1. Paweł KIEŁBASA, 2. Mirosław ZAGÓRDA

Faculty of Production and Power Engineering, University of Agriculture in Krakow (1)

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Ergonomic evaluation of mechanical vibrations of specialized agricultural machinery with general effects on humans

***Abstract**. The article presents an ergonomic evaluation of the general vibrations of a specialized agricultural machine performing the technological process of mulching a field. The scope of the research included the measurement of general vibrations on the supporting plane of the seat of the selected technical means in such a way as to locate the results of the measurements at a specific place of the treated field. A four-channel digital vibration level meter, class 1 SVAN 958, was used for the study. It was found that the above-normal values of general vibrations to which the operator of the technical means was exposed were incidental and did not pose a health hazard. Taking into account the operator's 8-hour exposure to mechanical vibrations, it was found that only in two cases the permissible values for juveniles were exceeded.*

***Streszczenie.** W artykule przedstawiono ocenę ergonomiczną drgań ogólnych specjalistycznej maszyn rolniczej realizującej proces technologiczny mulczowania pola. Zakres badań obejmował pomiar drgań ogólnych na płaszczyźnie nośnej siedziska wybranego środka technicznego w sposób umożliwiający umiejscowienie wyników pomiarów w konkretnym miejscu obrabianego pola. Do badań wykorzystano czterokanałowy, cyfrowy miernik poziomu drgań klasy 1 SVAN 958. Stwierdzono że wartości ponadnormatywne drgań ogólnych na które narażony był operator środka technicznego miały charakter incydentalny i nie stanowiły zagrożenia dla zdrowia. Biorąc pod uwagę 8 godzinną ekspozycję operatora na drgania mechaniczne stwierdzono, że tylko w dwóch przypadkach dopuszczalne wartości dla osób młodocianych zostały przekroczone. (**Ergonomiczna ocena drgań mechanicznych specjalistycznej maszyn rolniczej o oddziaływaniu ogólnym na człowieka**)*

Keywords: exploitation, ergonomics, mechanical vibrations
Słowa kluczowe: eksploatacja, ergonomia, drgania mechaniczne

Introduction

The interaction of technical systems with biological systems is the subject of inquiry of many authors. A significant part of the work deals with issues of workstation geometry [1,2], through the acoustic environment [3,4] and focuses mainly on issues of mental load [5,6]. However, mechanical vibrations, despite the use of modern solutions, still pose a significant threat. The sources of mechanical vibrations are the means of work used in the performance of work - installations, vehicles, machinery, tools, instruments. When working with equipment (the source of vibrations), they are directly transmitted to the human body. Vibration is one of the most common health hazards for workers in the work environment [7]. The result of long-term exposure to strenuous working conditions is musculo-skeletal complaints [8]. When evaluating the effects of mechanical vibrations on the human body, it is necessary to take into account, among other things, the physical and psychological characteristics of the human being, the frequency of vibration of the human body's own internal organs. The range of frequencies in which general vibrations are tested and evaluated is in the range of 0.7 Hz - 90Hz, while the range of frequencies in which vibrations entering the human body through the upper limbs are tested and evaluated is in the range of 5.6 Hz - 1400Hz [9]. In the range of 5.6 - 20Hz there is the highest sensitivity of the human body to local vibration activity [10]. The natural frequencies of most human organs range from 2 Hz - 25Hz, e.g.: the natural frequencies of the head are 5Hz and 25Hz, jaw 6 Hz - 8Hz, chest organs 5 Hz - 8Hz, upper limbs 3Hz, abdominal organs 4.5 Hz - 1 Hz, urinary bladder 10 Hz - 18 Hz, lower limbs 5Hz [11]. Research on the vibration environment in the human workspace is extremely important and is carried out in Poland based on the following standards [12-15]. These standards have been implemented into Polish legislation on the basis of Directive 2002/44/EC of the European Parliament and of the Council, and in accordance with this Directive, the current NDN values have been determined. Analyzing the hazards of vibration and noise in the thirteen vehicles studied, it was found that the occupational risk associated with these factors in only one case (a box truck) turned out to be high (exceeding the NDN); in 12 cases it was at most medium (exceeding 0.5 NDN) [16]. In another case, analyzing the instantaneous spectra of vibration effects on the driver and passenger of passenger cars, they found that at a speed of 50 km/h and at a frequency of about 23.4 Hz for local vibrations acting on the passenger in the X direction, the rms values of vibration acceleration were high enough to cause resonance of, for example, the eyeball or hand [17]. Despite the great recognition of the issue in question, there are no studies that interpret the effects of vibrations on the body of the operator of agricultural machinery in the space of the treated area. Mapping the spatial variation of general vibrations in particular will make it possible to identify at successive passes and actively counteract them. In addition, information on the magnitude of vibrations is very important from the point of view of machine operation.

Material and methods

The purpose of the study was to assess the ergonomic evaluation of the vibration environment (general vibration) during the technological process carried out with a John Deere 6930 agricultural tractor. The tractor was aggregated with a mulcher, which is an active machine that generates additional vibrations. Measurements were made with a Svantek SVAN 958 meter. Measurements were taken throughout the process implementation. This allowed the measured values of mechanical vibrations to be assigned geographical coordinates, necessary for spatial interpretation of the analyzed quantity. The time interval for each measurement trial was 60 seconds, followed by another measurement. Inverse Distance Weighted (IDW) method was used for interpolation of measured quantities treated as deterministic variables, and generation of vector and raster maps, performance of relevant operations on maps in the form of logical queries and the resulting spatial selection of data, as well as overlaying of mutually dependent data of individual maps were realized using ERSI ArcView GIS 3.3 software. With the help of SvanPC+ computer program, the analysis of mechanical vibrations (Fig.1) characteristics were generated, including the quantities: rms value (RMS), instantaneous peak value (PEAK), instantaneous peak-to-peak value (P-P) and maximum rms value (MAX).

Fig. 1. SVAN PC+ application interface

For each separate activity performed by the operator, the values of weighted vibration accelerations were measured in three mutually perpendicular directions: a_{wxi}; a_{wyi}; a_{wzi} - for general vibrations. All measurements and conversions were made according to current standards [12,13]. The total time of a worker's exposure to vibrations during a work shift t [min], which is the sum of the durations ti [min] of the i-th activities, was calculated according to the relation (1):

$$t = \sum_{i=1}^{n} t_i \qquad (1)$$

where: t_i - The number of activities performed with exposure to vibrations at the controlled workstation

When evaluating general vibration, the dominant weighted vibration acceleration is determined. This is the highest value of the corrected vibration acceleration selected from among the three directional components, which in practice means one component. For the assessment of short-term exposure to general vibration, whose exposure time does not exceed 30 minutes, the dominant value is selected a_{wmax}, among n specific effective corrected vibration accelerations a_{wli}, taking into account the relevant coefficients ($1{,}4a_{wx}$, $1{,}4a_{wy}$, a_{wz}), determined according to the relation (2):

$$a_{w\max} = \max\{a_{wl_i}\} = \max\{a_{wl1}, a_{wl2}, \ldots, a_{wln}\} \qquad (2)$$

where: a_{wli}– effective weighted values of vibration acceleration, measured for direction l (l = x or l = y or l = z) at the workstation, when performing the i-th activity [$m \cdot s^{-2}$].

If the total time of exposure of a worker to general vibration t exceeds 30 minutes, the analysis uses a quantity called 8-hour vibration exposure determined for each direction separately, according to the relation (3):

$$A(8)_l = \sqrt{\frac{1}{T}\sum_{i=1}^{n} a_{wl_i}^2 \cdot t_i} \qquad (3)$$

where: n- number of activities performed in vibration exposure, i- number of activities performed in vibration exposure, l- direction of vibration (x, y or z), ti - time of performing the i-th activity [min], T - 480 minutes, a_{wli} - corrected value of vibration acceleration, measured in x, y and z directions for the i-th activity in the vibration exposure [$m \cdot s^{-2}$]

To measure vibrations transmitted to the human body in a general way (while working in a sitting position), the measuring point was located on the tractor operator's seat in accordance with normative requirements[14].

Results

Analyzing the results of the peak vibration acceleration values (PEAK) of channel one (fig.2), it was found that their highest value was 3.090 m/s^2, while the lowest value was 0.109 m/s^2. The average value of peak vibration accelerations (PEAK) was 1.418 m/s^2.

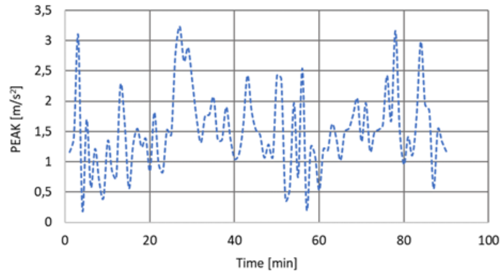

Fig. 2. Peak value of vibration acceleration (PEAK) measured at the seat of the agricultural tractor for the vertical direction of impact

Figure 3 shows the spatial distribution of the instantaneous peak value of vibration acceleration (PEAK) for channel one during mulching within the experimental field.

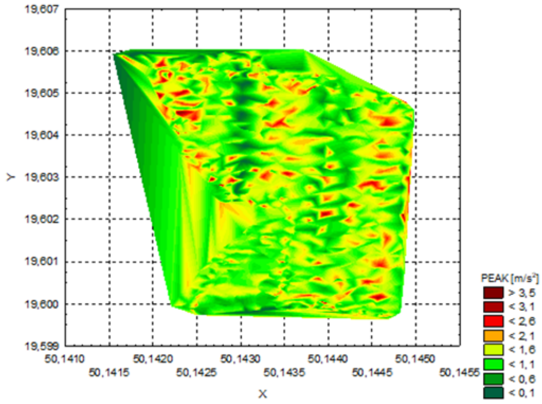

Fig. 3. Variation of the peak value of vibration acceleration (PEAK) measured on the seat of an agricultural tractor for the vertical direction of interaction within the experimental field.

It was noted that the highest vibration acceleration values were located in the southern and northwestern parts of the field. It should be noted that the areas with vibration acceleration values exceeding 3 m/s^2 occupied a small area in total and were concentrated in a dozen points throughout the experimental field. In the remaining area of the field, the value of vibration acceleration was characterized by a small variation, the value of which was about 1.1 m/s^2. Analyzing the inter-peak value of vibration acceleration (P-P) for channel one (fig. 4), it was found that the highest value was 6.165 m/s^2, and the lowest recorded value was 0.199 m/s^2. The average inter-peak value of vibration accelerations was 2.724 m/s^2.

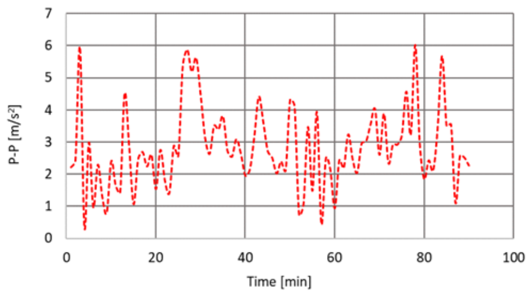

Fig. 4. The inter-peak value of vibration acceleration (P-P) measured on the seat of an agricultural tractor for the vertical direction of interaction

Figure 5 shows the spatial distribution of the instantaneous inter-peak value of vibration acceleration (P-P) for channel two during the implementation of a technological activity.

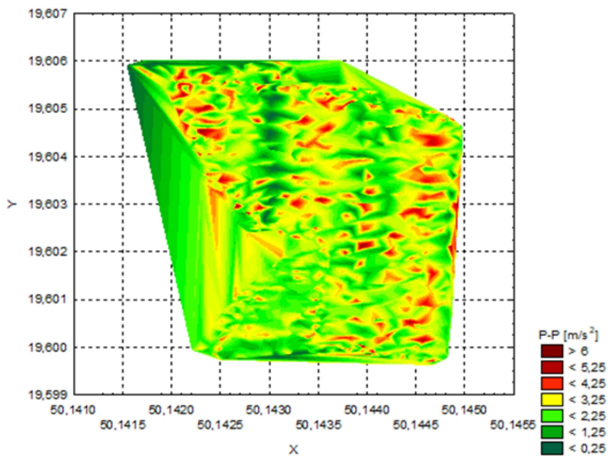

Fig. 5. Variation of the inter-peak value of vibration acceleration (P-P) measured on the seat of an agricultural tractor for the vertical direction of interaction within the experimental field.

It was observed that for the inter-peak value of vibration, the highest values exceeding 4.25 m/s^2were located in the northern, as well as the northeastern part of the field. It is worth noting that the extreme results of the inter-peak value within the experimental field were incidental.

Analyzing the maximum rms value of vibration acceleration (RMSMAX) for channel one (fig. 6), it was found that its maximum was 1.318 m/s^2, while its minimum was 0.042 m/s^2. The average value of the maximum rms value of vibration measured on the seat of the agricultural tractor was 0.551 m/s^2.

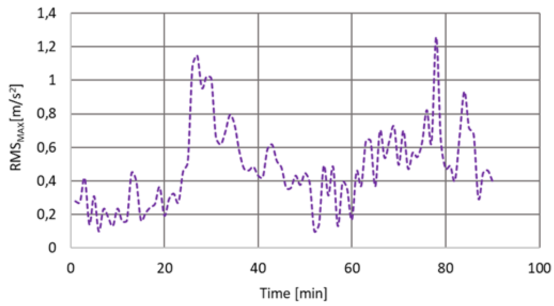

Fig. 6. The maximum rms value of vibration acceleration (RMS_{MAX}) measured on the seat of an agricultural tractor for the vertical direction of interaction

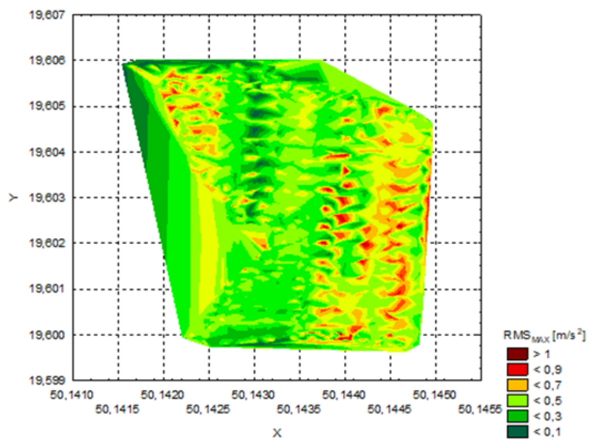

Fig. 7. Variation of the maximum rms value of vibration acceleration (RMS_{MAX}) measured on the seat of an agricultural tractor for the vertical direction of impact within the experimental field

Figure 7 visualizes the spatial distribution of the maximum rms value of vibration acceleration (MAX) for channel one during the implementation of the technological activity. It was noted that the highest values of vibration acceleration exceeding 0.8 m/s^2 were located in the eastern part of the field occupying a small area in total, but occurred very regularly. It should be noted that in the remaining area of the experimental field, the maximum rms value of vibration accelerations (RMS_{MAX}) measured on the seat of the agricultural tractor for the first channel was stable oscillating around the value of 0.6 m/s^2.

Figure 8 shows the distribution of the rms value of vibration acceleration measured on the seat of the agricultural tractor during mulching of the field.

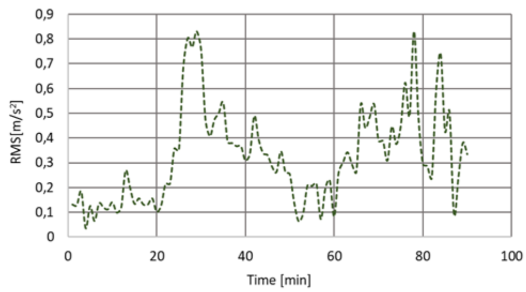

Fig. 8. The rms value of vibration acceleration (RMS_{MAX}) measured on the seat of an agricultural tractor for the vertical direction of interaction

Analyzing the course of the curve of the rms value of vibration during the conducted measurements, that the minimum was 0.035 m/s^2 while the maximum was 0.831 m/s^2, with an average value of 0.324 m/s^2. Thus, a significant variability of the effective value of vibration acceleration during the measurement was observed (the coefficient of variation was 59%). However, an analysis of the spatial structure of the rms curve of the vibration (fig. 9), the variation of the measured magnitude seems to be limited to a certain, particularly eastern part of the field.

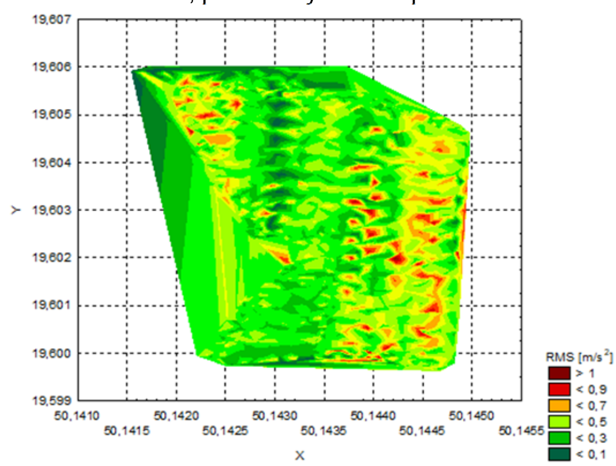

Fig. 9. Variation of the rms value of vibration accelerations (RMS) measured on the seat of a farm tractor for the vertical direction of interaction within the experimental field.

Also, the minimum values of the rms vibration acceleration (RMS) measured on the seat of the agricultural tractor for the vertical direction of interaction were located in the central part of the field. However, it should be noted that over most of the treated field area, the rms values of vibration accelerations on the tractor seat had a stable character. Analyzing the daily 8-hour exposure to vibrations (vertical direction) with a general effect, it was found that the obtained value of 0.347 m/s^2 when confronted with the norms such exposure does not carry any negative health effects. These effects in future could be monitored with wearable solutions [18]. However, the limit values for adolescents and pregnant women were exceeded.

Conclusion

In the case of the technological process analyzed, and taking into account the spatial location within the testing ground of the measured magnitudes of mechanical vibrations with general effects on the operator's body, it was found that the recorded supernormal values were incidental. Taking into account the operator's 8-hour exposure to mechanical vibrations, it was found that in two cases the permissible values for juveniles were exceeded. In the case of male operators, there were no contraindications to work in the identified vibration environment because the values of general vibration acceleration ranged from 0.130 m/s^2 to 0.347 m/s^2. Spatial visualization of vibrations of general effect on the operator's body allows us to identify places in the field space where vibrations are of an above-normal character, and the juxtaposition of this data with machine operating characteristics will allow the construction of a digital vibration structure of the field.

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***Authors**: Paweł Kiełbasa Associate Professor, University of Agriculture in Krakow, Faculty of Production and Power Engineering, Balicka Av. 116B, 30-149 Krakow, E-mail: pawel.kielbasa@urk.edu.pl; Mirosław Zagórda PhD University of Agriculture in Krakow, Faculty of Production and Power Engineering, Balicka Av. 116B, 30-149 Krakow, E-mail:miroslaw.zagorda@urk.edu.pl;*

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