the vibration transmitted to the operator by an agricultural tractor, and quantifying the maximum time during the work day.

## 2. EXPERIMENTAL PROCEDURE

This topic, first, lists the equipment used and then mentions the procedure adopted to carry out the experiment.
Equipments:
- 1 single-axle agricultural tractor with 14.7 horsepower and 2750 rpm motor (Fig. 2 a);
- 1 Agricultural implement attachment (Fig. 1 a);
- 1 Seat sensor with a Larson Davis tri-dimensional accelerometer, ICP Triaxial model, series: SEN027 (Fig. 2 b);
- HVM-100 signal acquisition module, HVM100 Larson Davis brand, model 1.33;
- Blaze software for reading signals.

A qualified operator in the category, with a mass of 65 kg, drove the tractor with the sensor attached to the operator's seat, which was fixed according to NHO09 (2013), as shown in Fig. 1 b.


Figure 2. Test conditions. (A) tractor with attached implement; (B) Seat sensor with triaxial accelerometer

For each condition, four replicates lasting one minute each were performed. The tractor was in motion during all the tests, simulating work situations and the rotation varied between low (966 rpm) and high (1422 rpm). In these rotations, the conditions under which the agricultural implements were in the soil were analyzed, performing the harvesting of the vegetation, and without hydraulic action (implement elevated). The conditions under which the tests were performed can be visualized in Tab. 1.

Table 1. Conditions established for the tests.

| FACTORS | **[LEVELS]** | | CONDITIONS |
|---|---|---|---|
| IMPLEMENT | **[S]** Soil | **[E]** Elevated | BS<br>BE |
| ROTATION | **[A]** High rotation (1422 rpm) | **[B]** Low rotation(966 rpm) | AS<br>AE |

For each condition presented in Tab. 1, four repetitions were performed with a duration of one minute, totalizing in 16 trials, whose data obtained in the experiment, were archived by the signal acquisition module.

## 3. METHODOLOGY

The experimental data obtained during field measurements were transferred to Blaze software and analyzed and manipulated statistically using Excel software.

For the statistical analysis, the boxplot graph was used to capture and describe important aspects of the data set obtained in the field, such as variability and symmetry of the data. The bar graph was also made, with the data averages, for better comparison and analysis of the conditions tested.

Subsequently, the analyzes of the technical data were carried out. At this moment, the international standard ISO 2631 (1997) and NHO 09 (2013) were used as reference.

For data manipulation, the rms - root mean square - value, or efficient value, was used, which is the square root of the arithmetic mean of the squares of the acceleration values. This value is considered the most important measure of the amplitude, since it provides the average of the energy contained in the vibratory movement (Ximenes, 2006).

And then, the maximum exposure time of the operator in relation to the occupational vibration was calculated using Eq. (1), shown below:

$$A(8) = A_{eq}\sqrt{\frac{T}{T_0}} \quad (1)$$

In which A(8) the normalized acceleration for a working day of 8 hours, $A_{eq}$ the equivalent acceleration, T the exposure time and $T_0$ the time corresponding to 8 hours, in seconds (s), $T_0$ = 4800 s.

NHO 09 (2013), which presents a table that relates the vibration dose value (VDV) to the normalized acceleration value, A(8), it is possible to find the maximum exposure time using Equation 1. In Tab. 2, below, this relation is shown, as well as the technical consideration and performance recommended by the standard.

Table 2. Judgment criterion and decision making.

| **A(8) ($m/s^2$)** | **VDV ($m/s^{1,75}$)** | **Technical Consideration** | **Recommended Action** |
|---|---|---|---|
| 0 a 0,5 | 0 a 9,1 | Acceptable | At least a maintenance of existing condition. |
| > 0,5 a < 0,9 | > 9,1 a < 16,4 | Above the action level | At least the adoption of preventive measures. |
| 0,9 a 1,1 | 16,4 a 21 | Region of uncertainty | Adoption of preventive and corrective measures aiming at reducing daily exposure. |
| Above 1,1 | Above 21 | Above the exposure limit | Immediate adoption of corrective measures. |

Source: Adapted from NHO-09 (2013).

For the analysis of the experimental data, the maximum exposure time was calculated considering the normalized acceleration, A(8) equal to 0.5m/s$^2$, that is, the acceptable value according to NHO 09 (2013). The value used for the equivalent acceleration, $A_{eq}$, is the vector sum of x, y, z, according to the normative orientation.

## 4. RESULTS AND DISCUSSIONS

After the data acquisition, the data was treated and analyzed through Excel software. First, by taking the vector sum of the acceleration of the three axes (x, y, z), we obtain the mean of the conditions analyzed, which are presented in Fig. 3.

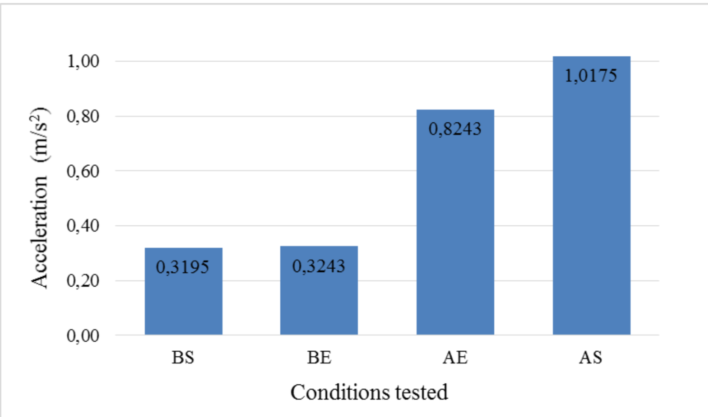


Figure 3. Average acceleration of the conditions tested

Subsequently, the boxplot graph was made for a better visualization of its characteristics, that is, the location, dispersion, asymmetry, and outiliers (discrepant measurements) of the data, presented in Fig. 4.

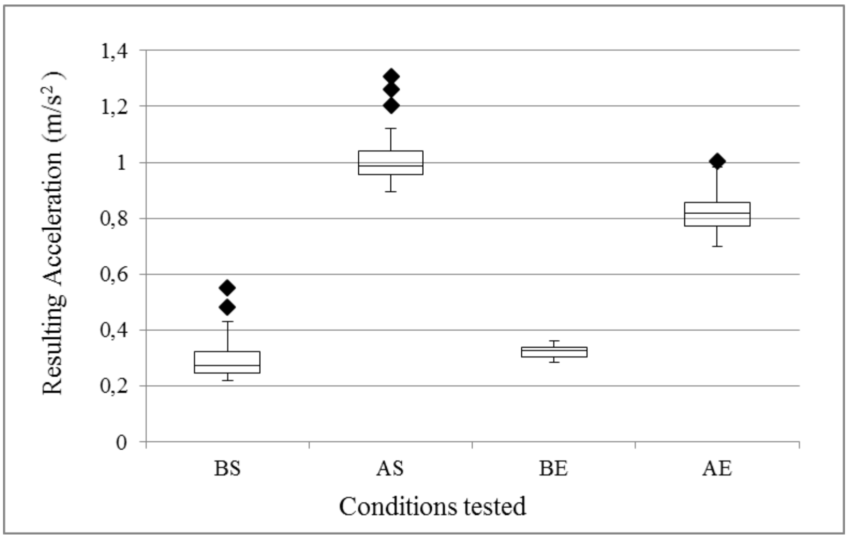


Figure 4. Behavior of the mean acceleration of the conditions tested

It can be observed that the accelerations followed the following increasing order: BS<BE<AE<AS. The boxplot graph (Fig. 4) shows that the data presented low variability, especially in the low rotation test with elevated implement, and the presented outiliers are due to the peaks resulting from the tests, where it is also noted that the low rotation test with elevated implement did not obtain considerable peaks.

In Fig. 5, it is then possible to clearly observe the peaks present, as well as the behavior of the tractor during the tests.

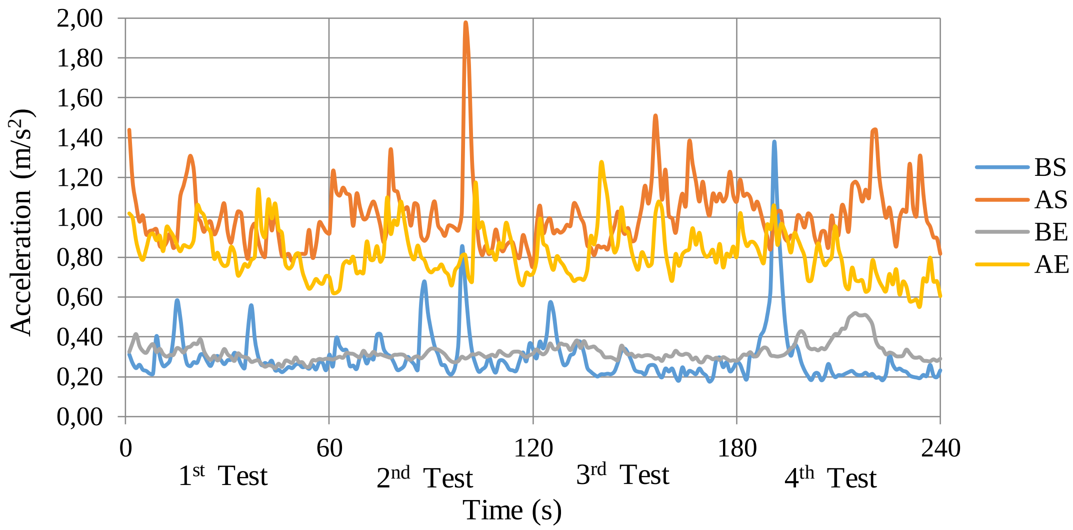


Figure 5. Behavior of the instantaneous acceleration of the four tests

The peaks presented in the curves (Fig. 5) are due to the operation of the implement in contact with the ground and the fact that it presents irregularities, which caused an increase in the level of vibration in the operator. These peaks are the outliers shown in the graph of Fig. 4, where it is noticed that the BE test (low rotation with ground implement) did not obtain peaks, presenting less variability of the data, and therefore not presenting outliers in its boxplot.

Still analyzing the curves in Fig. 5, and the graph of the averages, shown in Fig. 3, it can be observed that the conditions for high rotation achieved a higher vibration level and also the condition in which the agricultural implement was at the soil obtained higher vibration, showing that when the tractor is in high rotation and with an implement in operation, the soil contributes to the generation of occupational vibration. Whereas, in the low rotation situation, the operation of the implement in the soil contributed to the absorption of the vibration, transmitting less acceleration to the operator.

It was also found that in most of the tests performed, greater vibration acceleration was obtained on the x-axis, which, for the situations tested, measures the vibration in the lower limbs of the operator regarding the frontal mobility of the limbs, while only the high-rotation condition with elevated implement, obtained greater acceleration in the "z" axis, which measures the vibration in the lumbar region of the human body. It is known that operator with intense exposure to mechanical vibrations in the lower limbs can lead to circulation problems (Kerschan-Schindl *et al*., 2001).

These results implied the limit of exposure of working time to the conditions, which were calculated according to the NHO 09 (2013) standard, as shown in Fig. 6.

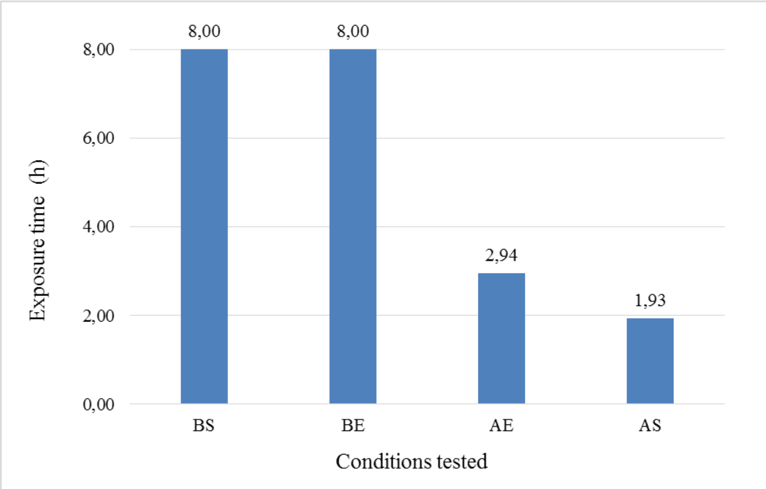


Figure 6. Exposure time for the conditions tested

It can be observed that the tractor in low rotation, presented a situation of lower risk to the occupational health of the operator, allowing it to work the 8 hours of the work day, without causing damage to health. While in high rotation condition, the exposure time is reduced drastically, not meeting the daily 8-hour value recommended by NHO 09 (2013). Under these conditions, the operator can be exposed to approximately 3 hours when the implement is elevated and without operation, and approximately 2 hours when the agricultural implement is in the ground performing the harvesting of the vegetation. Being that, when exceeding this time, can cause in serious damages to the health of the operator.

In addition, too much exposure to whole body vibration should be taken into account, as this exposure may contribute to lesions and/or disturbances in the gastrointestinal system, as observed in an experiment by Wikstrom *e. al*. (1994).

## 5. CONCLUSIONS

It was observed that the vibration levels obtained in the present study were higher when the tractor was in high rotation than in low rotation. In addition, the operator must be aware of the exposure limit so that there is no detriment to health, since for the operation in high rotation, the recommended time of exposure to the vibration is much lower than the 8 hours of work. It was also observed that the greatest occupational health risks are in the "x" and "z" axes, which refer to vibration in the lower limbs and lumbar region, respectively. It is recommended as immediate improvement, the use of seats with a higher level of absorption to reduce the transmissibility of vibration to the operator. It is also recommended to periodically perform maintenance on the tractor, as the conditions of the tractor can influence the level of occupational vibration.

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