OBJECTIFICATION AND DETERMINATION OF HAND-ARM VIBRATIONS

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Abstract: The paper is devoted to objectification and determination of the influence of hand-arm vibrations with selected machinery. We permanently meet with vibrations, but especially when performing work activities. When working with machinery, a person is constantly exposed to vibrations and they can very negatively affect the health of the person. The aim of the paper is to compare measured vibration values with the manual of the device and then to determine the maximum time exposure for work activities to avoid the employee being at risk of working with the device. Comparison of a final hand-arm vibration will be assessed by means of the hand-arm exposure calculator and software for a specific measuring device - vibration analyzer of the 4447 type. The proposed method - an extended risk matrix - is used to assess the risks of hand-arm vibration.

Keywords: VIBRATIONS, SAFETY, OCCUPATIONAL HEALTH PROTECTION

1. Introduction

Many work activities require regular and frequent use of vibrating tools and equipment. The handling of vibrating materials is also widely found in industries and provision of services. It is, for example, civil engineering, building of roads and railways, maintenance and improvement of real estate (maintenance of terrain, parks, watercourses, roads and their adjacent green belts), production of concrete products, forestry, foundry, heavy engineering, mining and surface mining, production and repair of automobiles, supply services to the public (works for water water management companies, gas companies, power plants and telecommunication companies), building and repair of ships and other.

When in contact with work equipment and mechanical tools, a person is often exposed to shocks and vibrations that are harmful to human health when exceeding certain values. Vibrations increase the fatigue of a person because a large amount of muscle is trying to capture their effects. Damages caused by vibrations are dependent on amplitude, frequency, acceleration, and vibration count. They are caused in particular by chainsaws, drills, pneumatic hammers - locally transmitted vibrations (hand-arm vibrations), vibrating machines where the worker is sitting or standing - tractors, mobile machines - whole body vibration, special transmission - carried on the back. (OSHA, 2011)

2. Health risks associated with hand-arm vibration exposure

Some hand tools produce high vibration acceleration levels that can cause permanent damage to the hands and arms. This risk is caused by the Hand-Arm Vibration Syndrome (HAVS) syndrome which depends on the following factors:
• position and method of gripping tools,
• the length of time interval of work activity with tools,
• heat and cold load in the working environment,
• vibration level.

Exposure to hand-arm vibration syndrome could cause serious health-damaging effects, circulatory disorders, such as vibration white finger (VWF), sensitivity of the senses impairment, muscle, bone and joint damage. The second and more serious manifestation of the disease is the so-called Raynaud’s syndrome, vibration white finger disease may occur at frequencies between 5-2,000 Hz, but the greatest risk is between 5-150 Hz. (OSHA, 2011)

3. Legal framework of the European Union related to factors at work

Measurement, objectification, and assessment of vibrations must firstly be in line with the applicable procedures and proposals that are underpinned by relevant valid binding legislation. The main legislative aspects used for the measurement and assessment of hand-arm vibrations for which the different methods of exposure determination are as follows:

This legislation sets out the limit and action values of vibration that can not be exceeded during the work performed. It contains methods for measuring and calculating the normalized vibration acceleration by means of which representative vibration values are obtained and then compared with the permissible values. This will also include assignment to the appropriate category of work. Table 1 lists the respective action and limit values of hand-arm vibrations. (Directive 2002/44/ EC)

<table>
<thead>
<tr>
<th>Resulting standardized acceleration $a_{hv}$</th>
<th>Transmission of vibration to the hands</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limit value $a_{hv,AL}$</td>
<td>5</td>
</tr>
<tr>
<td>Action value $a_{hv,AH}$</td>
<td>2.5</td>
</tr>
<tr>
<td>Equivalent acceleration $a_{eq}$</td>
<td>$a_{eq}$</td>
</tr>
<tr>
<td>Action value – acting less than 20 minutes</td>
<td>12.25</td>
</tr>
<tr>
<td>Action value – acting less than 120 minutes</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
• a) Equivalent weighted acceleration recalculated in terms of the normalized duration of work shift $T_{w}=8h$.
• b) Effective acceleration value determined at time $T$.

4. Material and methods

Risk assessment procedure according to “Non-binding guide to good practice with a view of implementation of Directive 2002/44/EC (Vibrations at Work) issued by the European Commission (EC) in 2009 is described in detail below.

The factors that govern the daily exposure of a person to vibrations are the frequency weighted vibration force (level) and the time of exposure of the person to this vibrational force. The greater the force is or the longer the exposure lasts, the greater the exposure of the person to the vibrations is.

The whole process can be modeled on the example of manual grinding of metallic material - performed irregularly during the work shift - profession of a locksmith.

To assess the threat rate, a representative sample value of 75% of the instruments was selected, i.e., acceleration...
The estimation of daily vibration exposure A(8) can be based on observation based on real work activities undertaken, i.e., on max. length of exposure to vibrations transmitted to the worker's hand and arm (Hand-arm vibration exposure calculator, 2012), for example:

- grinding and cutting with an electric angle grinder with maximum duration 1 hour and duration 10 min.

Using the daily exposure estimation diagram A(8) - Fig. 1, it is possible to determine the values for grinding and cutting on the apparatus under consideration, i.e.:

- grinding (7 m/s² per 60 min.): \( A(8) = 2.5 \text{ m/s}^2 \)
- cutting (7 m/s² per 10 min.): \( A(8) = 0.5 \text{ m/s}^2 \)

Total exposure to vibration will be evaluated by relationship:

\[
A(8) = (A(1)^2 + A(2)^2)^{1/2}
\]

i.e. after entering

\[
A(8) = (2.5^2 + 0.5^2)^{1/2} = (6.25 + 0.25)^{1/2} = 2.55 \text{ m/s}^2
\]

When comparing graph limits, this calculated value of the total vibration exposure resulting from the activity under consideration is just above the action value of 2.55 m/s², i.e., still within an acceptable range but indicating the need for taking measures.

**5. Analysis and experiment evaluation**

The aim of the experimental measurement was to assess whether the indicated values of the transmission of vibration to the hand and arm in the operating instructions comply with the legislative requirements of Directive 2002/44/EEC. The hand-arm vibration transmission measurement was performed using a 4447 vibration analyzer. The instrument meets the technical requirements of EN ISO 8041 and allows measurement according to the following standards:

- ISO 5349 Hand-arm vibrations,
- ISO 2631 Whole-body vibrations.

Vibrations were measured on three selected devices that were used in selected work activities where measured vibrations were evaluated and and it was determined whether the values were exceeded according to the standard and according to the relevant operating instructions being a part of each device.

Vibration values (measured and values mentioned in the operating instructions) were compared and analyzed by the following methods:

- by software that is a part of the 4447 vibration analyzer,
- by freely available hand-arm vibration evaluation calculator developed by the Health and Safety Executive (HSE), also subject to Directive 2002/44/EEC.

**Measurement No. 1: Jigsaw**

The jigsaw is used to cut wood. With special knives, it is also possible to cut steel, plastic or aluminum.

Specifications of the jigsaw are recorded in Table 2.

**Table 2: Specifications of the device – jigsaw**

<table>
<thead>
<tr>
<th>Performance</th>
<th>Number of strokes</th>
<th>Length of stroke</th>
<th>Inclined position</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>550 W</td>
<td>31 000/min</td>
<td>26 mm</td>
<td>45° on both sides</td>
<td>2.4 kg</td>
</tr>
</tbody>
</table>

Table 3 shows the values recorded in the manuals as well as the values obtained by measuring the vibrations by the analyzer from the device during activity - wood cutting.

**Table 3: Vibration values in manuals and vibration analyzer 4447 - jigsaw**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Vibration value in the device manuals</th>
<th>Vibration value measured by vibration analyzer 4447 at time exposures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood cutting</td>
<td>A(1) = 7.0 m/s²</td>
<td>A(4) = 0.741 m/s²</td>
</tr>
</tbody>
</table>

Vibration measurement on the machinery was performed using vibration analyzer 4447 according to ISO 5349-1: 2001 (ISO 5349-1:2001). The vibration sensor was located on the device's handle. By means of the device, sawing of 2 cm thick wood was carried out. (ISO 5349-2: 2001).

During measurement of vibrations, the limit and action values of vibrations were not exceeded. The measured vibration values obtained from the vibration analyzer match with the HSE hand-arm vibration exposure calculator aimed to evaluation of the hand-arm vibration. Values from activities performed by means of the machine device at time exposure A(1), i.e., 0.714 m/s² and even A(4), i.e., 1.482 m/s² were minimum and did not exceed the set and allowed values. Measured vibration values at 8 hour exposure were 2.096 m/s². With this machine device it is possible to work 8 hours or more because the vibrations should not be exceeded.

By means of the HSE hand-arm vibration exposure calculator, it is possible to compare and find out whether the values in the exposures fall within and do not exceed the action and limit value of vibrations, and also determine how long it is possible to work with the machine in order not to exceed the action and limit values. In this case, on the HSE Calculator (EC Handbook, 2009) (Fig. 2), that the values with this device are not exceeded and meet the action and limit values of the vibrations for a given time exposure. From the measured values, it has been found that with this device, it is possible to work without problems even 8 hours or more.

According to the value mentioned in the operating instructions, it is possible to work with the work equipment for only 1 hour and 1 minute so that the accelerating action is not exceeded and 4 hours and 5 minutes in order not to exceed the limit value.
Grinding with grinding paper. The device specifications can also be used when cutting. This machine can also be used for materials without the need for water. A special protection cover can avoid exceeding the limit value.

The measured vibration value at exposure of 1 hour A(1) was 1.459 m/s². The vibration value at exposure of 4 hours A(4) was 2.918 m/s², which means that the vibration action value, which is 2.5 m/s², was exceeded.

Upon these values, it can be stated that the worker can work with this device for 2 hours and 56 minutes to avoid exceeding the values.

At the vibration value measured for the 8 hour A(8) time exposure is 4.127 m/s² which exceeds the action value.

The vibrations on this machine were measured with a vibration analyzer using a tri-axis sensor. Vibration measurement on the device was done during iron grinding.

Table 5: Vibration values in manuals and vibration analyzer 4447 when grinding with an angle grinder

<table>
<thead>
<tr>
<th>Activity</th>
<th>Vibration value in the device manual</th>
<th>Vibration value measured by vibration analyzer 4447 at time exposures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron grinding</td>
<td>8.0 m/s²</td>
<td>A(1): 1.459 m/s², A(4): 2.918 m/s², A(8): 4.127 m/s²</td>
</tr>
</tbody>
</table>

The value of vibrations at an hour work A(1) was measured as 1.673 m/s². The value did not exceed either the action or limit value.

The value of four-hour A(4) vibrations was 3.347 m/s², and the worker can only work 2 hours and 13 minutes at this value to avoid exceeding the values according to the standard.

At work lasting eight hours A(8), the value of vibrations was 4.734 m/s², exceeding the limit value.

We obtained the measured vibration by means of a hand vibration analyzer 4447 on the machinery, i.e., an impact drill.

Table 7: Vibration values in a handbook and according to vibration analyzer 4447 for drilling in wood with impact

<table>
<thead>
<tr>
<th>Activity</th>
<th>Vibration value in the device manual</th>
<th>Vibration value measured by vibration analyzer 4447 at time exposures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilling in wood with the impact</td>
<td></td>
<td>A(1): 25.3 m/s², A(4): 1.673 m/s², A(8): 3.347 m/s², A(8): 4.734 m/s²</td>
</tr>
</tbody>
</table>

The measured data in the above mentioned three time exposures can be reassessed using the HSE hand-arm vibration calculator. According to the calculator, the employee can work for 8 hours without exceeding the HSE limit value (Handbook EC, 2009), Fig. 4.

Fig. 3: Measured values when working with an angle grinder

According to the operating instructions, it is only possible to work with the work equipment for 47 minutes, so that the acceleration action value is not exceeded and 3 hours and 8 minutes to avoid exceeding the limit value.

Suggestion of a method for estimation of a risk of hand-arm vibration

For management of risk of vibration transmission, by harmonizing the risks of exposure to vibrations, it is possible to apply a standard matrix of risks, e.g., with use of parameters of prior exposure E (duration of exposure), probability of health hazard caused by exposure to vibrations resulting from work activities P and impacts D, see the Tab. 8. (Pačaiová, 2014)

Measurement No.3: Impact drill

The impact drill is used for drilling in various types of materials. It can be drilled in wood, iron, concrete or steel. The device specifications are listed in Table 6.

Table 6: Specifications of the device – impact drill

<table>
<thead>
<tr>
<th>Weight</th>
<th>Performance</th>
<th>Idle speed</th>
<th>Without impact</th>
<th>Maximum chuck capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6 kg</td>
<td>701 W</td>
<td>0.2800 min⁻¹</td>
<td>0.4700 min⁻¹</td>
<td>13 mm</td>
</tr>
</tbody>
</table>

Fig. 4: Measured values when working with an impact drill

According to the operating instructions, it is possible to work with the work equipment only 5 minutes in order not to exceed the acceleration action value and 19 minutes in order not to exceed the limit value.

The measured vibration value at exposure of 1 hour A(1) was 1.569 m/s². The value did not exceed either the action or limit value.

The value of four-hour A(4) vibrations was 3.347 m/s², and the worker can only work 2 hours and 13 minutes at this value to avoid exceeding the values according to the standard.

The measured vibration at exposure of 8 hours A(8) was 4.734 m/s², exceeding the limit value.

The measured data in the above mentioned three time exposures can be reassessed using the HSE hand-arm vibration calculator. According to the calculator, the employee can work for 8 hours without exceeding the HSE limit value (Handbook EC, 2009), Fig. 4.
Impact vibration exceeded. Operating instructions applies. Damage to the upper limbs due to 89/391/EEC) Based on the assessment, it is possible to conclude also used to assess the risk of hand-arm vibration. (Dierective damage.

It is possible to work with this device max. 4 hours to avoid health results, it can be stated that the measured values are much lower the values mentioned in the operating instructions. Based on the according to the first recommendation, the use of tools with reduced vibrations is the appropriate measure. The problem of excessive vibration is widespread in most industrial plants using hand tools and tools. Excessive vibration interferes to a great extent with the working and living environment of the human being, thus affecting his/her health, physical and mental well-being. Legislation could also be more aware that by targeting vibration exposed workplaces and by thoroughly training workers using hand tools and tools during their working change, many negative effects of excessive vibration would be avoided.

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**Conclusion**

There are several recommendations for minimizing the harmful effects of vibration on the hand-arm system, while effectively combining them according to the type of work:

- replacing hand tools with a type that has a lower vibration level, allowing rest breaks, work device cycling, wearing warm gloves when working in cold environments or anti-vibration gloves, regular tool maintenance, training staff not to hold hand tools too firmly, advise workers to increase blood flow through repeated hand and finger exercises, education of workers and foremen regarding vibration hazard and encouraging them to report signals and symptoms of hand-arm vibration syndrome (HAVS).

According to the first recommendation, the use of tools with reduced vibrations is the appropriate measure. The problem of excessive vibration is widespread in most industrial plants using hand tools and tools. Excessive vibration interferes to a great extent with the working and living environment of the human being, thus affecting his/her health, physical and mental well-being. Legislation could also be more aware that by targeting vibration exposed workplaces and by thoroughly training workers using hand tools and tools during their working change, many negative effects of excessive vibration would be avoided.

**References**


**Table 8: Suggestion of a method for estimation of risk of hand-arm vibrations (Pačaiová, 2014)**

<table>
<thead>
<tr>
<th>Angle grinder (iron grinding)</th>
<th>8 (in the operating instructions)</th>
<th>47 minutes</th>
<th>3 hours 8 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact drill (drilling in wood with impact)</td>
<td>5.127 (measured values)</td>
<td>Limit value exceeded</td>
<td>3 2 2 10</td>
</tr>
<tr>
<td>Impact drill (drilling in wood with impact)</td>
<td>25.3 (in the operating instructions)</td>
<td>5 minutes</td>
<td>2 3 3 15</td>
</tr>
<tr>
<td>Impact drill (drilling in wood with impact)</td>
<td>4.734 (measured values)</td>
<td>Limit value exceeded</td>
<td>3 2 2 10</td>
</tr>
</tbody>
</table>

**Table 9: Application of the method for estimating the risk of the hand-arm vibration**

<table>
<thead>
<tr>
<th>Device</th>
<th>a_x (m/s^2)</th>
<th>Action value ([a_{x,max}])</th>
<th>Limit value ([a_{x,lim}])</th>
<th>Exposure</th>
<th>Probability</th>
<th>Impact</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jigsaw (wood sawing)</td>
<td>2.096 (measured values)</td>
<td>Limit and action values not exceeded</td>
<td>3 2 2 10</td>
<td>3 2 3 12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 8: Application of the method for estimating the risk of the hand-arm vibration**

<table>
<thead>
<tr>
<th>Impact (D)</th>
<th>Risk value (E+P) x D</th>
<th>Risk management</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – slight damage</td>
<td>2 to 3</td>
<td>4 to 6</td>
</tr>
<tr>
<td>2 – low risk, if (A(8)&lt;5) m/s^2, no measures are needed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 – serious damage</td>
<td>4 to 6</td>
<td>8 to 10</td>
</tr>
<tr>
<td>3 – high risk, if (A(8)&gt;5) m/s^2, it is necessary to take technical or organizational measures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 – very serious damage</td>
<td>8 to 10</td>
<td>12 to 5</td>
</tr>
<tr>
<td>10 – very high risk, if (A(8)&gt;5) m/s^2, it is necessary to take immediate measures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 – unlikely</td>
<td>2 – possible</td>
<td>3 – sure</td>
</tr>
<tr>
<td>1 – short-term (up to 20 min.)</td>
<td>2 average (from 20 to 60 min.)</td>
<td>3 – long-term Exposure (E)</td>
</tr>
</tbody>
</table>

Table 9 shows the vibration values mentioned in the operating instructions as well as the vibration values measured by the vibration analyzer. At recalculation to an 8-hour exposure, a freely available HSE calculator was used. The values mentioned in the operating instructions were recalculated to show how long it is possible to work with the device when calculated with the values mentioned in the operating instructions. Based on the results, it can be stated that the measured values are much lower than those mentioned in the operating instruction for the device. According to the measured values, the vibration action values would be exceeded only in case of working with an impact drill so it is possible to work with this device max. 4 hours to avoid health damage.

The proposed method, based on Directive 89/391/EEC, was also used to assess the risk of hand-arm vibration. (Directive 89/391/EEC) Based on the assessment, it is possible to conclude that the high risk is in the case of working with an angle grinder as well as with an impact drill if the vibration value mentioned in the operating instructions applies. Damage to the upper limbs due to vibration may occur in these cases even if the time exposure is not exceeded.

To calculate the exposure time, the available HSE calculator was used. The values mentioned in the operating instructions as well as the vibration values measured by the vibration analyzer. At recalculation to an 8-hour exposure, a freely available HSE calculator was used. The values mentioned in the operating instructions were recalculated to show how long it is possible to work with the device when calculated with the values mentioned in the operating instructions. Based on the results, it can be stated that the measured values are much lower than those mentioned in the operating instruction for the device. According to the measured values, the vibration action values would be exceeded only in case of working with an impact drill so it is possible to work with this device max. 4 hours to avoid health damage.

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<tr>
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<th>a_x (m/s^2)</th>
<th>Action value ([a_{x,max}])</th>
<th>Limit value ([a_{x,lim}])</th>
<th>Exposure</th>
<th>Probability</th>
<th>Impact</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jigsaw (wood sawing)</td>
<td>7 (in the operating instructions)</td>
<td>1 hour 1 minute</td>
<td>4 hours 5 minutes</td>
<td>2 2 3 12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jigsaw (wood sawing)</td>
<td>2.096 (measured values)</td>
<td>Limit and action values not exceeded</td>
<td>3 2 2 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>