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Evaluation of the vibration levels issued by agricultural tractors

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Vibration is one of the most relevant aspects, when dealing with the subject of ergonomics in agricultural tractors, although there are still few studies developed to evaluate this parameter and its implications for occupational health. This work aimed to evaluate the levels of vibration emitted by agricultural tractors with different powers, comparing the results with the norm in force in Brazil, in addition to evaluating these levels in three different types of surface. In its methodology, seven tractors, called A, B, C, D, E, F and G, were evaluated, from the same brand, with powers ranging from 75 to 215 hp. The frequency range chosen for the study varied from 5 to 10 Hz, the total data acquisition time was 20 min and the tractors operated under similar conditions, with five repetitions in each treatment (tractor x surface). Generally, the tractors studied showed higher vibration levels than the parameters set by the standard used by the International Organization for Standardization (ISO), in a daily working period of eight hours, in the frequency range varying from 5 to 10 Hz.

Key words: Agricultural machines, operator, surfaces, vibrational analysis.

INTRODUCTION

The main concern of ergonomics is the human element and its main goal is the well-being of the worker, whereas the increase in production and the product quality are the result of an adequate interaction between man and production system (Filip and Candale, 2012). It is expected that new generation tractors will naturally have better ergonomics, but these advances are occurring slowly and, in addition, most current tractors, when studied, have alarming levels of ergonomics, not providing machine operators farms neither comfort nor safety in daily work.

Agricultural tractors typically have a large mass and operate in terrain that has an uneven surface, exposing their operators more often to Whole Body Vibrations (WBV) than compared to on-road vehicles (de la Hoz – Torres et al., 2017; Kim et al., 2018). Heavy machine operators typically work for hours, thus being exposed to vibration for much of the day, which can lead to serious

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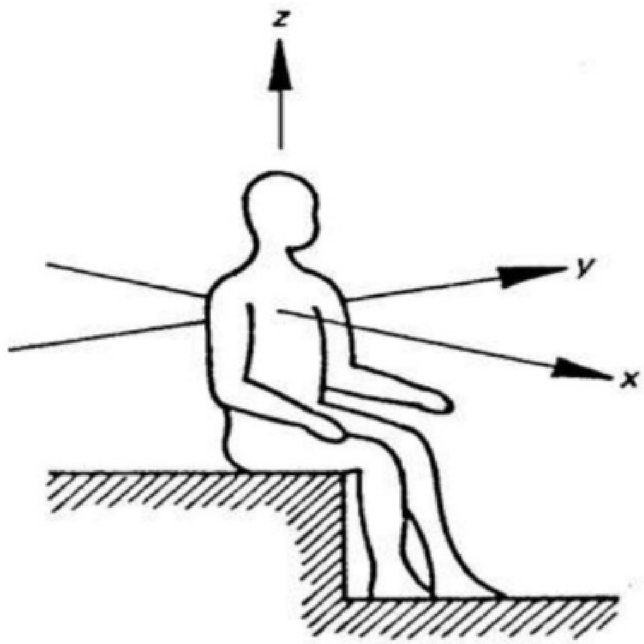

Figure 1. Coordinate system directions for mechanical vibrations in humans.
Adapted from ISO, 2631: 1978.

health problems (Kia et al., 2020). Among all health problems, spinal-related problems are the most serious and common (Raffler et al., 2017). The vibration direction is measured by its anterior-posterior axis (x-axis), lateral axis (y-axis) and longitudinal axis (z-axis), designated by ISO 2631:1978 (ISO, 1978) as shown in Figure 1. Operators of off-road vehicles are exposed to WBV on all three axes, unlike on-road vehicles where exposure predominantly occurs on the z-axis (Johnson et al., 2015), this causes agricultural tractor operators to suffer a larger set of harmful effects due to exposure to these vibrations (Kim et al., 2018).

According to Stojic et al. (2017), low frequency is the main vibration range to be studied, with greater attention to the 5 to 10 Hz ranges caused mainly on dirt roads. Within this perspective, considering that the study of ergonomics has great importance in the agricultural scenario, influencing from the product generated in the plantations to the harmful ones generated by the excessive vibration of the machines, and by the lack of studies in the literature in relation to this area of knowledge. This work aims to evaluate the levels of vibration emitted by agricultural tractors with different powers, making a comparative analysis of the results obtained with the norm ISO 2631: 1978 (ISO, 1978), besides evaluating these levels in three surfaces (asphalt, dirt and field). After analyzing the study, it was possible to determine the evaluation of the vibration levels of agricultural tractors and compare them to the ISO 2631: 1978 (ISO, 1978).

MATERIALS AND METHODS

The project was developed at the Laboratory of Machinery and Precision Agriculture (LAMAP) at the Faculty of Animal Science and Food Engineering (FZEA) of the University of São Paulo (USP), located in the city of Pirassununga / SP. The geographical location of the Campus is 21°59 'south latitude and 47°26' west longitude and average altitude of 635 m.

Seven tractors from the same manufacturer and different models were used to perform the vibrational analyses of the study, their characteristics are described in Table 1. The original factory seat was used for all tractors, and before starting the test, the seats were adjusted for the operator's weight and height. A single tractor operator participated in all tests, because operators of different weights and heights are able to interfere in the vibration values found (Costa and Arezes, 2009).

Regarding the vibration evaluation, the primary quantity used was the acceleration, expressed in ms^{-2}, established by the ISO 2631:1978 standard (ISO, 1978). In order to assess the vibrations transmitted by the operator's body, a vibration analyzer was used, model HD-2030HA-WB, Delta Ohm brand, serial number 12062930149, with a bandpass filter. The device for data acquisition was set to read accelerations in the entire body, storing every second.

In addition to the vibration analyzer, a seat-shaped accelerometer was connected to it, model 356B41, PCB Piezotronics brand, serial number LW145553, for tri-axial analysis. Both equipment mentioned worked together, and the contact between the vibration sensor and analyzer was established, via cable, for the acquisition and storage of the collected data.

To carry out the tests, the operator sat on top of the vibration sensor, which was placed under the tractor seat, in order to collect the data under the same conditions to which the operator is exposed in his daily work. In order to maintain the conditions found daily in the operation of agricultural machinery, the tests were

Table 1. Characteristics of the tractors used in the study.

Tractor	Power (at 2200 rpm) (hp)	Year of manufacture	Worked hours (h)	Traction	Tires	Weight (Kg)
A	75	1996	6540	4x2	Diagonals	2766
B	86	2005	1217	4x4	Diagonals	2463
C	120	2005	7834	4x4	Diagonals	3800
D	173	1997	7472	4x4	Diagonals	4502
E	75	2011	701	4x4	Diagonals	3748
F	110	2011	907	4x4	Diagonals	4105
G	215	2012	161	4x4	Diagonals	6729

carried out on three different surfaces: asphalt, dirt road and field. For the tests on the asphalt and dirt road, there were considered the existing streets and roads between the shed and the field. And the study in the field was done in a place with the characteristic of mobilized soil, normally used by the tractors of the place. None of tractors were operating implements at the time of the test.

The acquisition time was of 20 min, with the tractors operating under similar conditions and five repetitions in each treatment (tractor x surface). The signals were transformed into the frequency domain, using the FFT function (amplitude and phase), being digitally filtered in 1/3 octave bands to obtain effective acceleration. The maximum values obtained in each band were multiplied by weighting factors, generating the weighted accelerations. The analysis of the global weighted effective acceleration was carried out in the range between 1 and 80 Hz. In this work, the range between 5 and 10 Hz was highlighted for the evaluation of whole-body vibrations, because in this range are the main frequencies related to diseases involving the spine.

According to ISO 2631:1978 (ISO, 1978), three parameters must be considered for the assessment of vibrations: the conservation of the efficiency of operators work; the guarantee of the operator's well-being and health and the maintenance of operator's comfort. For that, ideal levels were stipulated for each parameter. They are, respectively: reduced efficiency level (NER), exposure limit (LE) and reduced comfort level (NCR). For such analyzes there are predetermined patterns of curves in function of the exposure time to vibration, plotted in graphs of the type frequency (Hz) x acceleration (ms^{-2}), for each of the different levels or limits evaluated, as well as for each of the directions actuation (x, y, z).

The values of the NER parameter curve, when exceeded, affect the efficiency of the work performed, thus generating operator fatigue. The LE parameter, when exceeded, can result in several harmful effects to the operator's health, and its curve is made by the values of the NER parameter multiplied by 2. Regarding the parameter NCR, its curve is made dividing the NER values by 3.15 and when indexes of the curve are exceeded, it can cause the loss of the operator's comfort state. After the tests, a relation was made between the data collected and the vibration indices recommended by ISO 2631:1978 (ISO, 1978), all of them considering the eight-hour workday.

RESULTS AND DISCUSSION

Figures 2 to 4 illustrate the vibration data collected with agricultural machines on the asphalt surface, these being the values found in the vibration for the third octave band in which the three axes (x, y and z) were measured. For comparison, values proposed by ISO 2631:1978 (ISO, 1978) were used, regarding the values of reduced efficiency level (NER), exposure limit (LE) and reduced comfort level (NCR), considering the work period.

In the analysis of Figures 2 to 4, it is possible to understand that in the frequency values below 5 Hz, there is a tendency of the higher the frequency the lower the acceleration value will be and in the study range, that represents the frequency values between 5 Hz and 10 Hz, the acceleration values tended to increase, however slowly, regardless of the axis analyzed. On the x and y axes, in the range between 5 to 6.3 Hz, most tractors exceeded the values recommended by ISO 2631:1978 (ISO 1978) in the values of NCR, NER and LE, however, in the range between 6.3 Hz at 10 Hz the LE values were more in accordance with the norm, mainly in relation to the y axis. The curves on the z axis were constantly exceeded, in all parameters (NCR, NER and LE). This is of great concern, since the most harmful diseases in relation to the high values of exposure to vibration, are usually related to an excess of vibration on the z-axis, which may cause problems in the spine of those who operate these agricultural machines. It can also be concluded that in most tests in which the tractors were operating on the asphalt, as the NCR and NER values were not respected, the operators were working with reduced comfort and their working efficiency below ideal, respectively.

Figures 5 to 7 illustrate the vibration values studied with the agricultural tractors on the dirt road, these being the vibration values found for the third octave band in which the three axes (x, y and z) were measured. Despite the difference on the dirt road, the seven tractors showed a similar behavior in their vibration patterns, regardless of the analyzed range, whether higher or lower than the study range, when within the study range there was LE extrapolation with greater frequency for the x and y axes, especially when at the frequency of 10 Hz. It is noteworthy that in the frequency values between 5 Hz and 10 Hz, the acceleration values were within the limits of NER, and never fit within NCR. In the z-axis analysis, few tractors, and in a few frequencies analyzed, presented acceleration values within LE, consequently always exceeding the limits of NCR and NER in the

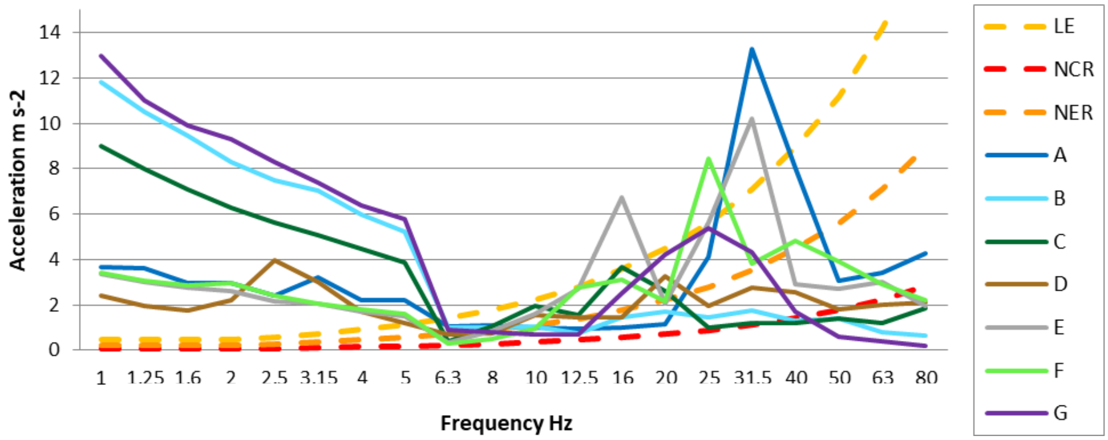

Figure 2. Comparing the vibration of tractors operating on asphalt with ISO 2631: 1978 (x-axis).

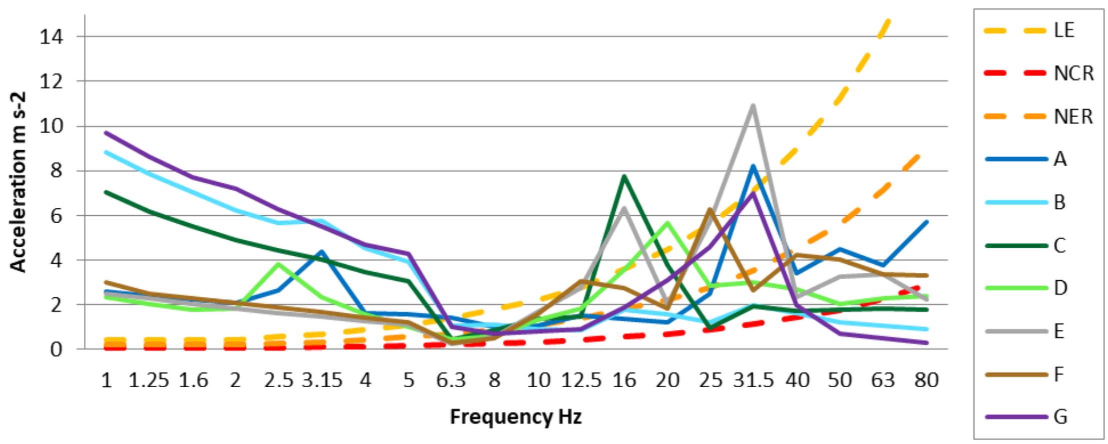

Figure 3. Comparing the vibration of tractors operating on asphalt with ISO 2631: 1978 (y-axis).

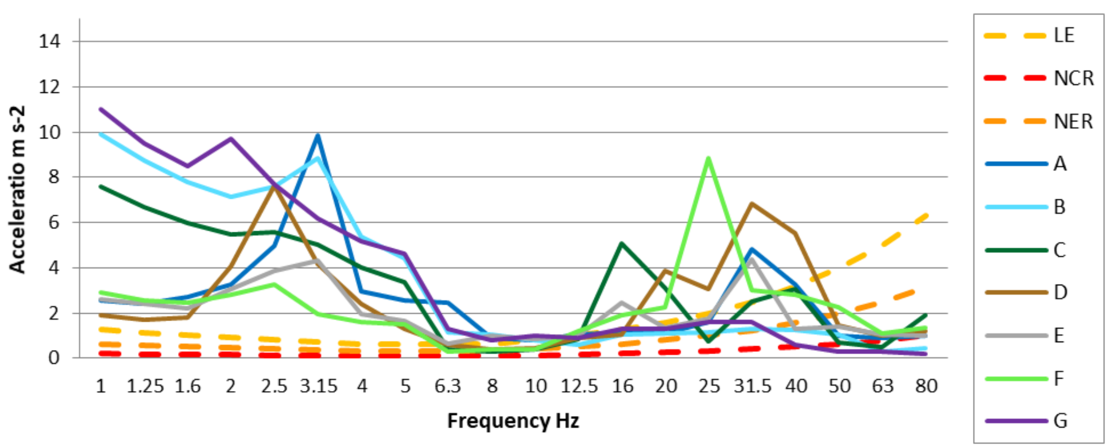

Figure 4. Comparing the vibration of tractors operating on asphalt with ISO 2631: 1978 (z-axis).

frequencies from 5 to 10 Hz. It is also concluded that the risks that the operators of these tractors are exposed to these levels of vibration are notorious, since the frequent exceedance of the LE shows the possibility of developing

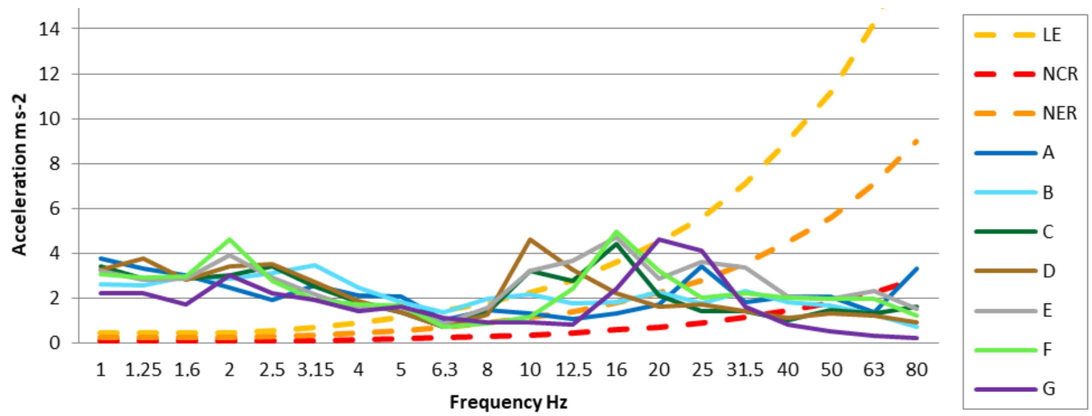

Figure 5. Comparing the vibration of tractors operating on dirt road with ISO 2631: 1978 (x-axis).

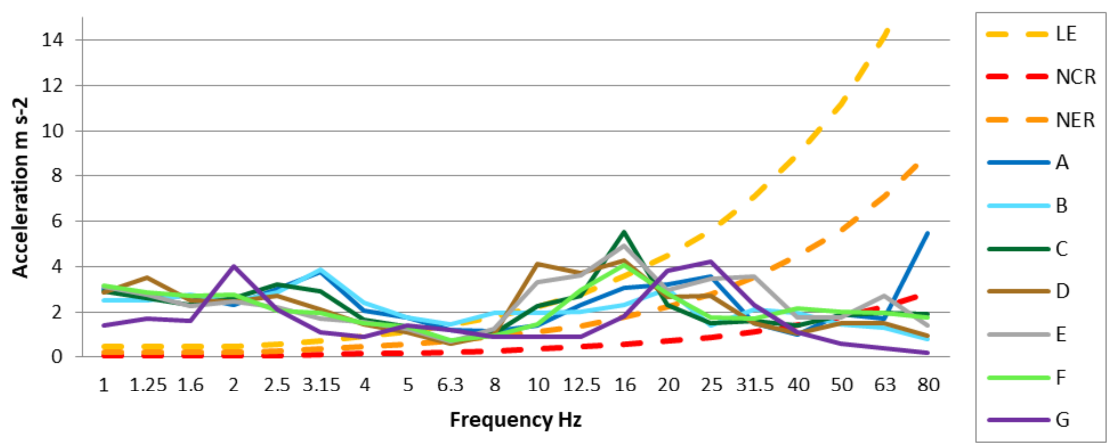

Figure 6. Comparing the vibration of tractors operating on dirt road with ISO 2631: 1978 (y-axis).

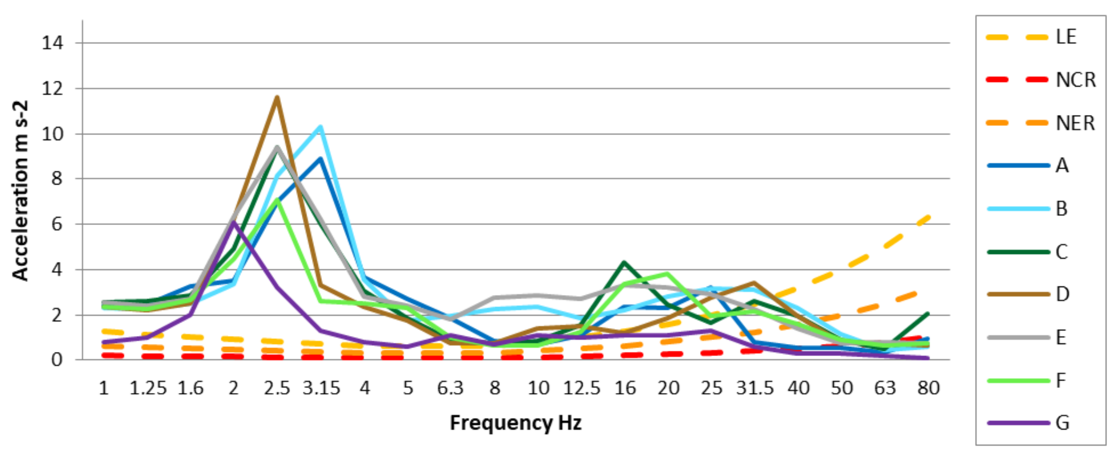

Figure 7. Comparing the vibration of tractors operating on dirt road with ISO 2631: 1978 (z-axis).

diseases related to the spine, since authors cite the 10 Hz range as one of the most harmful to the body structure as a whole.

Comparing the graphics of the dirt road with those of

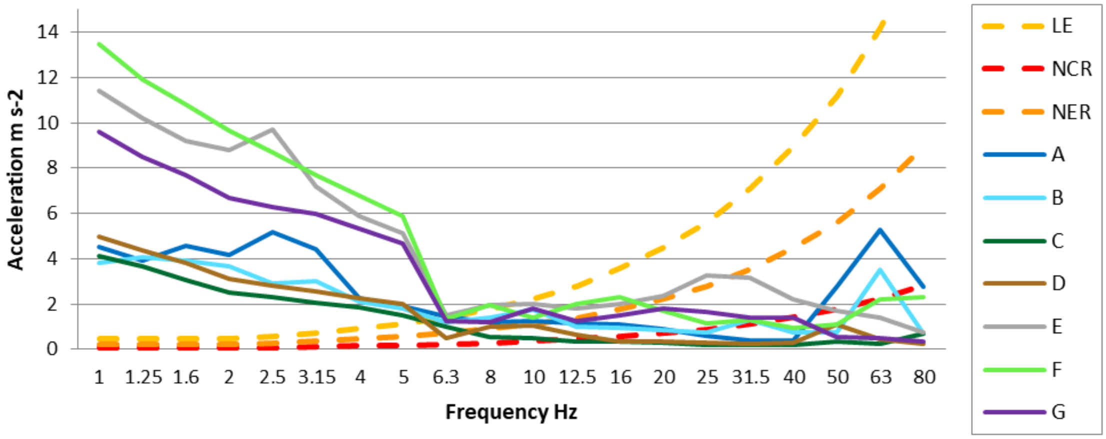

Figure 8. Comparing the vibration of tractors operating in the field with ISO 2631: 1978 (x-axis).

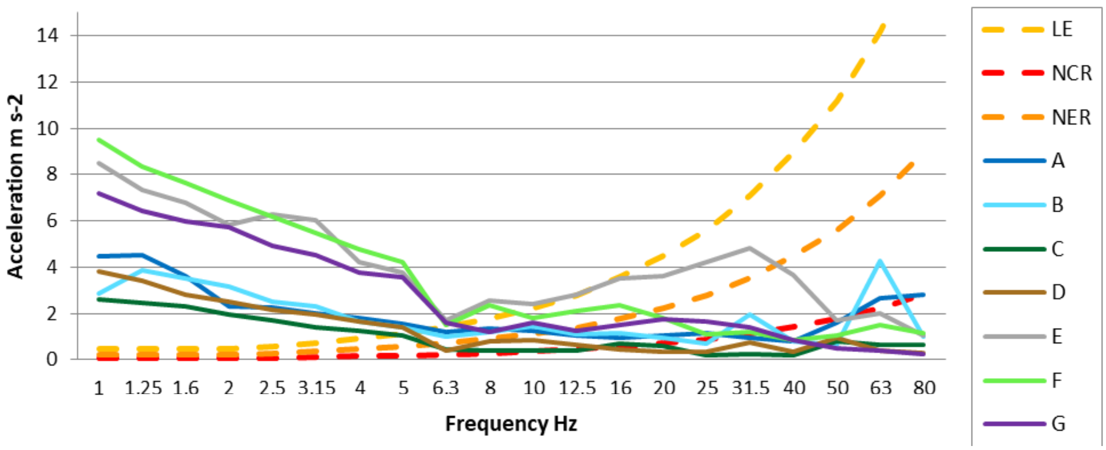

Figure 9. Comparing the vibration of tractors operating in the field with ISO 2631: 1978 (y-axis).

the asphalt, it can be concluded that there was no change in the vibration values in the studied range. With the compaction present on the dirt road, this surface still has more irregularity than the asphalt, because in both situations the tractor made the same effort.

Finally, Figures 8 to 10 illustrate the vibration values studied with the agricultural machines on the field surface, these being the values found in the vibration for the third octave band in which the three axes are measured (x, y, and z).

On the field surface, a certain pattern is noticed again, even with spacing in the acceleration values and in the variation in the collected frequencies. For the x and y axes, the descending curves are again noteworthy when approaching the range between 5 and 10 Hz, as well as the increases noted after passing through that range. Also, for these axes, there is a constant extrapolation of NCR and NER for the study range, with some tractors still exceeding the LE limits for a few times. For the z-axis, some similarity in the behavior of the spectra is perceived, but not as noticeable as that noted in x and y. In this part, it is noted that there is a greater incidence of exceeding the limits stipulated by the LE curve within the stipulated wavelength range, with few occurrences of tractors within the NER limits and no incidence of compliance regarding the NCR. The permanence of tractors exceeding the LE limits continues to demonstrate the possibility of the development of occupational diseases due to the incident vibration, as well as reduced productivity due to the extrapolation of NER and reduced operator welfare due to exceeding the limits of NCR.

Although the range stipulated for the analysis is between 5 and 10 Hz, there are peaks of acceleration in the z-axis spectra, for all terrains, in the range between 2 and 4 Hz. The same can be extrapolated to the frequencies between 5 and 10 Hz, which, although presenting lower acceleration values, they continue to exceed the boundary ranges for LE, NCR and NER.

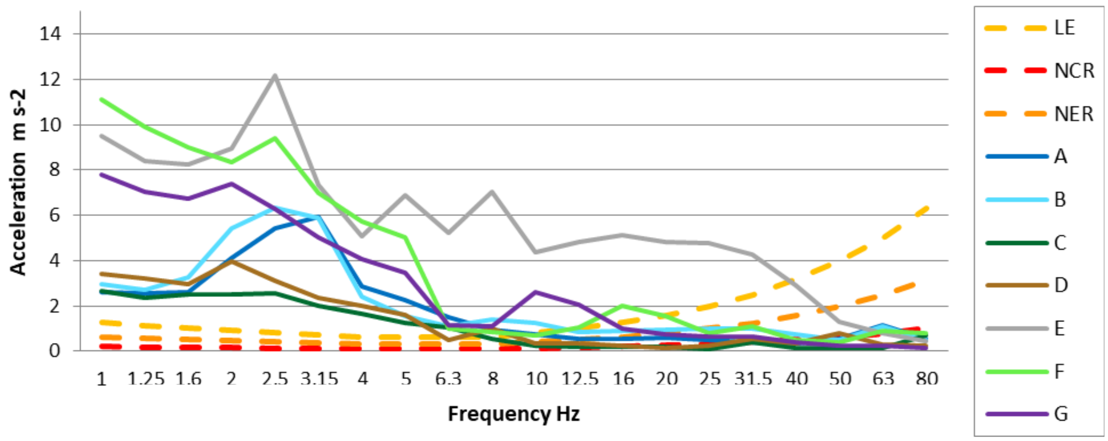

Figure 10. Comparing the vibration of tractors operating in the field with ISO 2631: 1978 (z-axis).

Something to be discussed more specifically about the field surface, is the fact that some of the newer tractors evaluated have presented acceleration values higher than the limits for the studied range. Looking at Figures 8 to 10, the tractors that exceeded the limits, whether LE, NCR or NER, were the E and F tractors, both manufactured in 2011. This highlights that even the tractors manufactured more recently still need an ergonomic improvement related to their vibration. One caveat to make is regarding the G tractor, which although it is also a new tractor and has a higher power than the others, it presented acceleration values within the LE limits for more times than the others. This fact can also be related to having a closed cabin and being the tractor with the highest weight among the seven tractors in the study, which can provide greater stability in movement.

Regardless of the surface, all tractors showed acceleration values exceeding the LE limits in the z-axis assessments. It is seen in the graphs that the curves of the normal ISO 2631:1978 (ISO, 1978) on the z-axis are more limiting, this is because if the vibration limits are exceeded on that axis, the probability of obtaining an orthopedic disease is greater than in the others axes. Agricultural tractors have several parts whose function is to reduce the vibration that will come into contact with the operator, for example, through the damping generated by the seats of these tractors, but finding solutions to reduce WBV in agricultural tractors is not a simple task, as each tractor works on different types of soil, which have different surfaces, which makes standardization difficult (Rao and Chaudhary, 2018).

In addition to the different types of soil, there are other factors that influence the vibration resulting from these tractors, such as the type of operation (Singh et al., 2019), the characteristics of the tractor (Cutini et al., 2017) and also incorrect postures by the operator, which can result from discomfort to serious harmful effects (Fethke et al., 2018). Taking into account all the factors analyzed, there is a lack of studies in this area and it is also noted that this subject has a large space for different projects and methodologies related to the identification and mitigation of vibrations emitted by agricultural tractors.

Conclusion

The seven tractors studied showed vibration levels above the thresholds established by ISO 2631:1978 (ISO, 1978) within the analyzed range from 5 to 10 Hz. The limits were exceeded in the three parameters studied (NER, LE and NCR), in the three-axis studied (x, y, z) and on the three surfaces studied (asphalt, dirt road and field), within the 8 h working period daily. It is understood by the study done that there are still many agricultural tractors that have vibration levels that are not ideal, and there is also a large area for new research related to this topic that has not yet been explored.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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