International Journal of Occupational Safety and Ergonomics
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tose20

Proposal for an Indexical Method of Evaluating Risk of Hand Tool Operators' Exposure to Mechanical Vibrations

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Published online: 08 Jan 2015.

INTERNATIONAL JOURNAL OF OCCUPATIONAL
SAFETY AND ERGONOMICS (*JOSE*) 2002, VOL. 8, NO. 2, 183–194

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The article presents proposals for an indexical evaluation of exposure of hand tool operators to vibrations. The presented indices have been developed on the basis of the results of laboratory tests. The examinations studied the effect of pressure force and grip force exerted by an operator on a hand tool as well as the amplitudes and frequencies of an exciting signal on vibrations transmitted in the hand-tool handle system.

hand-arm vibration   tool   feed force   griping force

1. INTRODUCTION

Proper management of occupational safety and health protection requires occupational risk assessment. According to a definition, "occupational risk is the probability of an occurrence of adverse events related to the work performed, causing losses, especially an occurrence of health-related adverse events in the workers, as a result of hazards present in the work environment or the method of working," whereas risk evaluation is a "process of

This study is part of the National Programme (formerly National Strategic Programme) "Occupational Safety and Health Protection in the Working Environment" (project 02.4.8) supported in 1998–2001 by the State Committee for Scientific Research of Poland. The Central Institute for Labour Protection is the Programme's main co-ordinator.

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analysing risk and determining acceptable risk" (our translation; Zawieska, 1999, p. 23). The employer is obliged to evaluate and to document this risk and to implement necessary preventive measures (Zawieska, 1999). In the case of work with hand tools, this means an obligation to determine exposure to vibration, even if the values of the measured variables do not exceed the admissible values specified in relevant regulations. The expected seriousness of the effects of a hazard caused by occupational risk depends on the hazard itself and the specific situation in which it has occurred. The probability that there will be effects of a hazard depends on many different factors including the effectiveness of preventive measures, workers' compliance with relevant safety regulations, the number of exposed people, and the duration of each worker's exposure. First of all, however, this hazard depends on the requirements related to the technological process and the physical conditions in a given workplace (Engel & Kowalski, 2001; Engel, Zawieska, & Kowalski, 2001).

In order to reduce the occupational risk of vibration disease among hand tool operators, it is necessary, among other things, to determine the qualitative and quantitative relationships between the vibrations penetrating the hand-arm system (Dobry, 1997; Lundström, 1986), the vibrations generated by tools (Burström, 1994; Burström, & Lundström, 1994), and the mechanical and climatic parameters of the conditions in which the tools are used.

2. LABORATORY TESTS

The literature shows that indices characterising the flow of vibration energy in the hand tool-operator's hand system have not been developed yet. Such indices could be used to assess and predict the vibration hazard to people and to design hand tools that would be safe in terms of generated vibrations. In this connection, work related to the transmission of mechanical vibration in the hand tool-operator's hand system has been taken up in the Central Institute for Labour Protection. A series of tests have been carried out on a specially designed test stand to determine the effect of selected factors related to work with vibrating hand tools on the transmission of vibration to the operator's hands (Figure 1; Kowalski, 1999).

The tests consisted in measuring the transfer function of the operator's forearm and hand. The transfer function was determined on the basis of signals of vibration velocity in the measurement handle and a point on the operator's hand in specific measurement conditions (Figure 2). The transmission of vibrations was defined as the ratio of the amplitude of vibration

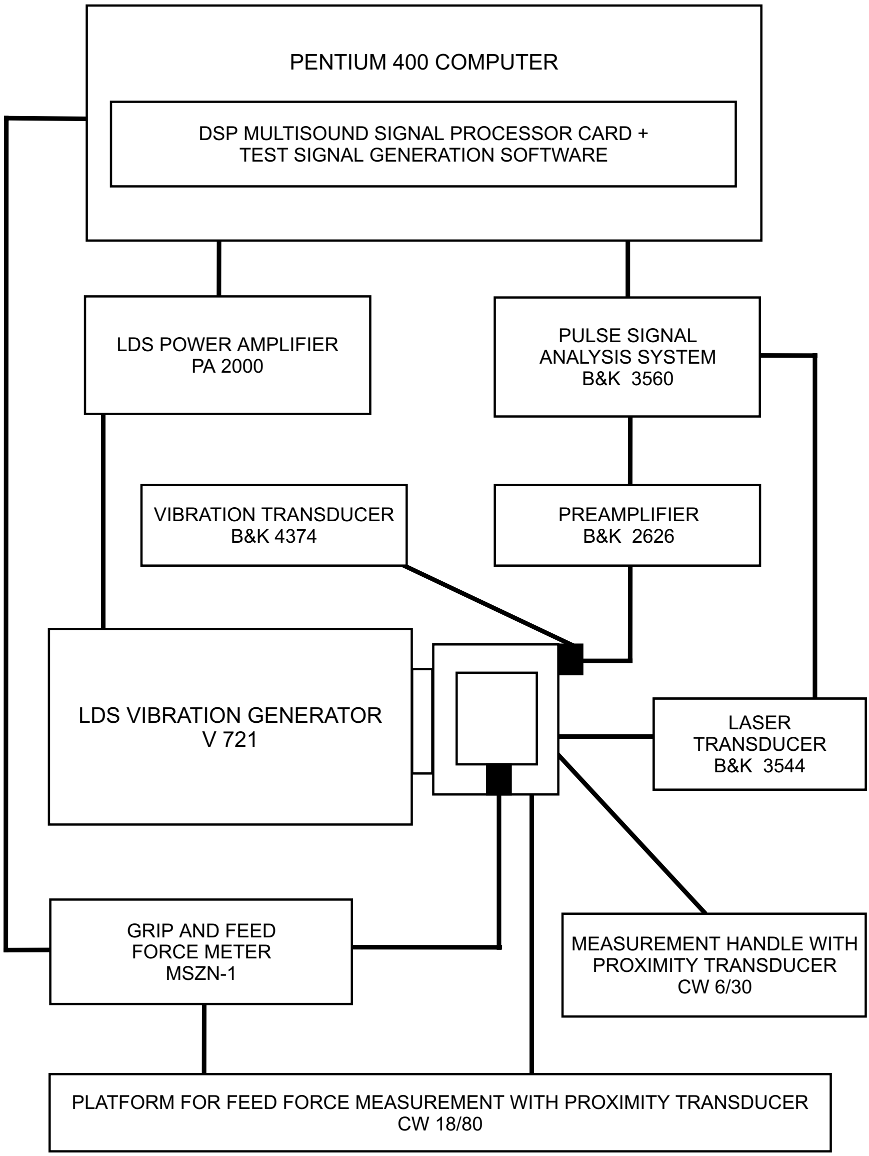

Figure 1. Diagram of a test stand.

velocity in the measurement point on the operator’s hand to the amplitude of handle-generated vibration velocity as a function of frequency. The total value of vibration velocity was also measured in the measurement frequency range of 4–800 Hz.

The hand tool was simulated with the use of a vibration generator equipped with a measurement handle that made it possible to measure grip force. Feed force was controlled using a measurement platform. The

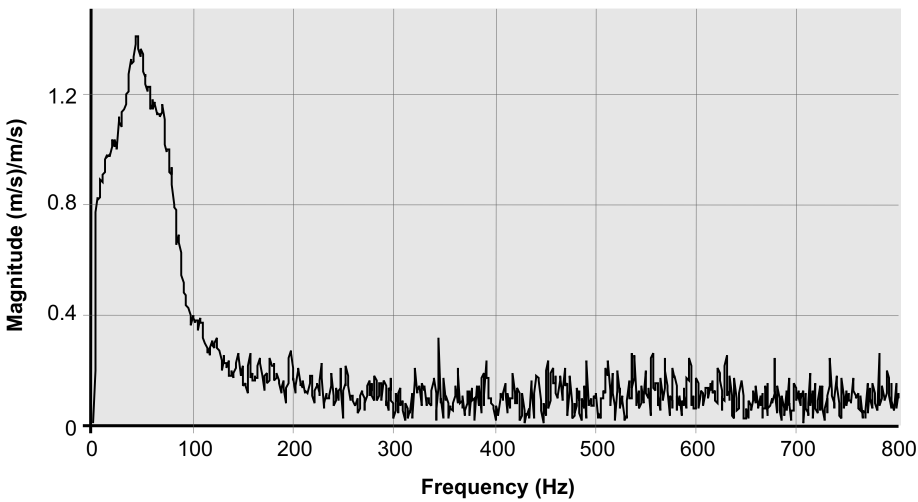

Figure 2. Example of a transfer function of an operator's forearm and hand.

operator's position during the tests is shown in Figure 3; there was to be a fixed angle of 90° between the arm and the forearm.

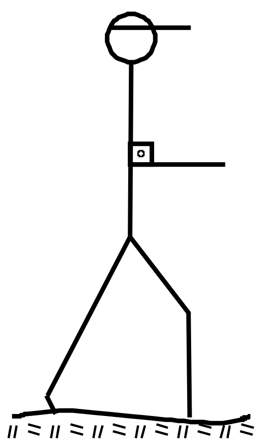

Figure 3. Operator's position during tests.

A vibration reference signal detector was placed directly on the handle in the force axis (i.e., the axis parallel to the operator's forearm). The measurement point on the operator's hand was located on the elbow. The vibration signal in this point was measured using a laser transducer in one direction, parallel to the direction of the excited vibration and to the operator's forearm.

The air temperature in the laboratory during the measurements was 22 °C (thermal comfort) and the relative humidity was approximately 60%.

3. PARTIAL INDICES

On the basis of laboratory tests, the relationships between selected factors and the transmission of vibrations in the operator's hand-hand tool system were determined. These relationships represented the basis for creating a proposal for evaluation indices of hand tool operator's exposure to vibrations (Engel & Kowalski, 2000). Using the determined transmittance of the operator's hand-forearm system, characteristics of vibration transmission in specific conditions were determined. Averaged actual values of vibration transmission as a function of the four selected factors were used to determine the indices in the form of so-called partial polynomials.

The four determined partial indices (in the form of polynomials) represent information about the effect of the four selected factors on exposure to vibration in hand tool operators.

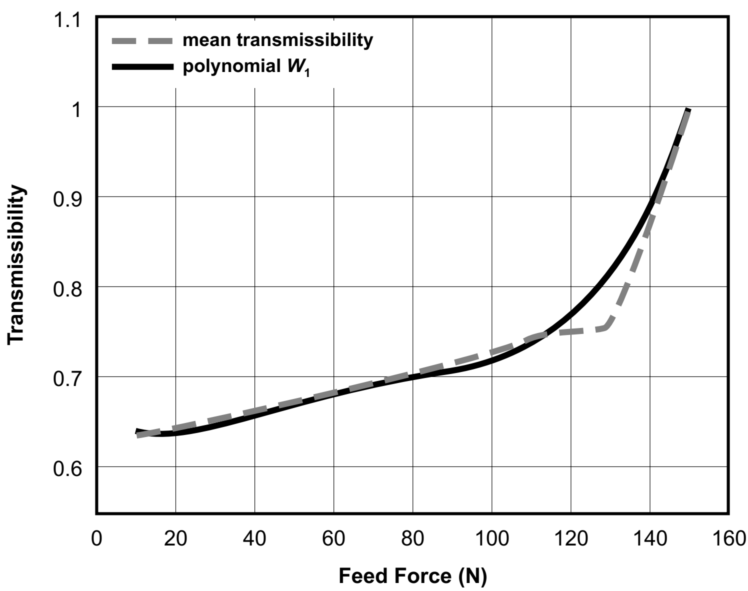

Figure 4. W_1 **index—transmission of vibrations as a function of feed force.**

The W_1 index (Figure 4) determines the effect of feed force exerted by the operator on the tool handle on the value and characteristics of hand-transmitted vibration energy (Kowalski, 1998):

$$W_1 = 0.45883 \cdot 10^{-8} \cdot F_N^4 + 0.1121 \cdot 10^{-5} \cdot F_N^3 + 0.000095114 \cdot F_N^2 - 0.0022212\ F_N + 0.65378, \quad (1)$$

where F_N—operator's feed force on the handle of a hand tool.

The W_2 index (Figure 5) determines the effect of grip force exerted by the operator on the tool handle on the value and characteristics of hand-transmitted vibration energy (Kowalski, 1998):

$$W_2 = -0.41667 \cdot 10^{-7} \cdot F_Z^3 - 0.34375 \cdot 10^{-5} \cdot F_Z^2 + 0.021292 \cdot F_Z + 0.666, \quad (2)$$

where F_Z—operator's grip force on the handle of a hand tool.

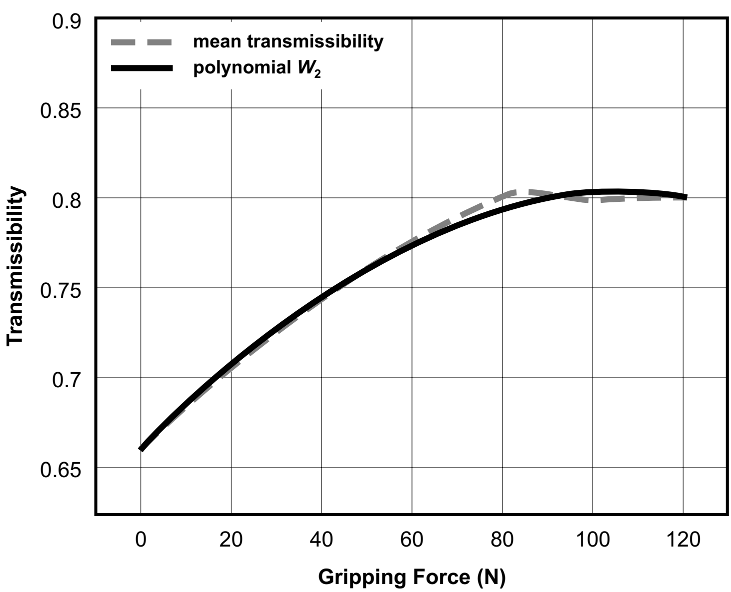

Figure 5. W_2 index—transmission of vibrations as a function of grip force.

The W_3 index (Figure 6) determines the effect of the amplitude of the vibration signal in the tool handle on the value and characteristics of hand-transmitted vibration energy (Kowalski, 2000):

$$W_3 = 0.000011936 \cdot A^4 - 0.00060816 \cdot A^3 + 0.011607 \cdot A^2 - 0.10958 \cdot A + 1.1956, \quad (3)$$

where A—amplitude of the vibration signal in the tool handle.

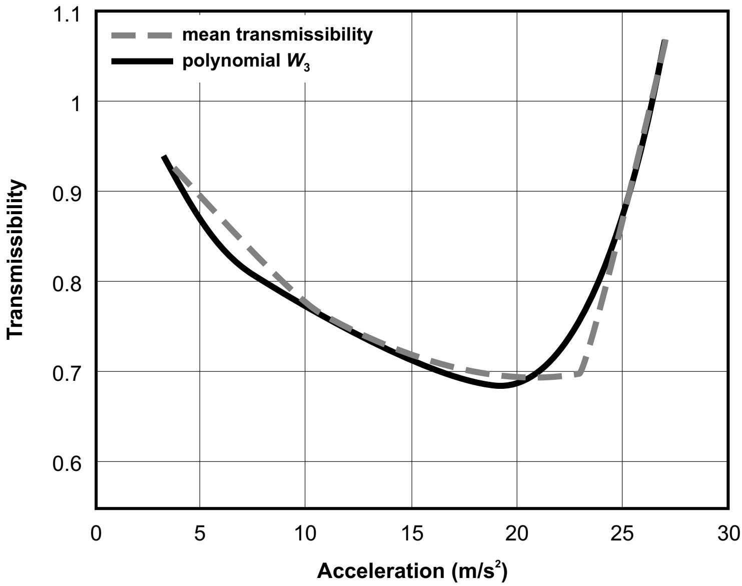

Figure 6. W_3 **index—transmission of vibrations as a function of amplitude.**

The W_4 index (Figure 7) determines the effect of the frequency of the vibration signal in the tool handle on the value of hand-transmitted vibration energy (Kowalski, 2000):

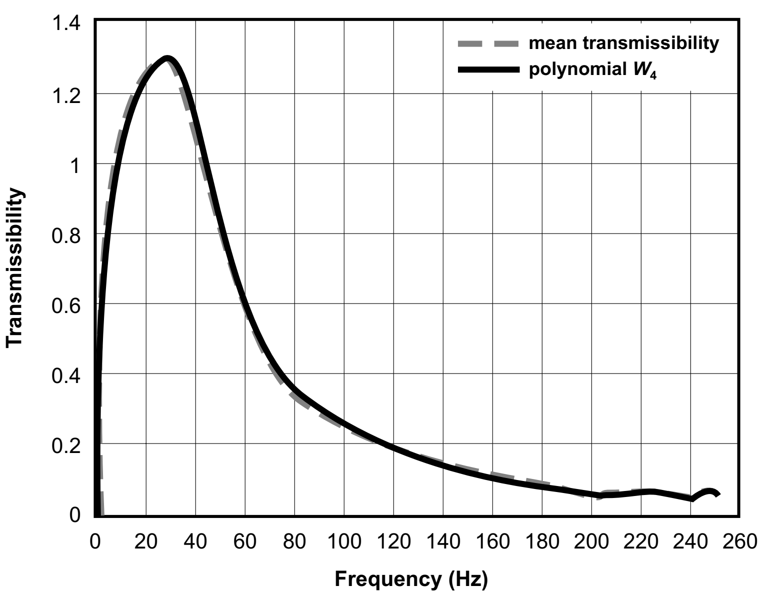

Figure 7. W_4 **index—transmission of vibrations as a function of frequency.**

$$W_4 = -0.56596 \cdot 10^{-27} \cdot f^{14} + 0.10477 \cdot 10^{-23} \cdot f^{13} - 0.87244 \cdot 10^{-21} \cdot f^{12} + 0.43150 \cdot 10^{-18} \cdot f^{11} - 0.14097 \cdot 10^{-15} \cdot f^{10} + 0.31998 \cdot 10^{-13} \cdot f^{9} - 0.51661 \cdot 10^{-11} \cdot f^{8} + 0.59692 \cdot 10^{-9} \cdot f^{7} - 0.4897 \cdot 10^{-7} \cdot f^{6} + 0.27892 \cdot 10^{-5} \cdot f^{5} - 0.00010607 \cdot f^{4} + 0.002544 \cdot f^{3} - 0.036252 \cdot f^{2} + 0.29498 \cdot f + 0.0017, \quad (4)$$

where f—frequency of the vibration signal in the tool handle.

Each partial index is built so as to make its numeric value fall between 0 and 1. Therefore, each index can be evaluated separately in the same way, that is, 0 means there is no vibration transmission: 0% of transmitted vibrations, 100% of vibration energy attenuation, dissipation, or both, whereas 1 means complete transmission of the vibrations reaching the operator's hand: 100% of transmitted vibrations, 0% of vibration energy attenuation, dissipation, or both (Engel & Kowalski, 2000).

4. TOTAL INDEX OF VIBRATION EXPOSURE

In order to simultaneously consider all parameters related to hand tool use in the form of a single value, the total index of vibration exposure W_{CED} was introduced. This index allows to determine the degree of hand tool operators' exposure to mechanical vibration in specific conditions of the work environment using a single value (Engel & Kowalski, 2001).

On the basis of test results and a simulation, the total index of vibration exposure W_{CED} was developed as follows:

$$W_{CED} = \frac{1}{2}\sqrt{\frac{(W_1^2 + W_2^2)}{4} \cdot W_3^2 \cdot W_4^2 \cdot \ldots \cdot W_n^2} \quad . \quad (5)$$

Figure 8 shows frequency characteristics of the total index W_{CED} depending on the values of partial indices.

The form of W_{CED} does not limit the possibility of considering in the future a greater number of partial indices determining the effect of other factors related to hand tool use.

In order to obtain a one-number value of the W_4 partial index (determining the effect of vibration frequency), it is necessary to perform an operation similar to integration of the frequency characteristics of vibration acceleration with an appropriate correction coefficient:

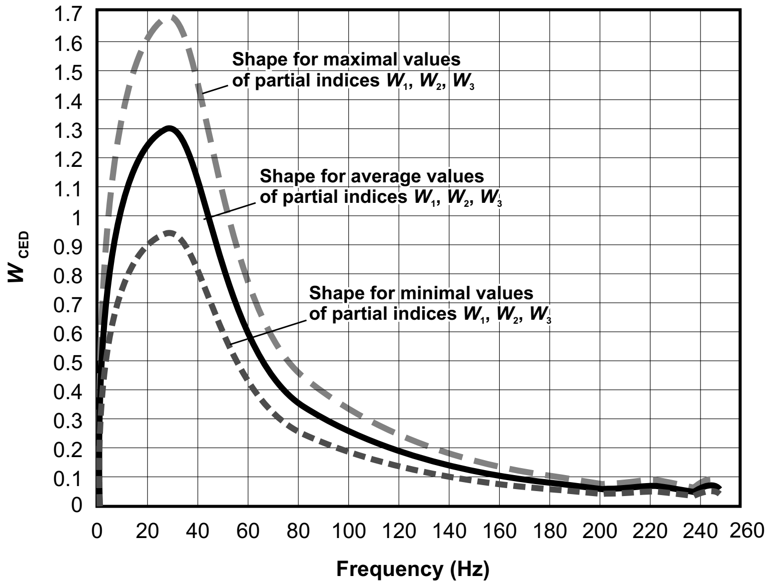

Figure 8. Frequency characteristics of the total index W_{CED}.

$$W_4^* = \sqrt{\sum_{f=1}^{250} [0.32287 \cdot a(f)]^2} \quad , \tag{6}$$

where f—frequency, $a(f)$—value of vibration acceleration at frequency f.

When W_4^* (and W_1, W_2, and W_3) are introduced, the value of the W_{CED} expression falls within the range of 1.756–3.567 (for the ranges of the studied partial indices). Obviously, it is possible to build the W_{CED} index in such a way that its value falls, for example, within the 0–1 range; however, its direct physical interpretation would then be more difficult.

5. TOTAL INDEX OF RISK EVALUATION

In view of the scope of our study, the proposed evaluation criteria refer to work conditions that do not pose a health hazard and are regarded as standard conditions in the following documents:

- feed force: 50 N (according to EN ISO 10819; European Committee for Standardization [CEN], 2000),
- grip force: 30 N (according to EN ISO 10819; CEN, 2000),

- amplitude of vibration acceleration: 2.8 m/s^2 (Minister Pracy i Polityki Społecznej, 2001).

The mere assessment of exposure of hand tool operators to the noxious effect of mechanical vibrations, provided by the exposure index W_{CED}, may be insufficient.

Taking into account the aforementioned, with respect to the mechanical vibrations transmitted by the hands of a hand tool operator, a one-number index of risk evaluation W_R has been introduced (Engel, Zawieska, & Kowalski, 2001), represented by Equation 7:

$$W_R = 1.972 - \frac{W^*_{CED}}{1.81}, \tag{7}$$

where W^*_{CED}—total index W_{CED} after W_4^* has been introduced

In order to facilitate occupational risk assessment in workers exposed to hand-transmitted vibrations, W_R has been defined in such a way that its value is from 0 to 1. The W_{CED} index makes it possible to consider the effect of the examined factors (feed and grip forces, and vibration amplitude and frequency) also when risk is evaluated using the W_R index. Sample W_R values for specific values of force and amplitude are presented in Table 1. It contains parameters corresponding to standard conditions of a hand tool operator's work according to the aforementioned ISO standards (in the case of amplitude, the admissible value of 2.8 m/s^2 was taken into account).

TABLE 1. Risk Evaluation Index W_R in Relation to Feed and Grip Forces and Amplitude

Feed Force (N)	Grip Force (N)	Amplitude (m/s^2)	W_R
150	120	26.5	0.01
120	90	25.0	0.50
110	40	3.7	0.50
80	100	25.5	0.50
50	**30**	**8.9**	**0.79**
10	0	19.8	1.00

As expected, W_R can have the same value not only when the conditions of tool use are identical (including the same amplitude) but also with a specific setting of all parameters: such an effect is presented in Table 1 for $W_R = 0.5$. For amplitudes that differ significantly (3.7–25.5 m/s^2), the same value of the evaluation index was obtained by selecting appropriate values of the forces. Taking this effect into account is one of the basic principles of the proposed method of evaluating exposure. Table 2 contains a proposal for evaluating risk related to work with a hand tool with the use of the W_R index. It was assumed that there was a risk of adverse effects of exposure to occupational vibration even at minimal exposure.

TABLE 2. Proposal for an Evaluation of Exposure to Hand-Transmitted Vibration

Value of Risk Evaluation Index W_R	Risk
0.81–1.0	Small (or no risk)
0.51–0.8	Medium (acceptable)
0.31–0.5	Big (unacceptable)
0.00–0.3	Very big (inadmissible)

The proposed evaluation criteria are formulated only on a theoretical basis, as a result of calculations and a simulation, and an analysis of some standards on the evaluation of hand-transmitted vibrations. Therefore, in order to make them practically applicable, further studies in real conditions are necessary. They should take into account the latest achievements in medical diagnostics and prophylaxis with respect to the impact of mechanical vibrations on the human body.

6. SUMMARY

In this study, a method of using the developed indices to evaluate occupational risk in hand tool operators through an introduced risk index W_R has been proposed. A proposal for criteria for its evaluation has also been presented. The proposed method of evaluating occupational risk related to work associated with exposure to mechanical vibration makes it possible to take into account the effect of the selected four factors. It also provides an opportunity to include many other factors in the future (by determining respective further partial indices). A single final parameter represented by the vibration exposure risk index in the form of a single number is easy to evaluate. There should be further studies concerning a practical verification of the proposed index evaluation criteria.

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