Full Length Research Paper

Vibration levels emitted by agricultural tractors

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Received 12 August, 2017; Accepted 29 August, 2017

The objective of this study was to evaluate the vibration levels emitted by agricultural tractors with different capacities, comparing the results with the current norms in Brazil. The test was carried out with four tractors of different strengths - Massey Ferguson MF 4292 (engine power of 110 hp at 2,200 rpm, manufactured in 2011, and at the moment of the beginning of the tests has worked for 2,560 h), MF 4275 (engine power of 75 hp at 2,200 rpm, manufactured in 2011, and at the time of the beginning of the tests has worked for 3,036 h), MF 680 (engine power of 173 hp at 2,200 rpm, manufactured in 1997, and at the time of the beginning of the tests has worked for 9,010 h) and MF 297 (engine power of 120 hp at 2,200 rpm, manufactured in 2005, and at the time of the beginning of the tests has worked for 5,715 h).

The studied tractors presented, in general, vibration levels higher than those established by International Standard Organization (ISO) 2631 for 8 h daily work, ranging between 5 and 10 Hz.

Key words: Frequency, ergonomics, personal protective equipment.

INTRODUCTION

Nowadays, stimulated by the increase in the rigor of work safety standards, there is a tendency to improve the conditions of ergonomics and safety of the operator. However, most agricultural tractors present comfort and safety problems, causing among others, a decrease in the operational capacity and the occurrence of accidents in agricultural activities.

Kyuhyun et al. (2017) stated that even with the advancement in technology, agricultural tractors have a level of comfort lower than what is recommended when compared to passenger cars, paving way for researchers aiming to improve the ergonomics of these machines.

Vibration problems make the agricultural tractor operator more susceptible to accidents. According to Araújo et al. (2002), environmental risks are classified as physical, chemical and biological hazards.

Among the ergonomic factors that harm agricultural tractor operators, vibration stands out among the main ones. These vibrations, in general, are of low frequency, but can generate problems of vision, irritability, lumbar deformations and digestive problems (Servadio et al., 2007).

Cutini et al. (2016) made it clear in their research that the vibrations to which tractors operators are exposed to,...
if it continues this way may result to a number of harmful effects on their health. In this same line of thought, Stojic' et al. (2017) commented that for the tractors, the vibration spectrum to be studied is the low frequency one, with emphasis on the 5 and 10 Hz range, which is mainly caused by traffic on unpaved roads.

In the rural environment it is common to use personal protective equipment (PPE) in the application of phytosanitary products. However, little attention is paid towards preventing the effects of vibration at the operator's operating station. Cunha et al. (2012) stated that, even with the technological advancement in the production of agricultural machinery, these are not ergonomically adequate for an eight-hour workday.

The vibrations consist of a complex mixture of several waves, with different frequencies and directions. However, several researches only studied vertical vibration, making it difficult to analyze this parameter in depth.

According to ISO 2631 (ISO, 1978), three points should be taken into account for the evaluation of this interaction: preservation of work efficiency, preservation of health and safety, and preservation of comfort. To do so, ideal levels were set for each of the concerns. They are, respectively, the reduced efficiency level (NER), the exposure limit (LE) and the reduced comfort level (NCR).

NER is understood as the values that, when exceeded, will affect the efficiency of the work performed, more specifically time dependent, generating fatigue. LE values are the reduced efficiency level values multiplied by 2, characterizing a maximum level of safe exposure due to the multiplication of NER criteria values.

As for the NCR, this is also derived from the NER, which is divided by 3.15, characterizing the level in which the loss of the comfort state occurs. For such analyses, there are established patterns of curves in function of time of exposure to vibration, plotted in graphs of frequency (Hz) × acceleration (m s\(^{-2}\)) (ISO, 1978), for each of the different levels or limits evaluated, as well as for each of the actuation directions (x, y, z), as exemplified in Figure 1. Thus, further research to understand how the three-dimensional vibration of agricultural machinery is transmitted to the human body is needed (Tiemessen et al., 2007; Antonucci et al., 2012).

Therefore, the present study has as its objective to evaluate the vibration levels emitted by agricultural tractors with different potencies, comparing the results to the current norms in Brazil.

**MATERIALS AND METHODS**

This study was developed at the Faculty of Animal Science and Food Engineering (FZEA) at the University of São Paulo (USP), in Pirassununga County, in an area owned by USP Administrative Office at Fernando Costa Campus, in Pirassununga. The geographical location of the campus is 21° 59' south latitude and 47° 26' west longitude and average altitude of 635 m.

The test was carried out with four tractors of different strengths: Massey Ferguson MF 4292 (110 hp engine power at 2,200 rpm, manufactured in 2011, with 2,560 worked hours at the moment tests began), MF 4275 (75 hp at 2,200 rpm, manufactured in 2011, with 3,036 worked hours, at the moment tests began), MF 680 (engine power of 173 hp at 2,200 rpm, manufactured in 1997, with 9,010 worked hours, at the moment tests began) and MF 297 (engine power of 120 hp at 2,200 rpm, manufactured in 2005, with 5,715 worked hours, at the moment tests began), all of which were located at USP Administrative Office at Fernando Costa Campus, in Pirassununga.

Regarding the evaluation of vibration, the primary magnitude used was the acceleration, expressed in m s\(^{-2}\), based on ISO 2631 (ISO, 1978). A human vibration analyzer, model HD-2030HA-WB, brand Delta Ohm, serial number 12062930149, was used, it was under the responsibility of Laboratory of Agricultural Machinery and Precision Agriculture (LAMAP), which enabled the study to evaluate the vibrations transmitted by the whole body with filter band pass. The data acquisition device was set to read full body accelerations, with storage at every second.

In conjunction with the vibration meter, an accelerometer in the form of a seat, model 356B41, brand PCB Piezotronics, serial number LW145553, of tri-axial analysis, also under LAMAP's responsibility, was used. The vibration sensor was placed between the tractor seat and the operator.

The analyses were taken in three different terrains: asphalt, land and field. For ground analysis, roads commonly used daily by tractors were used for locomotion to the fields, and were characterized by their compaction. Regarding asphalt analysis, the tracks and streets between the shed where the machines were located and the work area (field), was considered.

Finally, the field condition was understood by the mobilized soil characteristic used for crops in general, where the machine worked directly. The total time of acquisition was 20 min, with tractors operating under similar conditions, and five replications were performed in each treatment (tractor × terrain).

The signals were transformed to the frequency domain using the FFT function (amplitude and phase), being digitally filtered in 1/3 octave bands to obtain the effective acceleration. The maximum values obtained in each band were multiplied by weighting factors,
thus generating the weighted accelerations. The overall weighted effective acceleration analysis was performed in the range of 1 to
80 Hz. The range between 5 and 10 Hz was highlighted for studies of whole body vibration due to its range of important vibration frequencies and its influence on the spine.

The evaluations were made with the tractor motor in nominal rotation. The tractor seat was the original factory for all tractors, and before the beginning of the test, it was adjusted for the weight and size of the operator.

The results were compared to the values recommended by ISO 2631 (ISO, 1978) for exposure to LE, NCR and NER, both considering the daily 8 h work.

RESULTS AND DISCUSSION

The vibration values for the 1/3 eighth-octave band measured for the three directions (x, y and z axis) with tractors on the asphalt are shown in Figures 2, 3 and 4, respectively. LE, NCR, and NER values account for a daily work period of 8 h.

For the asphalt terrain on both axes, there is a downward trend in acceleration values in all tractors, observing that in frequencies between 6 and 10 Hz the values are generally below the reduced efficiency level. However, the results indicate that, for the MF 4275 tractor, the values were above the allowed limit, which will possibly affect the efficiency of work, more specifically the time dependent generating fatigue (ISO, 1978).

Although for higher and lower frequencies, the tractors exhibit similar behaviors, it is frequently observed that NER and NCR values are exceeded, with the usual extrapolation of LE. Considering the greater influence of the z-axis vibrations on spinal disorders, the constant overrunning of limits emphasizes not only a reduction in comfort due to NCR overruns, but also a decrease in the quality of the work due to the passage of NER, as well as the possibility of the development of occupational diseases with the overcoming of LE.

The results indicated that, in general, the seat structures were able to absorb part of the impact and in some situations create a good working condition for the machine operator. The vibration values for the 1/3 eighth-octave band measured for the three directions (axes x, y and z) with the tractors on the ground are shown in Figures 5, 6 and 7, respectively. LE, NCR, and NER values account for a daily work period of 8 h.

With the change of terrain, the tractors presented similar behavior with respect to the vibration patterns, showing a tendency of decrease in the values of acceleration. For the x and y axes within the critical range (between 5 and 10 Hz), there was little extrapolation of LE. However, the few times the acceleration values were below the limits of NER, they were not included within the NCR.

As for the z-axis analysis, the acceleration values exceeded the limits of the LE, and consequently, extrapolated the limits of NCR and NER in the frequencies of 5 to 10 Hz, being evident of the risks to which the operators of such machines are exposed, since the frequent overshoot of LE, as previously mentioned, highlights the possibility of the development of diseases related to the vertebral column.

In the terrain, compared to the asphalt terrain, it is possible to affirm that there was deterioration in the values of vibration in the studied range. Such an event can be explained by the fact that, even with the presence of compaction, the so-called terrain presents a greater irregularity than the asphalt.

Santos Filho et al. (2003) found similar results, in which the instantaneous vibrations at the base of the seat were eight times higher than the vibrations at the seat. This claim is within the parameters that were used by Da Silva et al. (2011) in a similar study of the ergonomic evaluation of a sugarcane harvesting machine.

The vibration values for the 1/3 eighth-octave band measured in the three directions (axes x, y and z) with the tractors in the field are shown in Figures 8, 9 and 10, respectively. Exposure limit (LE), reduced comfort level (NCR), and reduced efficiency level (NER) values were considered in a daily work period of 8 h.

In the so-called field, in the x and y axes, the descending curves up to the range of 5 to 10 Hz are again remarkable, with a subsequent increase in values. Still for these axes, the constant extrapolation of NCR and NER to the study range is observed, and visually exceeding the limits of the LE.

In the z-axis, the values are above the LE for frequencies below 10 Hz. If based on the vibration parameters suggested by Gialamas et al. (2016), all the tractors studied need improvement (decrease) in the vibration values to which the operators of these machines are exposed. The vibration levels were typically below the limits established for 8 h of work at frequencies of 5 to 10 Hz for the three directions (az-axis, ax-axis and ay-axis) in all of the studied tractors.

The presence of tractors exceeding the limits of LE demonstrates the possibility of occupational diseases development due to the incident vibrations, as well as the reduction of productivity due to NER extrapolation. It is believed that these values would have a much greater variation if the measures had been carried out during the course of a continuous agricultural operation, as demonstrated in several experiments (Vilibor et al., 2014; Antonucci et al., 2012; Cunha et al., 2012).

Conclusion

The studied tractors in general presented vibration levels higher than those established by ISO 2631 (1978) for an 8 h workday for the range of 5 to 10 Hz, in the three axes studied (x, y and z) (asphalt, terrain and field). There is a need for further studies on mitigation, as well as study of vibration levels emitted by agricultural tractors and its
Figure 2. Acceleration (x-axis) for 1/3 octave bands of tractors operating on asphalt according to ISO 2631 (ISO, 1978) for limit of exposure (LE), reduced comfort level (NCR) and level of reduced efficiency (NER).

Figure 3. Acceleration (y-axis) for 1/3 octave bands of tractors operating on asphalt according to ISO 2631 (ISO, 1978) for limit of exposure (LE), reduced comfort level (NCR) and level of reduced efficiency (NER).

Figure 4. Acceleration (z-axis) for 1/3 octave bands of tractors operating on asphalt according to ISO 2631 (ISO, 1978) for exposure limit (LE), reduced comfort level (NCR) and level of reduced efficiency (NER).
Figure 5. Acceleration (x-axis) for 1/3 octave bands of tractors operating on land according to ISO 2631 (ISO, 1978) for exposure limit (LE), reduced comfort level (NCR) and level of reduced efficiency (NER).

Figure 6. Acceleration (y-axis) for 1/3 octave bands of tractors operating on land according to ISO 2631 (ISO, 1978) for exposure limit (LE), reduced comfort level (NCR) and level of reduced efficiency (NER).

Figure 7. Acceleration (z axis) for 1/3 octave bands of tractors operating on land according to ISO 2631 (ISO, 1978) for exposure limit (LE), reduced comfort level (NCR) and level of reduced efficiency (NER).
Figure 8. Acceleration (x-axis) for 1/3 octave bands of tractors operating in the field according to ISO 2631 (ISO, 1978) for exposure limit (LE), reduced comfort level (NCR) and level of reduced efficiency (NER).

Figure 9. Acceleration (y-axis) for 1/3 octave bands of tractors operating in the field according to ISO 2631 (ISO, 1978) for exposure limit (LE), reduced comfort level (NCR) and level of reduced efficiency (NER).

Figure 10. Acceleration (z axis) for 1/3 octave bands of tractors operating in the field according to ISO 2631 (ISO, 1978) for exposure limit (LE), reduced comfort level (NCR) and level low efficiency (NER).
origins, in order to provide better working conditions to the operators of these machines. The seat structures in general were not able to absorb the vibrations in order to create a good working condition for the machine operator.

**CONFLICT OF INTERESTS**

The authors have not declared any conflict of interests.

**REFERENCES**


