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STRATEGY FOR EFFECTIVE MEASUREMENT OF HAND TRANSMITTED VIBRATION AT THE WORKPLACE

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Abstract. *This paper shows the stages in the evaluation of vibration exposure and they involve the following steps: identification of a series of discrete operations which make up the subject's normal working pattern, selection of operations to be measured, organization and duration of the measurement, estimation of daily vibration exposure time, measurement equipment, location and attachment of the accelerometers, measurement of vibration magnitude, sources of uncertainty in vibration measurement, calculation of daily vibration exposure. In addition, one example of the calculation of daily vibration exposure of workers employed in the "DalCin" d.o.o. Company has been presented here.*

Key words: *hand transmitted vibration, measurement of daily vibration exposure*

1. INTRODUCTION

Operating machinery, such as pneumatic, electric, hydraulic or internal combustion engine-driven chain saw, pecussive tools or grinders, may expose workers to hand transmitted mechanical vibration that can affect the comfort, working efficiency and health and safety. Depending on the type of work and the duration of exposure during working day, one or both arms can be exposed to vibration which may be transmitted to the sholuder, causing the various diseases that affect the blood vessels, nerves, bones, joints, muscles or connective tissues of the hand. Vibrations of machines and tools transmitted to a human body are recognized as a physical agents which could have impact on worker's health and safety. For this reason, the European Parliament and the Council adopted the Directive 2002/44/EC which lays down minimum requirements for the protection of workers from risks to their health and safety arising or likely to arise from the exposure to mechanical vibration. The Directive defines that daily vibration exposure limit value standardized to an eight-hour reference period shall be 5 (m/s^2) and the daily

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exposure action value standardized to an eight-hour reference period shall be 2,5 (m/s^2) [1]. Based on both practical experience and laboratory experimentation concerning human response to hand transmitted vibration, the international standard ISO 5349-1 prescribes general requirements for measuring and evaluating hand transmitted vibration exposure, while ISO 5349-2 provides practical guidelines to perform measurement correctly.

2. Characterization Of Hand-Transmitted Vibration Exposure

The assessment of the level of exposure to hand-arm vibration is based on the parameter named daily vibration exposure, $a_{hv(eq,8h)}$, expressed in (m/s^2), [1, 2]. It is the vibration total value, a_{hv}, normalized to an eight-hour reference period, i.e. 8-h energy-equivalent total value. Instead of a term $a_{hv(eq,8h)}$, a convenient alternative denotation is *A(8)*. The daily vibration exposure is defined by equation

$$A(8) = a_{hv(eq,8h)} = a_{hv}\sqrt{\frac{T}{T_0}} \tag{1}$$

where T is the total daily exposure duration to vibration a_{hv}, and T_0 is the reference duration of working day (8 h or 28800 s).

Vibration total value, a_{hv} (m/s^2), is calculated from the three single-axes root-mean-square (rms) values of the frequency-weighted hand-transmitted vibration, a_{hwx}, a_{hwy} and a_{hwz}, according to the equation

$$a_{hv} = \sqrt{a^2_{hwx} + a^2_{hwy} + a^2_{hwz}} \tag{2}$$

If the work process is such that the daily exposure consist of several operations with different vibration magnitude, than the daily vibration exposure A(8) should be obtained using the equation

$$A(8) = \sqrt{\frac{1}{T_0}\sum_{i=1}^{n} a^2_{hvi} T_i} \tag{3}$$

where a_{hvi} is the vibration total value for *i-th* operation; n is the number of individual vibration exposures (operations); T_i is the duration of the *i-th* operation; T_0 is the reference duration of working day (8 h or 28800 s).

Since the vibration exposure is dependent on the magnitude of vibration and on the duration of the exposure, two main quantities should be evaluated for each *i-th* operation during the exposure to vibration, that are the vibration total value a_{hvi} and duration (per day) T_i of vibration exposure for operation *i*.

3. Measurement Methodology

Stages in which the evaluation of vibration exposure can be broken up are as follows [3]:

- Preparation of the measurement procedure which include identification of discrete operations which make up the worker’s normal working pattern; selection of operation to be measured, estimation of daily vibration exposure duration, organization and duration of the measurement.

- Measurement of vibration magnitude, which implies selection of measurement equipment, location and attaching of accelerometers, check and verification of the measurement chain.
- Calculation of the daily vibration exposure and evaluation of uncertainties.

3.1. Preparation of the measurement procedure

The work process may be composed of different operations, often repeating. As the operator can change tools during different working operations or change working regime during one operation, the level of vibration exposure may vary greatly from one operation to another. So, it is very important to select the operations to be measured and choose an appropriate measurement method for each operation.

3.1.1. Selection of operation to be measured

To obtain a good picture of the worker’s average daily vibration exposure it is necessary to identify all the machines and tools being used during working day, i.e. sources of vibration exposure. Further, all working modes of one power tool have to be identified. For example, chain saws may be idling, operating under load while cutting through a tree trunk, or operating under low load while cutting side branches. Also, it is good to recognize changes in the operating conditions which might affect vibration exposure. A good example is a grinder used initialy for bulk metal removal, then followed by more complicated operations of cleaning and shaping. It is allways useful to get information from workers and their supervisors about situations producing the highest vibration magnitude, as well as to use the information from manufacturers on vibration emission values.

3.1.2. Organization of the measurement

The measurement can be organized in following ways:

a) Long-term measurement of continuous tool operation

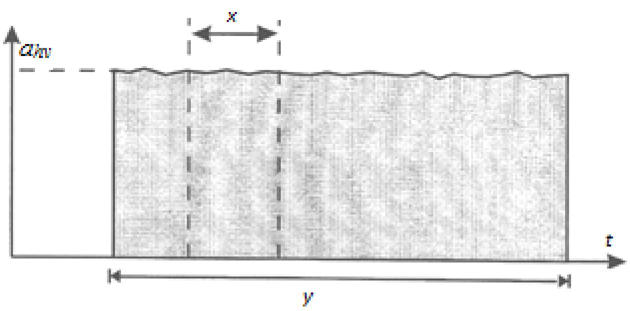

Fig. 1 Long-term measurement of continuous exposure [3]

A good examples of this type of operation are floor polishing or ride-on lawn mowers. The worker's hand is always in contact with the power tool or hand-held workpiece during long-term continuous operation. The vibration magnitude can be measured over long periods. The exposure time is the time for which the power tool has been used by worker. The coresponding vibration pattern is shown in Figure 1, where *x* represents duration of measurement and *y* represents operating time equal to exposure time in this case.

b) Long-term measurement of intermittent tool operation

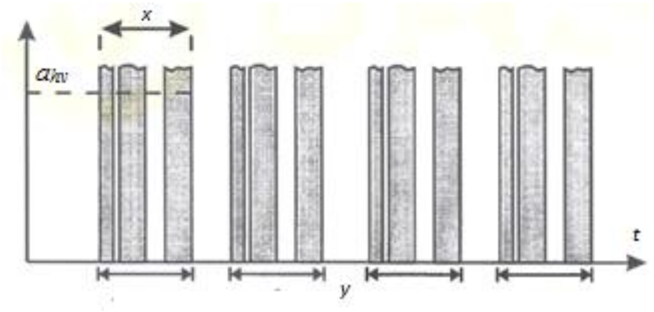

Fig. 2 Long-term measurement of intermittent exposure [3]

The examples of this type of operation are the use of grinders, chain saws and scaling hammers. The worker's hand is always in contact with the power tool or hand-held workpiece but the tool is not operated continuously because of short breaks in operation. In this case, the vibration magnitude should be long-term measured over a representative period of tool use (including periods when tool does not operated) and the exposure time is the time for which the tool is used during the working day. The coresponding vibration pattern is shown in Figure 2, where *x* represents duration of measurement and $y = \Sigma\, x$ represents total tool use time equal to exposure time in this case. The adventage of this type of measurement is that the vibration magnitude represents the actual task, including running-up and running-down periods of the machine, but at the other hand, the vibration magnitude is highly dependent on time the power tool is truly operating in worker's hand.

c) Short-term measurement of intermittent tool operation

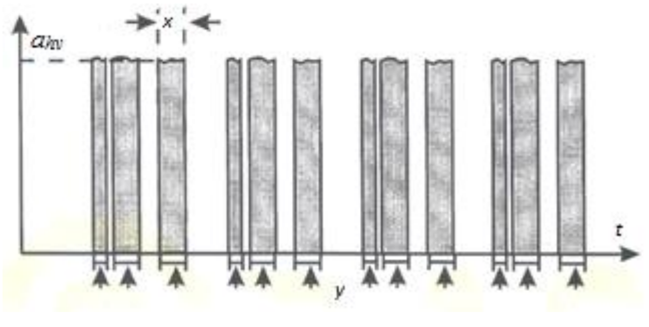

Fig. 3 Short-term measurement of intermittent exposure [3]

The examples of this type of operation are the use of hand-held grinders, pedestal grinders, chain saws and scaling hammers. The worker's hand is always in contact with the power tool or hand-held workpiece but the tool is not operated continuously because of long breaks in operation or when the hand is taken off the tool during use. In this case, the vibration magnitude should be short-term measured over a period of continuous operation and the exposure time is the time for which the power tool is being operated during the working day. The coresponding vibration pattern is shown in Figure 3, where *x* represents duration of measurement and $y = \Sigma\, x$ represents total operating time equal to the exposure time in this case. As the vibration measurement does not include periods when the machine is running-up and running-down to idling or off, this coud be considered as disandvatages of this type of measurement if run-up or run-down times are comparable to the time spent at operating speed.

d) Fixed-duration measurement of single impacts or bursts of tool operation

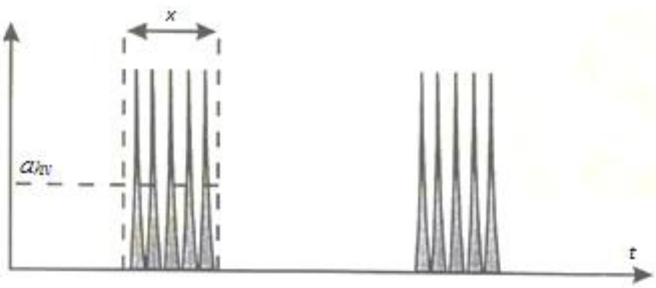

Fig. 4 Fixed-duration measurement of single impacts or bursts of tool operation [3]

Typical examples of this type of operation are the use of nail guns and powered impact wrenches producing irregular single impacts or bursts of vibration with long brekas between them. The average vibration magnitude should be measured over a fixed duration which include a known number (one or more) of impacts or bursts. The typical vibration pattern is shown in Figure 4. The exposure time is calculated as the measurement duration multiplied by the number of impacts per day devided by the number of impact or bursts in the measurement period, according to

$$T = \frac{number\ of\ impacts\ per\ day}{number\ of\ impacts\ in\ measurement\ period} \times measurement\ duration \tag{4}$$

e) The vibration evaluation where more then one tool is used: If the worker uses more than one power tool during working day, then appropriate methods described above should be used to determine a partial vibration exposure $A_i(8)$ for each individual task. After each task was analysed separately, the total daily vibration exposure can be calculated according to

$$A(8) = \sqrt{\sum_{i=1}^{n} A_i^2\left(8\right)} \tag{5}$$

3.1.3. Duration of vibration measurement

It is necessary to average the measurement over a representative period for typical use of a tool or process. It is recommended to start the measurement at the moment when worker puts his hands to vibrating surface and finish it when contact between hands and tool is terminated. During measurement, a variations in the vibration magnitude are possible, as well as periods with no vibration exposure.

The minimum acceptable duration of measurements depends on the vibration signal, used instrumentation and operation characteristics. The total measuring time (that is the number of samples multiplied by the duration per measurement) should be at least 1 minute. It is preferable to take a number of shorter duration measurement samples than to perform a single long duration measurement.

3.1.4. Estimation of daily vibration duration

It is necessary to determine the daily exposure duration for each vibration source. It could be done by measuring the concrete exposure time during a period of normal use of vibration source, by using a stopwatch or analyzing video records of the work process (it is the most reliable source of information).

Another way to determine the daily exposure duration is to get information on work rate (for example, the number of work cycles per shift or the shift length).

If the vibration has been averaged over a complete work cycle, then the duration of the work cycle multiplied by the number of cycles per day defines the daily exposure time.

3.2. Measurement of vibration magnitude

3.2.1. Measuring equipment for hand-transmitted vibration

Vibration measurement should be performed by the equipment confirming to the requirements of ISO 8041 [3]. It is necessary to check this instrumentation for correct operation before and after use. Basic measurement system consists of vibration meter unit and accelerometer. The single-unit vibration meter must have built-in frequency weightings and integrating facilities. There are also more sophisticated measurement systems based on frequency analysis (e.g. one-third-octave or narrow band), which may use digital data recorders to store amplitude-time information, or use computer-based data acquisition and analysis techniques.

The type of accelerometer to be chosen for measurement depends on the expected vibration magnitude, the required frequency range, the physical characteristics of the surface being measured and environmental conditions.

3.2.2. Location and orientation of accelerometers

It is preferable to perform simultaneous triaxial measurement of vibration using the triaxial accelerometer. In practice, the basicentric coordinate system is used, with the origin in a vibrating appliance, workpiece, handle or control device gripped by the hand, as described in ISO 8727.

Vibration should be measured at or near the surface of the hand(s) where the vibrations enters the body, preferably at the middle of the gripping zone. Therefore, it is important before actual measurement to observe how a power tool or hand-held workpiece is held and to identify the best location and orientation of the accelerometer. Figure 5 shows the examples of measurement locations for some common power tools.

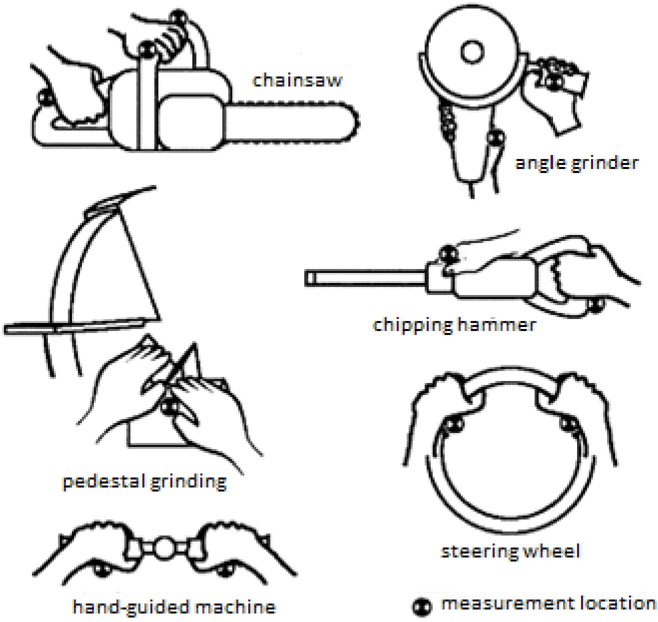

Fig. 5 Examples of measurement locations [3, 4]

Additionally, International Standards ISO 8662-2 to ISO 8662-14, ISO 7505 and ISO 7916 specify measurement locations for measuring the vibration at the handles of different hand-held power tools for the purpose of determining vibration emission values. For avoiding interference with the power tool controls or with the safe operation, the best location is where the on-off switch is positioned. It is often necessary to use special mounting adaptors for transducer which should fit under the hand or between fingers.

3.2.3. Attaching accelerometers

The accelerometers should be rigidly attached to the vibrating surface. Typical mounting methods, some of these depicted in Figure 6, are as follows:

- stud mounting (screwed),
- mounting by glue or cement,
- clamp or nylon strap connections,
- hand-held adaptors.

The choice of mounting method depends on the particular measurement situation and each method has some advantages and disadvantages. The mounting system should have a flat frequency response across the range of frequencies being measured, i.e. it should not attenuate or amplify and should not have any resonances in the frequency range. It is inevitable that mounting of an accelerometer causes some disruption in work operations.

Thus, mounting should be arranged in the way that the operator can work as normally as possible.

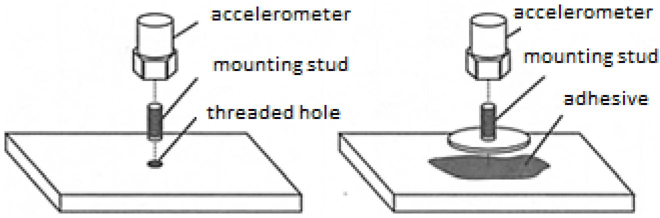

Fig. 6 Examples of stud mounting methods [3, 4]: accelerometer can be mounted by a stud screwed into a threaded hole or adhered to the tool by glue or wax

3.2.4. Check of measurement chain

The whole measurement chain should be checked before and after a measurement, by using a vibration calibrator as a reference vibration source producing known sinusoidal acceleration at a known frequency.

3.3. Calculation of the daily vibration exposure

The daily vibration exposure *A(8)* in (m/s^2) is calculated according to equation (1). In order to compare different operations and to evaluate the individual contribution of a particular operation to the daily exposure *A(8)*, it may be useful to calculate the partial vibration exposure for the individual operation, $A_i(8)$, using

$$A_i(8) = a_{hvi}\sqrt{\frac{T_i}{T_0}} \tag{6}$$

where a_{hvi} is the vibration total value for *i-th* operation; T_i is the duration of the *i-th* operation; T_0 is the reference duration of working day (8 h or 28800 s).

The daily exposure is then given by equation

$$A(8) = \sqrt{\sum_{i=1}^{n} A_i^2(8)} \tag{7}$$

where *n* is the number of operations.

3.3.1. Uncertainties of evaluation of daily vibration exposure

The uncertainties associated with the evaluation of *A*(*8*) are often high (20-40 %), so it is normally to present the value of *A*(*8*) with two significant figures. The uncertainties associated with instrumentation and calibration, electrical interference, mounting and mass of the accelerometer are usually small compared with those resulting from the selection of measurement location and variability of the work operation. The uncertainties of the estimation of exposure time resulted from uncertainties in measurement of duration of exposure, wrong estimates of the number of work cycles per day or wrong information supplied from workers. The experimenter should determine the main sources of uncertainties and multiple measurement should be made in order to determine the extent of uncertainties and to calculate the standard deviation regarding the dominant sources of uncertainty.

4. CASE STUDY

The exposure of workers to the hand-transmitted vibrations is especially present in those industries in which the production process is based on the use of hand-held power tools and machines, such as pneumatic, electric, hydraulic or internal combustion engine-driven chain saw, percussive tools or grinders. A good example of such an industry is the “DalCin” company from Banja Luka engaged in the production of metal furniture. In order to assess the risk of exposure of workers to harmful effects of mechanical vibration, the measurement of hand-transmitted vibration was carried out for a few operations in the department for grinding and polishing.

4.1. Preparation of measurement

Preparation of measurement includes selection of operations to be measured, decision making about the measurement organization and estimation of the vibration exposure duration.

Since each worker uses one power tool during whole working day, it was decided to analyze the vibration exposure of workers at workplaces where following power tools are used:

1. Random orbital sander
2. Small angle grinder
3. Angle sander
4. Pedestal belt grinder

The workpiece is the metal construction of chair built from 8 rods of rectangular cross section. Since each rod has 4 perpendicular surfaces, that is 32 surfaces in total to be machined. By collecting some information from workers, the examiner concluded that an average of 50 chairs are worked on per day. Also, by observing the work process and measuring duration of some operation, the examiner found that an average duration of one operation sequence (one surface of the rectangular rod) is about 13 s. Thus, for each chair, the operating cycle is made up of two main periods:

- 415 s to grind each of 32 surfaces of the workpiece;
- 35 s to manipulate with the workpiece (rotation of the workpiece and replacement of sandpaper, during which the tool doesn’t operate).

The vibration pattern is similar to that shown in Figure 2. It was decided to do the measurement as a long-term measurement of intermittent tool operation. One operating cycle has a duration of 450 s. At a work rate of 50 workpieces per day, the total daily exposure time is then 375 minutes or 6.25 hours.

4.2. Measurement of the vibration magnitude

For this analysis, the following equipment, showed in Figure 7, was used:

- hand-held analyzer type 4447,
- triaxial accelerometer type 4524 B 001,
- adaptors for fixing and locating the accelerometer to the gripping zone of vibration, all produced by Bruel&Kjaer.

Fig. 7 Hand-held vibration analyzer, accelerometer and adaptors (L-shape, T-shape, cube)

4.2.1. Mounting the accelerometer

Regarding the characteristics of used power tools, three different adaptors were used in this analysis. In the case of the pneumatic random orbital sander, the worker holds the T-shape hand adaptor equiped with accelerometer between his fingers, in the midle of the gripping zone, Figure 8.

Fig. 8 Random orbital sander: the accelerometer attacheb by T-shape hand adaptor

When the small angle grinder is used, the worker holds the L-shape handle adaptor equiped with accelerometer on the underside of the tool handle, Figure 9.

Fig. 9 a) Small angle grinder, b) The accelerometer attached by L-shape hand adaptor

In the case of the angle sander, the accelerometer was fixed by the cube adaptor, Figure 10.

Fig. 10 a) Angle sander, b) The accelerometer attached by nylon strap

The specificity of the operation done on the pedestal belt grinder is that the worker holds the workpiece in his hands and feeds workpiece to the working part of the machine, such that the workpiece is the source of vibration transmitted to the hands, Figure 11. Because of that, the accelerometer fitted in the cube adaptor was mounted directly to the metal rod of the chair, Figure 12.

Fig. 12 a) Pedestal belt grinder, b) The accelerometer attached by nylon strap

4.2.2. Measurement results

The primary quantity which is measured and used to describe the vibration magnitude is the root mean square (r.m.s.) frequency-weighted acceleratinon for the x, y and z axis. The evaluation of vibration exposure is based on the vibration total value, which combines all three axes, according to equation (2). All quantities are expresed in (m/s^2).

All measured r.m.s. values (a_{hwx}, a_{hwy}, a_{hwz}) and vibration total values (a_{hv}) for each investigated workplace are shown in Table 1.

Table 1 Results of measurement

Vibration values (m/s^2)				
Work place	1	2	3	4
a_{hwx}	2,7	1,4	2,7	1,1
a_{hwy}	5,8	2,2	5,8	0,8
a_{hwz}	3,1	0,5	1,9	0,8
a_{hv}	7,2	2,7	6,7	1,6

4.3. Evaluation of the daily vibration exposure

Daily vibration exposure is quantityderived from the magnitude of vibration (vibration total value) and the daily exposure duration, accorting to the equation (1).

Since the duration of operatig cycle for each workplace is about 450 s, and there are 50 cycles per working day, the daily exposure time is

$$T = \sum_{i=1}^{50} t_i = 450 \times 50 = 22500s\ (6,25h) \tag{8}$$

The daily vibration exposure A(8), calculated by equation (1), for each workplace is

- Random orbit sander

$$A(8) = a_{hv}\sqrt{\frac{T}{T_0}} = 7,2\sqrt{\frac{6,25}{8}} = 6,4\ \ (\mathrm{m/s^2}) \tag{9}$$

- Small angle grinder

$$A(8) = a_{hv}\sqrt{\frac{T}{T_0}} = 2,7\sqrt{\frac{6,25}{8}} = 2,4 \ \ (\text{m/s}^2) \tag{10}$$

- Angle sander

$$A(8) = a_{hv}\sqrt{\frac{T}{T_0}} = 6,7\sqrt{\frac{6,25}{8}} = 5,9 \ \ (\text{m/s}^2) \tag{11}$$

- Pedestal belt grinder

$$A(8) = a_{hv}\sqrt{\frac{T}{T_0}} = 1,6\sqrt{\frac{6,25}{8}} = 1,4 \ \ (\text{m/s}^2) \tag{12}$$

Results of the analysis show that the workers using random orbit sander and angle sander are exposed to vibration which daily exposure values exceeds the exposure limit value of 5 (m/s^2) prescribed by the EU Directive 2002/44/EC. Therefore, it is necessary that the employer takes some measures to protect the workers from the risk to their health and safety arising or likely to arise from exposure to mechanical vibration.

5. CONCLUSION

Having completed the evaluation of exposure of workers to the hand-transmitted vibration and once the exposure limit value is exceeded, the employer has an obligation to establish and implement a program of technical and organization measures intended to reduce vibration exposure to a minimum value. A good technical preventive measure which may be implemented immediately is reorganization of working process in a way that one worker uses more than one power tool, i.e. to perform more than one operation by use of different tools. In this way, a worker may use the power tool producing too high vibration magnitude for a shorter period. In combination with another tool producing low vibration magnitude, it is possible to reduce the overall daily vibration exposure. Apart from this, if there is a choice between different tools, the tool resulting in the lowest vibration exposure should be used. All equipment should be carefully maintained. Also, tools with handle shapes with high pressures on the skin in the area of contact should be avoided. It is always preferable to use tools requiring the smallest contact grip and feed forces. The mass of hand-held tools should be kept to a minimum, provided that vibration magnitude or contact forces are not increased. Anti-vibration gloves can be useful where the use of gloves reduce the vibration exposure.

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STRATEGIJA EFIKASNOG MERENJA VIBRACIJA KOJE SE PREKO RUKE PRENOSE NA LJUDSKO TELO

U ovom radu predstavljena je strategija efikasnog mjerenja vibracija koje se na ljudsko telo prenose putem ruke. Metodologija kojom se određuje nivo izloženosti vibracijama podeljena je u nekoliko koraka: identifikacija niza diskretnih operacija od kojih je sačinjena uobičajena aktivnost jednog radnika tokom radnog dana; izbor operacija za koje je potrebno izmeriti izloženost vibracijama; organizacija merenja, određivanje vremena tokom kojeg je potrebno vršiti merenje i određivanje trajanja izlaganju vibracijama tokom dana; izbor merne opreme, izbor lokacije i načina pričvršćivanja akcelerometra; merenje amplitude vibracija; utvrđivanje merne nesigurnosti; proračun dnevne izloženosti vibracijama. U radu je dat prikaz proračuna dnevne izloženosti vibracijama prema prethodno definisanoj metodologiji za jednu grupu radnika proizvodnog preduzeća koje se bavi mašinskom obradom metalnog nameštaja.

Ključne reči: *vibracije prenesene rukom, merenje dnevne izloženosti vibracijama*