RESEARCH OF VIBRO-ACOUSTIC ENVIRONMENT IN CABS OF AGRICULTURAL TRACTORS

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Abstract. The working conditions of the operator of agricultural machinery depend on many factors such as microclimate, ergonomics, noise, vibration and changes over time in respect to the usage intensity. The quality of the workplace from the perspective of human safety and health is unchallengeable at modern machinery but unfortunately the ratio of old to new tractors is still very high. The statistical data of the registry of the Republic of Lithuanian agricultural machinery show that the majority (more than 50 %) wheeled tractors were manufactured in 1990's or even earlier.This machinery is known as insufficient to guarantee healthy working conditions, therefore the relationship between the machinery used in farms is slightly related to the number of occupational diseases (especially NIHL and musculoskeletal). This shows the necessity to investigate the vibro-acoustic environment which is, according to various sources and our research data, between 80-90 dB(A) in these tractors. Similar tendencies were obtained analyzing the results of the whole body (WBV) and hand-arm vibration (HAV). It was found that theWBVacceleration values of more than 05 m·s^{-2} were exceeded in 80 % of all tractors while the HAV exposition value of 2.5 m·s^{-2} was exceeded at 33 % of all workplaces respectively.

Keywords: noise exposure, vibration exposure, WBV, HAV, tractor.

Introduction

The statistical data of occupational diseases obtained from the reports of the State Labour Inspectorate of the Republic of Lithuania show the necessity to consider the quality of working environment and to reduce the effects of stress factors. According to the statistical data in Lithuania in 2011, musculoskeletal diseases and NIHL were the dominant occupational diseases and amounted to 76.1 % of the total number (52.5 % and 23.6 % respectively) [1]. The detailed structure of occupational diseases by causality shows the domination of physical hazards (69.4 %). WBV and HAV are the prevailing hazards together with acoustic noise and structure 98 % of all occupational diseases in this category [1]. The largest number of occupational diseases was registered for the operators of hand-held tools and mobile equipment (70 %) as well as for tractor operators [1]. These numbers show the necessity to analyze the reasons of high morbidity after long-term exposure of noise and vibration.

Absence of hazardous vibration effects on humans is assured by regulating the vibration exposure values. The assessment of the level of vibration exposure is based on the calculation of the daily exposure value [2] normalized to an eight-hour reference period $A(8)$. This value is expressed as the square root of the sum of the squares (RMS) (total value) of the frequency-weighted acceleration values, determined on the orthogonal axes a_{hwx}, a_{hwy}, a_{hwz}. Regarding to the ISO standards [3; 4] the daily exposure value is calculated in m·s^{-2} as follows:

$$A(8) = \sqrt{\frac{1}{T_0}\sum_{i=1}^{n} a_{wv,i}^2 \, T_i} \,, \tag{1}$$

where $a_{wv,i}$ – frequency and axis weighted acceleration in time period i, m·s^{-2};
T_0 – duration of eight hour reference period (28800), s.
T_i – duration of period i, s;

The values of $A(8)$ are legitimated by the EU Directive 2002/44/EC [2] for both hand-arm and whole body vibrations and the vibration exposure values are as follows:

1. daily HAV exposure limit value standardized to an eight-hour reference period – 5 m·s^{-2};
2. daily HAV exposure action value – 2.5 m·s^{-2};
3. daily WBV exposure limit value – 1.15 m·s^{-2};
4. daily WBV exposure action value – 0.5 m·s^{-2}.

As well as the vibration exposure values, the EU Directive 2003/10/EC [5] regulates the minimum health and safety requirements to workers arising from noise. The limit values and exposure action values in respect of the daily noise exposure levels ($L_{EX,8h}$) and peak sound pressure are fixed at:

1. peak sound pressure (p_{peak}): maximum value of the C-weighted instantaneous noise pressure;
2. daily noise exposure level ($L_{EX,8h}$)for a nominal eight-hour working day as defined by ISO 1999:2004 [6];
3. weekly noise exposure level as a time-weighted average of the daily noise exposure levels for five working days as defined by ISO 1999:2004.

The exposure limit values and exposure action values in respect of the daily noise exposure levels and peak sound pressure are fixed at:

1. exposure limit values: $L_{EX,8h}$ = 87 dBA and p_{peak}= 200 Pa (or L_{Cpeak} = 140 dBC);
2. upper exposure action values: $L_{EX,8h}$ = 85 dBA and p_{peak} = 140 Pa (or L_{Cpeak} = 137 dBC);
3. lower exposure action values: $L_{EX,8h}$ = 80 dBA and p_{peak} = 120 Pa (or L_{Cpeak} =135 dBC).

If the worker (operator) is exposed to noise less than eight hours per day and the noise level changes tangibly at different time periods, the A-weighted sound pressure level can be calculated as the output of the working time and noise level over the time period T_e [6; 7]:

$$L_{A,eq,Te} = 10\lg\left[\frac{1}{T_e}\sum_{i=1}^{n} t_i \cdot 10^{0.1 L_{Aeq,i}}\right], \text{ dBA }, \quad (2)$$

where $L_{Aeq,ti}$ –equivalent A-weighted sound pressure level over the measurement period t_i;
i – number of measurement intervals. Overall duration $t_i$of the intervals is T_e.

Daily noise exposure of 8 hours is calculated as follows:

$$L_{EX,8h} = L_{Aeq,Te} + 10\lg\left(\frac{T_e}{T_0}\right), \text{dBA }, \quad (3)$$

where $L_{Aeq,Te}$ –measured A-weighted sound pressure level over particular time period T_e;
T_0 – reference duration of 8 working hours, dimensions T_0 and T_e have the same dimensions (hours, minutes, seconds).

The measurement values of noise and vibration at particular workplaces are analyzed using the principles of the noise (vibration) dose over the time period. If the noise or vibration value is higher than the exposure limit the worker should expect negative effects on his health over time.

The research results obtained in Great Britain [8] include the analysis of the vibration data at tractor cabs of various suspension constructions: unsuspended, suspended cab, suspended front axle & cab and fully suspended (front & rear axles). The average vibration acceleration values were measured on the seats of the tractors. Vibration acceleration values from 1.0 $m \cdot s^{-2}$ to 1.2 $m \cdot s^{-2}$ were found during the ploughing operation, 1.8 $m \cdot s^{-2}$ to 2.2 $m \cdot s^{-2}$ when cultivating and 1.6 $m \cdot s^{-2}$ to 1.7 $m \cdot s^{-2}$ during the transport operations. The UK researchers make a conclusion, that the daily exposure of WBV is exceeded at workplaces of tractor drivers during the majority of agricultural operations except cultivation (on rough ground) and trailer transport operations. These results are in agreement with the results obtained by Huub [9]. The vibration acceleration values a_w on asphalt paving at the speed of 25 $km \cdot h^{-1}$ were 0.25 $m \cdot s^{-2}$ and 1.1 $m \cdot s^{-2}$ on country road respectively. The HAV acceleration values at a speed of 7 $km \cdot h^{-1}$ changed from 0.5 $m \cdot s^{-2}$ to1.1 $m \cdot s^{-2}$ and depended on the suspension type. The increase in speed up to 15 $km \cdot h^{-1}$ significantly increased the vibration acceleration value from 1.0 $m \cdot s^{-2}$ to 2.5 $m \cdot s^{-2}$ which is of unacceptable level.

Interesting results of vibration measurements were found by Mirzaei & Mohammadi [10]. This research was based on the measurement of vibration acceleration when tractors were moving in a specified asphalt track at the speed of 10 $km \cdot h^{-1}$ and pulling the trailer. The HAV acceleration values were as high as 12.2 ± 4.7 $m \cdot s^{-2}$ when the tractor was loaded (mass of 10000 kg) and 23.7 ± 16.7 $m \cdot s^{-2}$ without loading. Fereydooni *et al.* [11] investigated the vibration at various tractors as a function of engine revolutions. HAV at 1300 rpm was found from 0.5 $m \cdot s^{-2}$ to1.0 $m \cdot s^{-2}$ at various tractors and increased to 1.0 $m \cdot s^{-2}$ and 2.4 $m \cdot s^{-2}$ respectively at 1700 rpm. The above mentioned studies show the tendency of unacceptable vibrational comfort at most operations and various operation modes of the tractor.

Turkish researchers Melemez & Tunay [12] estimated the noise exposure for tractors without cabins. These tractors were equipped with wood loading equipment and the results showed that the noise level of 90 dB(A) was exceeded at 45 % of all workplaces. Moreover, only 15 % of the operators were exposed to noise levels below the 85 dB(A).The results were much different at the machines with original cabs, where the average noise level was ~78 dB(A). Aybek *et al*. state that the largest mean noise level occurred at the tractors without cabins (89.8 ± 0.59 dB(A)) while the smallest mean level was found for the tractors with original cabins (86.7 ± 0.30 dB(A)). These results are consistent with the previous findings in this study and clearly show that the noise insulation at original cabs is accomplished better.

The concluding remark from the reviewed results is that original cabs reduce the individual noise exposure most. Franklin *et al*. [14] conclude that the average noise level in old tractors is 6 dB higher than at new tractors. Critical effect of open windows and doors was found on acoustic climate at the cab. Noise reduction of 16 dB decreases to 8 dB when the doors or windows are left open. Pessina & Guerretti [15] found that the average noise level at the driver's ear on used and worn tractors was about 87-88 dB(A).

Many other studies can be found on the issues of noise and vibration at various mobile machines and equipment but unfortunately there are very few scientific papers with generalized results. The main goal of this study was to summarize the results of vibro-acoustic measurements in the cabs of agricultural machinery in Lithuania and to prognosticate the number of workplaces where a particular noise level or vibration acceleration value is expected to be exceeded.

Materials and methods

The vibration measurements were carried out at the cabs of various tractors ($n = 62$). These measurements were carried out by using the human-response vibration meter *Bruel&Kjær* type 2512 with transducer types 4322 and 4340. The calibration of transducers was performed using the vibration calibrator *Bruel&Kjær* type 4294 each time before beginning the measurement which were carried out according to the requirements of the ISO standards [3; 4].

Collection of noise and vibration values lasted for several years and the data analysis was performed according to the requirements of the Lithuanian standards LST ISO 1999:2004ir LSTISO9612:2009. The noise levels were measured at the ear level using the DeltaOHM HD2010 sound pressure level meter which is the 1st precision class meter and meets the requirements of the IEC 60804 standard.

Statistical analysis of the collected data was performed by grouping the values of vibration acceleration and equivalent sound pressure level ($L_{A,eq}$, dBA) to the frequency table (Equation 4). Statistical distribution of the noise levels is shown in Fig. 1 and Fig. 2.

$$N = f\left(L_{A,eq}\right) \tag{4}$$

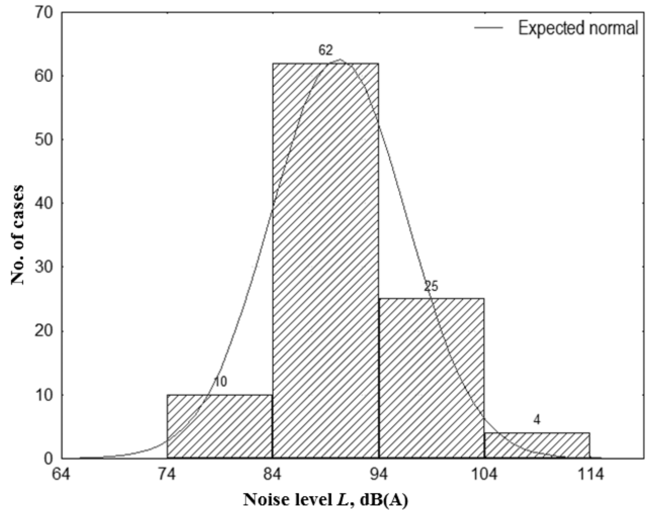

Fig. 1. **Histogram of noise level distribution and the curve of expected normal distribution**

Further investigation was done by using the dependence of descending percentage distribution of the workplaces (N_L, %) where a particular noise level $L$was exceeded. These characteristics were later described as the third degree polynomial dependence as follows:

$$N_L = a \cdot L^3_{A,eq} + b \cdot L^2_{A,eq} + c \cdot L_{A,eq} + d \quad (5)$$

where a, b, c and d – regression coefficients.

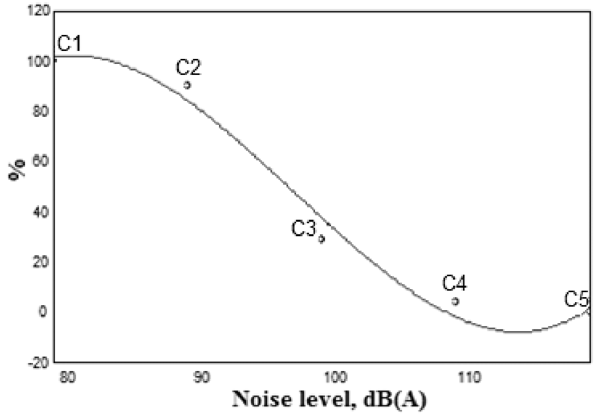

Fig. 2. **Descending total percentage distribution of workplaces and its polynomial dependence**

As well as the noise level analysis, the data of vibration measurements at the tractors of agriculture, melioration and municipal economies were described as a function of workplaces and particular vibration levels (Fig. 3).

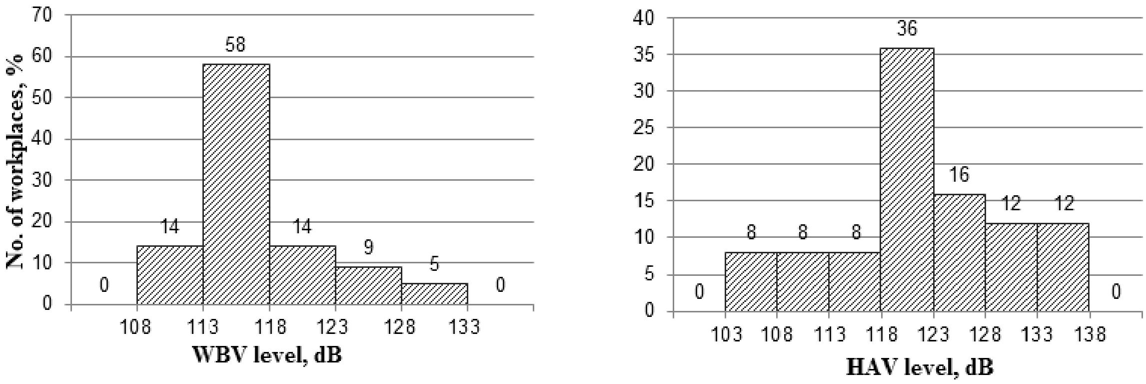

Fig. 3. **Histograms of WBV and HAV level distribution in agricultural tractors**

The results of the vibration level distribution clearly show that agricultural and other tractors lack the vibrational comfort for both, WBV and HAV cases.

Results and discussion

The measurement results of noise and vibration and their analysis show that the noise, WBV and HAV exposure levels are of unacceptable level at most tractors. As the research results were based on the values of noise and vibration described in the EU directives, their analysis was performed under the same conditions. The approximation curves for WBV and HAV are shown in Fig. 4.

The results for WBV show that only 20 % of all investigated agricultural tractors meet the requirements of safe and healthy conditions, i.e., the exposure action value is less than 114 dB (0.50 $m \cdot s^{-2}$). The maximum permissible exposure limit value 122 dB (1.15 $m \cdot s^{-2}$) for the whole body vibration is expected to be exceeded at 35 % of all tractors.

Similar results were found at the tractors when HAV was measured. The HAV exposure action value of 2.5 $m \cdot s^{-2}$ (128 dB) was exceeded at 33 % of workplaces, while the exposure limit value (5.0 $m \cdot s^{-2}$ or 134 dB) at 10 % respectively.

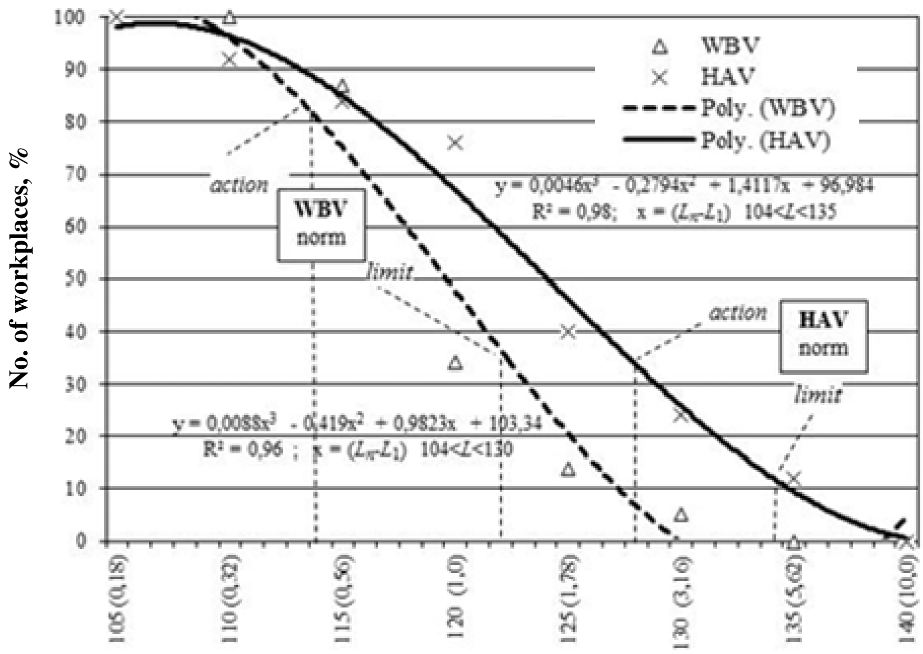

Fig. 4. **Levels of WBV and HAV as a function of workplaces where particular level is exceeded**

The analysis of the noise exposure levels at the cabs of the tractors show similar tendencies as those related with HAV and WBV. As predicted from the equation (5) the values of noise exposure are as follows (Fig. 5):

1. Lower exposure action value of 80 dB(A) is exceeded at 73 % of workplaces;
2. Upper exposure action value is exceeded at 55 %;
3. Exposure limit value is exceeded at 46 %.

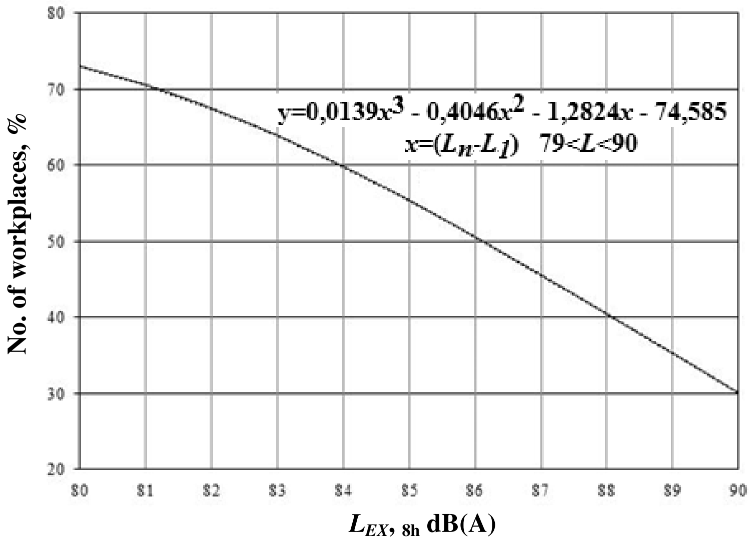

Fig. 5. **Percentage distribution of workplaces of tractor drivers where particular noise exposure levels are exceeded**

The results clearly show the necessity to consider the vibro-acoustic environment at agricultural tractors as one of the most prevailing risk factors on the operators. Increasing of the number of modern machinery is still insufficient to reduce the number of the operators exposed to high levels of noise and vibration. In respect that tractor operators are exposed to HAV, WBV and occupational noise simultaneously it can be stated that more than 50 % of all workplaces can be identified as potentially hazardous.

Conclusions

1. The noise and vibration level analysis in agricultural tractors was generalized by using the methods of mathematical statistics. The noise and vibration exposure levels and the number of workplaces at which these levels are expected to occur were expressed mathematically as the third degree polynomial dependences.
2. According to the measurement results at the tractor cabs in Lithuania it can be concluded that 80 % of all tractors exceed the whole body vibration exposure action value of 0.5 $m \cdot s^{-2}$ while the exposure limit value (1.15 $m \cdot s^{-2}$) is exceeded at 35 % of workplaces. The hand-arm vibration exposure action value of 2.5 $m \cdot s^{-2}$ was exceeded at 33 % while the exposure limit value of 5.0 $m \cdot s^{-2}$ at 10 % of all workplaces respectively.
3. Lower exposure value of the noise level at agricultural tractors was exceeded at 73 % of all workplaces, the upper exposure value of 85 dB(A) – at 55 % and the exposure limit value of 87 dB(A) at 46 % of all investigated workplaces of tractor drivers.

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