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# MEASURING VIBRATIONS LEVEL DURING TRANSPORTATION WORK FOR AN ELECTRICAL TRACTOR

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**Abstract:** Vibrations usually aren't wanted in any technical system. This rule applies also to agricultural tractors, since their apparition could affect the normal functioning of the machine. One new type of agricultural tractors are the electrical ones, which have appeared in nowadays agriculture because of the need to protect the environment and to mitigate the technology's negative impact on the environment. Because of the electrical engine construction, this will generate less vibration during normal functioning, fact which will attenuate also the tractor's total vibration level. Because transportation is one very important work for which the electrical tractor could be used, its vibration comportment during this type of work is of particular interest for engineers. This paper presents researches done in order to assess the vibration level of an experimental model electric tractor during transportation work. The experiments were performed on the experimental plots from INMA Bucharest on a total distance of 3 km. The raw data for longitudinal, transversal and vertical directions were recorded and processed in order to obtain the RMS values for vibration.
**Keywords:** vibration level, electric tractor, transportation

## INTRODUCTION

A system vibration is always caused by an excitation force. This force could be applied from outside the system, or could be coming from inside. Effect of this force, the vibration, is completely determined by the excitation force, its direction and frequency. This is the reason why, through vibration analysis could be determined the excitation forces which acts on a functioning machine. The effect depends on the machine's state and the knowledge of vibration characteristics will allow for a flaw diagnose in case of need.

It's considered that an agricultural tractor vibration is characterizing its functioning state. Vibrations are caused mainly by dynamic effects of the execution tolerances of subassemblies, by gaps and direct contact between moving parts of the gears as also by effect of forces which are unbalanced in rotating or alternating moving parts. Many times, the reduced amplitude vibrations could excite the resonance frequencies of some parts, being eventually amplified until unacceptable levels.

In most cases, vibrations are unwanted, because are causing dramatic shortening of the life span of tractors changeable parts and accidental stops which are affecting the work quality they are performing. This is the reason why is considered that if an equipment doesn't vibrate, it will continue to work for a long time, while if the one which vibrates it's left without taking measures it will have a short life span. Each tractor part will produce a vibration with one or several specific frequencies. Knowing the spectral component of the global vibration, it could be determined in which of the moving parts has appeared an issue. The main source of vibration of a classic tractor it's its diesel engine. For this reason are sought solutions for vibration reduction, like mounting the engine on rubber supports which will cushion and absorb the vibrations [3].

Advantages of electric engines driven tractors are multiple: zero emissions, batteries recharging from charging stations using renewable energy, reduced noise and vibrations in exploitation, high torque from almost zero rotating speeds. Disadvantages arise from reduced autonomy due to batteries limitations, relatively long recharging time and need for battery replacement at several years of usage.

At international level there are researches done in order to assess the vibration effect on the operator both for different agricultural equipment handled by hand [7,9] and for agricultural vehicles [1,2,5,6]. The measuring method is the same in both cases, with several differences due to particular equipment's using conditions. Ideally the weighted vibration level should be under 2.5 $m/s^2$, so that the human worker to be shielded by any danger [11]. One of the electric tractors advantage is represented by the low level of vibrations during work, fact which will assure a nice working environment, without any negative effects for the worker. Vibration measurement represents a serious tool to assess the design of agricultural transportation equipment and it's used to measure the dynamic response during simulations and real-life tests [4, 8].Within this paper is presented the assessment of vibration level during transportation work for an electric tractor prototype produced by INMA Bucharest and partners, in order to verify the degree of comfort of the driver as also to limit the unwanted vibration effects on its reliability.

## MATERIAL AND METHOD

The transportation experiments were conducted on a 28.8 kW prototype of agricultural electric tractor. The electric motor used for propelling the tractor gives maximum output torque, even at very low revolutions per minute. The tractor was fitted with a mechanical transmission which allowed for a minimum travel speed of 1.71 km/h and maximum of 26 km/h for a nominal rotational speed of the electric motor of 2350 $s^{-1}$.

Vibration measurements were performed on vertical, transversal and longitudinal direction, using a triaxial accelerometer, mounted on the tractor's floor, according to figure 1, using mounting methods provided in [10].

Figure 1. Accelerometers mounting

The data acquisition software for raw vibration data was DEWESOFT, software dedicated for the used Sirius data acquisition system. The accelerometer was calibrated on each channel using a Type 4294 Calibration Exciter with 10 $m/s^2$ r.m.s. acceleration at 159.2 Hz. The accelerometers were mounted on the metallic parts of the tractor through magnetic supports, fact which assured a stable position during measurements. The data acquisition was performed with a 10 kHz sample rate, continuously and the recorded data was saved in ASCII files.

The root mean square (r.m.s) was calculated using formula 1 for each string of recorded values.

$$a_{rms} = \sqrt{\frac{\sum_{i=1}^{n} a_i^2}{n}} \quad (1)$$

where $a_i$ is the instantaneous value of the i-th sample acceleration and n represents the total amount of samples.

Vibration determination was done on a combined test route of tarmac road and dirt road. The track characteristics were as follows:

- Total distance 6,4 km
- Maximum speed 26 km/h
- Mean speed 6 km/h

The tractor was pulling a loaded trailer with a total mass of 1400 kg.

## RESULTS

In figure 2 are presented the vibration evolution in time measured by the floor mounted accelerometer, inside the cabin (x axis longitudinal direction – red, y axis vertical direction – blue, z axis transversal direction - green) on tarmac road and in figure 3 the vibration measured on dirt road. In order to quantify energetically the vibration level and to report the measured values to the limits imposed in regulations and directives, the raw values were processed and reported as r.m.s. values.

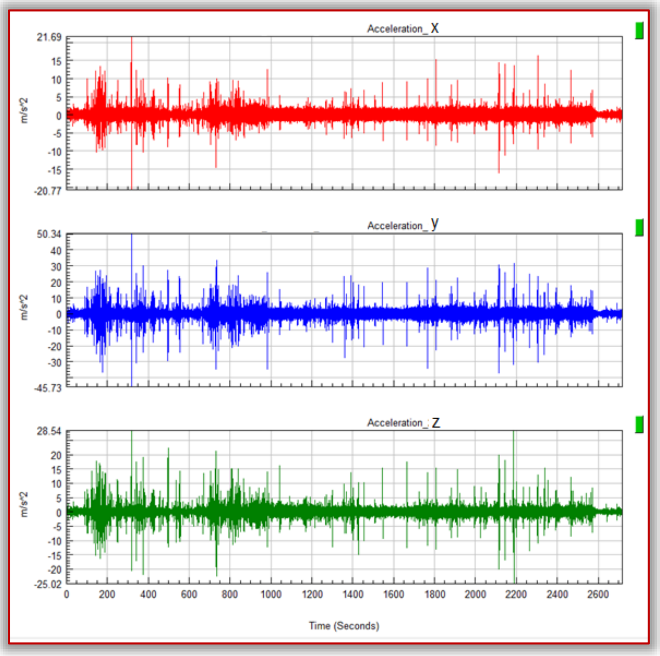


Figure 2. Vibrations evolution during transportation experiment for tractor's floor on tarmac road

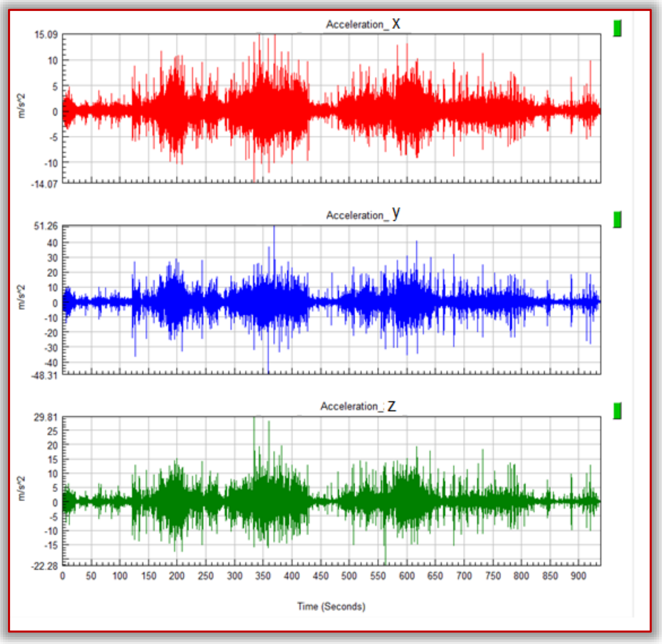


Figure 3. Vibrations evolution during transportation experiment for tractor's floor on dirt road

In figures 2 and 3 can be observed the random character of the recorded vibrations, due to the road conditions. However, the amplitudes are relatively low, and cannot affect the tractor's reliability. In table 1 are presented the vibration statistical parameters computed based on the recorded waves for vibrations, for all the transportation route. The values are reported for longitudinal and vertical direction, for both measuring points (electric tractor chassis and floor).

Table 1: Electric tractor statistic vibration data

| Vibration data | X axis | Y axis | Z axis |
|---|---|---|---|
| | Tarmac road | | |
| Maxim ($m/s^2$) | 21.69 | 50.34 | 28.54 |
| Minim ($m/s^2$) | -20.77 | -45.73 | -25.02 |
| R.M.S ($m/s^2$) | 0.629 | 1.198 | 0.6165 |
| | Dirt road | | |
| Maxim ($m/s^2$) | 15.05 | 51.26 | 29.81 |
| Minim ($m/s^2$) | -14.07 | -48.31 | -22.28 |
| R.M.S ($m/s^2$) | 1.035 | 1.932 | 1.138 |

In figure 4 and 5 are presented the power spectrums peak versus frequency, of the recorded vibrations in both conditions, tarmac and dirt road, with the identified frequencies and peaks. The amplitudes identified are really low, under 0.6 $m/s^2$ for both conditions, which means that the identified frequencies don't have an important impact on the total impact vibration data.

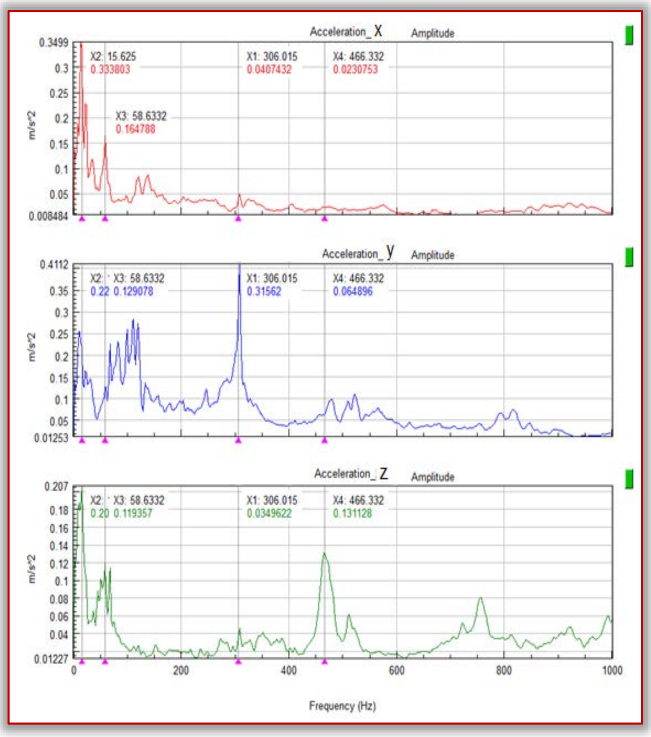


Figure 4. Power spectrum of vibrations during transportation experiment for tractor's floor on tarmac road

In figure 4 we can observe a high amount of small amplitude peaks, due to the higher test speed and to the leveled aspect of the road. In figure 5 we observe a smaller number of peaks but with higher amplitudes. This is due to the lower transportation speed and to a less leveled road. Biggest amplitudes are observed on the y axis, which corresponds to the vertical direction and which are accounted for the dynamic movement of the tractor's mass due to the bumps and holes which were present on the dirt road.

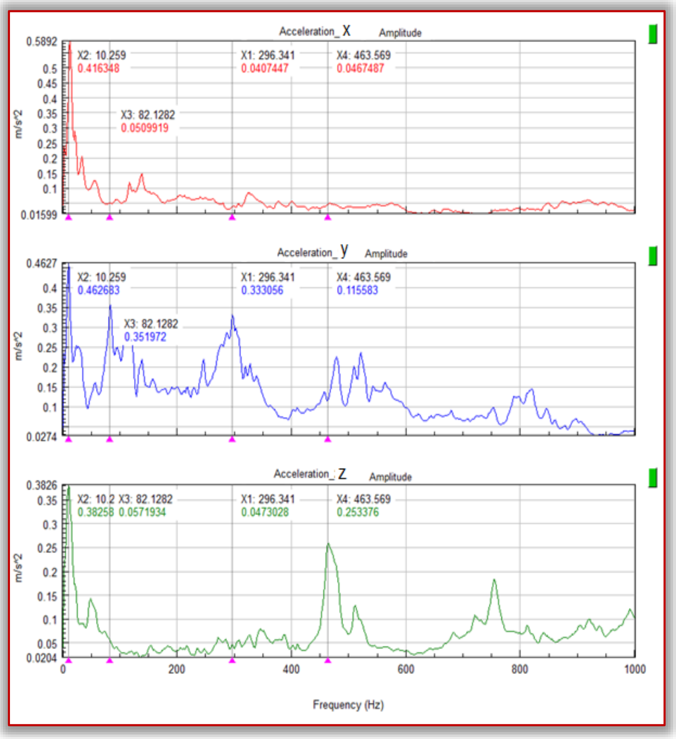


Figure 5. Power spectrum of vibrations during transportation experiment for tractor's floor on dirt road

## CONCLUSIONS

The paper presented measurements performed for assessment of vibrations level for electric tractor during transportation work which allow for improving of safety conditions that has to be assured in order to mitigate vibration effects. The recorded vibrations had a random character, which was mainly provoked by the road characteristics, the electrical engine having no negative effect on the tractor's behavior.

The obtained results for the vibration level on the tractor's floor were under 2.5 $m/s^2$ r.m.s values. These results are under the attention limit, specified in European directive 2002/44/EC, meaning that the operator's integrity isn't endangered. Also, the obtained results assure the fact that the tractor's reliability isn't affected by vibrations during transportation work.

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