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OPERATOR'S WHOLE BODY VIBRATIONS DEPENDENT OF AGROTECHNICAL SURFACE, SPEED OF MOVEMENT AND SEAT UPHOLSTERY

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Abstract: The paper presents the recorded vibrations that affect the operator's body when an agricultural tractor moves along three types of agrotechnical surfaces, i.e. asphalt, an alfalfa field, and a field path, and when seven different tractor seat upholsteries are used. The research was performed in accordance with the HRN ISO 2631-1 and HRN ISO 2631-4 standards. The tractor used in the research was an IMT 560 and the duration of the measurement was 30 minutes, which was repeated three times for every tractor seat upholstery type. The research was exploitative. The measurements were performed using an MMF VM30 meter. The paper reveals a different level of vibrations in dependence with different surfaces and seat upholsteries. The fewest vibrations were produced by asphalt, and the best upholsteries are memory foam and sponge.

Keywords: agricultural tractor; agrotechnical surfaces; seat upholstery; vibrations

1 INTRODUCTION

Vibrations are generally considered to be oscillatory motions of a mechanical system. Oscillation is a periodical motion around an equilibrium point, i.e. a motion that repeats itself after a certain period. Vibrations are a result of dynamic forces in machines with moving parts, as well as in the structures linked to machines. In the beginning, the insignificant vibrations can cause a resonance in some other parts of the structure and they can increase and become the main and rather serious source of increased vibrations and noise. Different machine parts vibrate at different amplitudes and frequencies. Vibrations cause material fatigue and wear. They are often a cause of machine defects [1].

The vibrations transferred to the operator's body, i.e. whole-body vibrations occur when the body leans against a vibrating surface, e.g. when the driver is sitting on a vibrating chair, standing on a vibrating floor, or lying on a vibrating surface [2].

The authors [3] posit that the most important machine component regarding the influence of vibrations is the seat as operators spend most of their time in a seated position. Seat construction, the back of the operator, the depth of the seat, and the upholstery of the seat can exert a complex impact on the operator's ability to operate the machine, as well as on the occurrence of occupational diseases. The same authors claim that the seat upholstery wears out in time so that it is necessary to mend it. A defective seat cannot ensure proper sitting posture, which can cause occupational diseases. Overexposure to mechanical vibrations can have a negative impact on the human body, e.g. overexposure to high vibrational frequencies can lead to physical problems such as spinal dysfunction [3].

The authors [4] in their research claim that a suspended front axle of a tractor generally dampens the vibrations transferred to the operator's seat. The vibrations decrease on average from 13% to 15% but they may be reduced as much

as 30%. The authors [5] suggest that a seat suspension has been almost a universal feature of agricultural tractors during the last 30 years. The suspension system was introduced to enable the operator to manage the machine in a more comfortable and easier way, which has resulted in increased work productivity. The authors [6] argue that operators might drive tractors for as long as twelve hours a day, which can cause back problems. The analysis of vibrations produced by agricultural machinery is complex as it depends on many factors. The abovementioned authors emphasize that tyre pressure and seat suspension affect vibrations. The authors [7] posit that tractor speed, tyre pressure and the distribution of the transported weight are the most crucial factors that affect the comfort of a tractor operator riding on a tractor that moves along an asphalt surface. Lower tyre pressure is more comfortable for the operator; however, it is not always possible to lower tyre pressure for distinct reasons, one of the most important being the quality of the surface along which the tractor is moving. The authors [8] claim that air seat reduces both high and low vibration frequencies. The same authors argue that low vibration frequencies can be reduced by assembling an air container next to the seat or onto the cabin. The authors [9] suggest that the sitting posture of the driver, i.e. the position of his legs during driving is in significant connection with the sitting comfort.

The authors [10] conducted a research on Masey Ferguson tractors using the limits of vibration exposure as a criterion. They established that after an eight-hour exposure to vibrations, the allowed limit was not exceeded. Additionally, they claim that it is important to bear in mind that in certain situations, some frequencies pertaining to axles do exceed the permitted limits. Thus, it was concluded that seats can absorb vibrations and create ergonomically proper work conditions. The study was performed on an asphalt surface. The authors [11] conducted a study on vibrations on two tractors. One tractor was a newer model with a cabin, whereas the other was an older model without

a cabin. It was concluded that it is easier to measure vibrations on a tractor without a cabin and that the engine itself is the greatest source of vibrations in both tractors. The cabin was emphasized as an important part of tractor equipment because it protects the operator from vibrations, dust, and the objects that might appear in the operator's vicinity. Higher vibration levels were established on the older tractor.

The aim of the research is to measure the levels of vibrations that affect the operator's body when an agricultural tractor moves on various agrotechnical surfaces at various speeds in dependence with different upholstery of the tractor seat. Additionally, the aim is to establish potential interdependencies. It is hypothesized that due to a tractor's movement along various agrotechnical surfaces in dependence with different seat upholstery, the level of vibrations affecting the operator's body will increase.

2 MATERIALS AND METHODS

MMF VM30-H is the measuring device used for the measurement of mechanical vibrations that affect the body of the operator when an IMT 558 agricultural tractor is in motion. The tractor moved along three different surfaces, namely asphalt, an alfalfa field, and a field path. The following are the seat upholstery on which the driver sat: a seat without an upholstery (i.e. only a metal seat framework), cork, styrofoam, sponge, memory foam, cotton wool, and air cushion, Tab. 1. Each measurement was repeated three times. The motion speed was 4, 5 and 6 km/h. The research shown here was exploitative. The measurements were performed in 2017 in a period of 20 days. The average daytime air temperature in the days when the measurements took place ranged between 18° and 19°, whereas the relative humidity was between 58% and 60%.

Table 1 Characteristic of the seat upholstery material

Type	Main characteristic	Thickness
Industrial Cork	density 110-120 kgm ⁻³	100 mm
Viscoelastic polyurethane memory foam	density 80 kgm ⁻³	100 mm
Expanded polystyrene (EPS) – Styrofoam	density 15 kgm ⁻³	100 mm
Polyuretan sponge	density 35 kgm ⁻³	100 mm
Cotton wool cushine	density 120 gm ⁻³	100 mm
Orthopedic PVC air cushion	diameter 330 mm	100 mm

The research was performed in accordance with the standards [12] and [13]. The measurements were performed while the driver was sitting in accordance with the standard [12]. The seat therefore represents the contact point between the operator and the tractor. The measuring device was set in the exact position in accordance with the operators sitting position. It was set onto the seat so that the axes were recorded in the following directions [12]: *x* axis: longitudinally (along the axis of motion – forward (positive) / backward (negative)), *y* axis: laterally (at the right angle to the motion direction) and *z* axis: vertically, upward (positive) / downward, vertically to the surface (negative). The vibrations were recorded based on a coordinate system

for particular body parts. The device recorded the vibrations that were directly transferred through the seat to the operator's body.

According to [14], the limit values for the daily level of vibration exposure were established. The limit value for the vibration transferred to the body of the operator is 1.15 m/s². *W_d* and *W_k* are the weight filters used in the measurements. *W_d* is used for vibration measurement in the direction of the *x* and *y* axes in the sitting position, whereas *W_k* refers to the vibrations in the direction of the *x* axis.

The R.M.S. measurement method used for the measurement in motion accounts for the occasional impulse and transient vibrations. It applies a short integral time constant. The size of vibrations is defined as a maximum transient vibration value (*MTVV*), which is the maximum for *a_w(t₀)*.

$$a_w(t_0) = \left\{ \frac{1}{\tau} \int_{t_0-\tau}^{t_0} [a_w(t)]^2 dt \right\}^{\frac{1}{2}} \tag{1}$$

a_w(t) – the current frequency of the recorded acceleration (m/s²),
 τ – time of integration for the current averaging,
 t – time (s),
 t₀ – time of observation (s).

$$MTVV = \max [a_w(t_0)] \tag{2}$$

MTVV - maximum transient vibration value (m/s²)

The measured values were statistically analyzed using an application for statistical analysis in the MS Office Excel 2013, and IBM SPSS Statistics v.19.0.1. The paper shows the descriptive statistical values and multiple analysis of variance (MANOVA). Multiple correlations and the regression equation in this analysis were performed.

3 RESULTS AND DISCUSSION

The measurement of vibrations for the upholstery-free seat produced on the asphalt surface resulted in the occurrence of the maximum vibration value recorded in the direction of the *y* axis at all motion speeds. The lowest recorded value was established in the direction of the *x* axis at all speeds (Fig. 1). Furthermore, a conspicuously highest level of vibrations was recorded on the alfalfa field in the direction of the *x* axis at all speeds, whereas the lowest level was recorded in the direction of the *z* axis at 4 km/h, with all other values being the same. The vibrations recorded on the field path were the lowest in the direction of the *z* axis at all speeds, whereas the highest value was recorded in the direction of the *x* axis at 4 km/h. All other values were identical.

The highest level of vibrations for the cork seat (Fig. 2) was established in the direction of the *y* axis at all motion speeds on the asphalt surface, whereas the lowest recorded value for the same surface occurred in the direction of the *x* axis at 4 km/h, while all other values were the same.

Additionally, the highest recorded values on the field path happened in the direction of the z axis at 5 km/h) and at 6 km/h in the direction of all three axes.

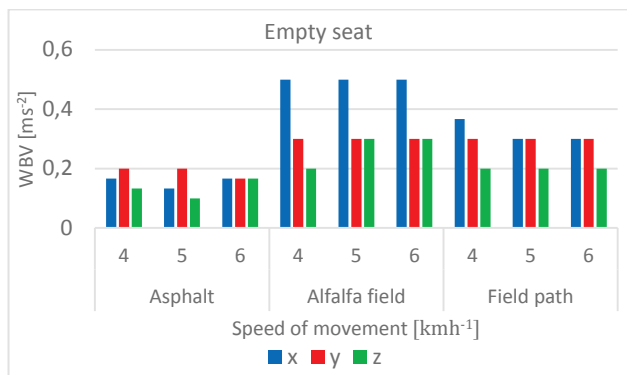


Figure 1 Measured vibration data – empty seat

Fig. 3 shows the highest levels of vibrations recorded on the asphalt surface in the direction of the y axis at all motion speeds, whereas the lowest values were recorded in the direction of the x axis at all motion speeds as well as in the direction of the z axis at 5 and 6 km/h.

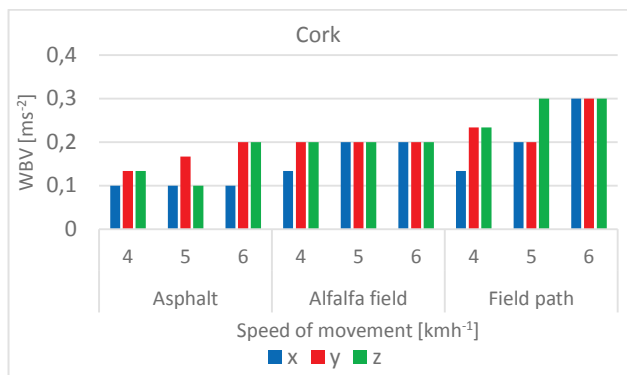


Figure 2 Measured vibration data – cork seat

The highest values of vibrations on the alfalfa field were found in the direction of the z axis at all speeds, while all other vibration values were the same.

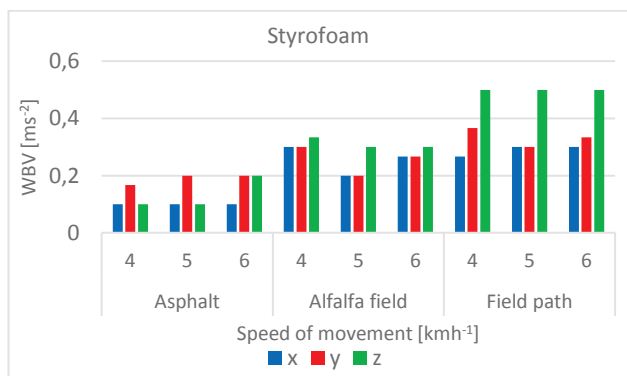


Figure 3 Measured vibration data – Styrofoam seat

The vibration measurement for sponge (Fig. 4) resulted in the highest values on the asphalt surface in the direction of the x axis at 4 km/h, while the lowest value was recorded

in the direction of the y axis at 4 and 5 km/h, while all other values were the same. Moreover, the highest level of vibrations was recorded on the alfalfa field in the direction of the x axis at all speeds as well as in the direction of the z axis at 5 and 6 km/h, whereas the lowest value was recorded in the direction of the y axis at 4 km/h, while all other values were the same. The vibrations recorded on the field path are the lowest in the direction of the y axis at all speeds, whereas the highest value was recorded in the direction of the z axis at all motion speeds and in the direction of the x axis at 6 km/h. All other vibration values were the same.

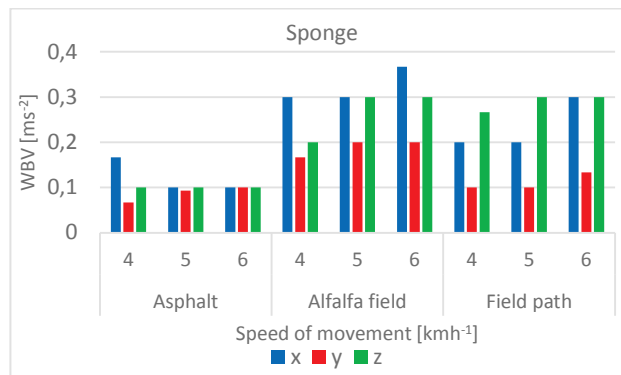


Figure 4 Measured vibration data – sponge seat

The vibrations recorded on memory foam (Fig. 5) have the same values on the asphalt surface in the direction of all three axes and at all motion speeds. The highest vibration value was recorded on the alfalfa field in the direction of the z axis at all speeds and in the direction of the x axis at 5 km/h, while all other values were the same. The lowest level of vibrations on the field path was recorded in the direction of the y axis at all speeds, whereas the highest value was recorded in the direction of the z axis at 6 km/h. All other vibrations had the same values.

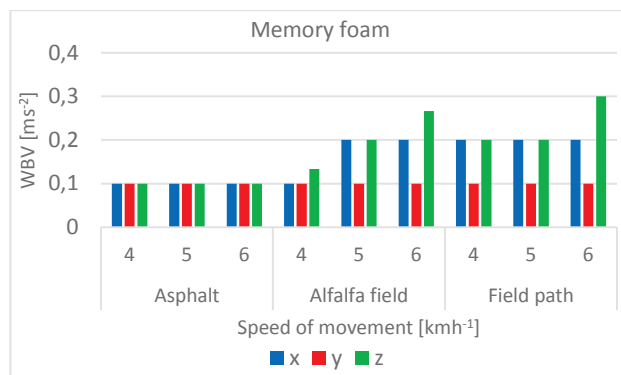


Figure 5 Measured vibration data – memory foam seat

The vibrations recorded on cotton wool (Fig. 6) have the same values on the asphalt surface in the direction of all three axes and at all motion speeds. The highest vibration value was recorded on the alfalfa field in the direction of the x axis at all speeds and in the direction of the z axis at 6 km/h, while the lowest value was recorded in the direction of the y axis at all speeds and in the direction of the z axis at

4 km/h. Moreover, the lowest level of vibration was recorded on the field path in the direction of the y axis at all speeds, while the highest values were recorded in the direction of the z axis at all speeds and in the direction of the x axis at 5 and 6 km/h.

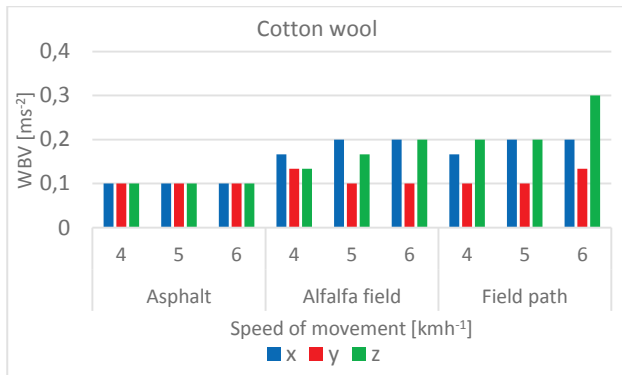


Figure 6 Measured vibration data – cotton wool seat

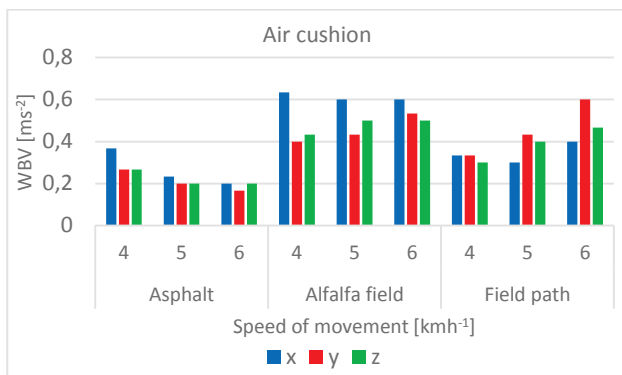


Figure 7 Measured vibration data – air cushion seat

The vibrations recorded on the air cushion (Fig. 7) on an asphalt surface show the highest values in the direction of the x axis at all speeds and in the direction of the z axis at 6 km/h, while the lowest level was recorded in the direction

of the y axis at 6 km/h at all speeds, while all other values were the same. Furthermore, the highest vibration level was recorded on the alfalfa field in the direction of the x axis at all speeds, whereas the lowest was recorded in the direction of the y axis at 4 and 5 km/h, as well as in the direction of the z axis at 6 km/h. The vibrations recorded on the field path show the lowest value in the direction of the z axis at 4 km/h and in the direction of the x axis at 5 and 6 km/h. The highest value was recorded in the direction of the x axis at 4 km/h and in the direction of the y axis at all speeds.

Tab. 2 shows the statistical significance of all tested effects and their interaction in the direction of the x axis, with the impact of the independent variables ‘seat upholstery’ and ‘agrotechnical surface’ being highly significant, and the impact of the independent variable ‘motion speed’ being significant. The mutual interaction of all three independent variables is highly significant.

The impact of all independent variables in the direction of the y axis is highly significant. The interaction of the independent variables (‘agrotechnical surface’, ‘motion speed’) is significant, whereas it is highly significant for all other variables (Tab. 3).

The impact of all three independent variables in the direction of the z axis is generally highly significant, which is shown in Tab. 4. Moreover, the interaction of the independent variables (‘seat upholstery’, ‘motion speed’) is significant, while it is highly significant for all other variables.

Tab. 5 shows the correlation coefficient, the connection between a dependent and independent variable (i.e. the vibrations that impact the body of the operator in the direction of the x, y, and z axes). Additionally, according to [15], the actual significant connection in the direction of the z axis is discernible, whereas the connection in the direction of the x and y axis is slight.

Table 2 Tests of Between - Subjects Effects - Dependent Variable: xos

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power ^b
Corrected Model	3.340 ^a	62	0.054	42.423	0.000	0.954	2630.250	1.000
Intercept	10.290	1	10.290	8103.375	0.000	0.985	8103.375	1.000
Seat upholstery	1.533	6	0.256	201.250	0.000	0.906	1207.500	1.000
Agrotechnical surface	1.007	2	0.503	396.500	0.000	0.863	793.000	1.000
Motion speed	0.012	2	0.006	4.625	0.012	0.068	9.250	0.772
Seat upholstery * Agrotechnical surface	0.609	12	0.051	39.938	0.000	0.792	479.250	1.000
Seat upholstery * Motion speed	0.066	12	0.006	4.333	0.000	0.292	52.000	1.000
Agrotechnical surface * Motion speed	0.045	4	0.011	8.875	0.000	0.220	35.500	0.999
Seat upholstery * Agrotechnical surface * Motion speed	0.068	24	0.003	2.240	0.002	0.299	53.750	0.995
Error	0.160	126	0.001					
Total	13.790	189						
Corrected Total	3.500	188						

Table 3 Tests of Between - Subjects Effects - Dependent Variable: yos

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power ^b
Corrected Model	2.472 ^a	62	0.040	22.161	0.000	0.916	1373.951	1.000
Intercept	7.957	1	7.957	4421.901	0.000	0.972	4421.901	1.000
Seat upholstery	1.653	6	0.276	153.129	0.000	0.879	918.772	1.000
Agrotechnical surface	0.301	2	0.150	83.571	0.000	0.570	167.141	1.000
Motion speed	0.023	2	0.011	6.299	0.002	0.091	12.599	0.891
Seat upholstery * Agrotechnical surface	0.305	12	0.025	14.140	0.000	0.574	169.682	1.000
Seat upholstery * Motion speed	0.055	12	0.005	2.547	0.005	0.195	30.558	0.967
Agrotechnical surface * Motion speed	0.022	4	0.005	3.053	0.019	0.088	12.213	0.793
Seat upholstery * Agrotechnical surface * Motion speed	0.113	24	0.005	2.624	0.000	0.333	62.986	0.999
Error	0.227	126	0.002					
Total	10.656	189						
Corrected Total	2.699	188						

Table 4 Tests of Between - Subjects Effects - Dependent Variable: zos

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power ^b
Corrected Model	2.546 ^a	62	0.041	59.697	0.000	0.967	3701.231	1.000
Intercept	10.478	1	10.478	15232.692	0.000	0.992	15232.692	1.000
Seat upholstery	0.890	6	0.148	215.538	0.000	0.911	1293.231	1.000
Agrotechnical surface	1.020	2	0.510	741.769	0.000	0.922	1483.538	1.000
Motion speed	0.078	2	0.039	56.385	0.000	0.472	112.769	1.000
Seat upholstery * Agrotechnical surface	0.407	12	0.034	49.308	0.000	0.824	591.692	1.000
Seat upholstery * Motion speed	0.017	12	0.001	2.000	0.029	0.160	24.000	.905
Agrotechnical surface * Motion speed	0.029	4	0.007	10.462	0.000	0.249	41.846	1.000
Seat upholstery * Agrotechnical surface * Motion speed	0.106	24	0.004	6.423	0.000	0.550	154.154	1.000
Error	0.087	126	0.001					
Total	13.110	189						
Corrected Total	2.632	188						

Table 5 Coefficient of variation dependent variable x, y and z axes

Model	r	r ² Square	Adjusted r ² Square	Std. Error of the estimate
xos				
1	0.379	0.144	0.130	0.12727
yis				
2	0.309	0.095	0.081	0.11488
zos				
3	0.633	0.401	0.391	0.09233

4 CONCLUSION

The two-way variance analysis generally shows that the impact of the two independent variables 'seat upholstery' and 'agrotechnical surface' in the direction of the x axis is highly significant in relation to the dependent variable. The impact of the independent variable 'motion speed' is significant. The interaction of all independent variables is highly significant.

Additionally, the impact of all three independent variables in the direction of the y axis is highly significant, the interaction of the independent variables 'agrotechnical surface' and 'motion speed' is significant, and the impact of all other independent variables is highly significant. The impact of all three independent variables in the direction of the z axis is highly significant, while the interaction of the

independent variables 'seat upholstery' and 'speed motion' is significant. For all other independent variables, the impact is highly significant.

The correlation coefficient shows a connection among dependent variables (i.e. the vibrations that affect the operator's body in the direction of the x, y, and z axes) and the independent variables for which an actual significant correlation in the direction of the z axis was established, while a slight correlation was established in the direction of the x and y axes.

The published research shows that none of the recorded vibration values that affect the operator's body exceeded the limit value of 1.15 m/s².

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