IMPROVED METHODS OF ASSESSMENT OF VIBRATION RISK

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Abstract

Measurement methods described in ISO 5349-1 and ISO 5349-2 are subject to a high level of uncertainty (±20% to 40%). The only right solution to decrease the level of this uncertainty is the use of daily vibration exposure meters (DVEM). Similar to noise dosimeters, daily vibration exposure meters must be small enough to be worn and must not interfere with normal working activities. The development of such small devices became possible thanks to new technologies of MEMS accelerometers which have many advantages including shock resistance, no DC-shift effect, very low power and frequency response down to DC. The introduction of MEMS breaks the technological barrier of weight and dimension and additionally reduces the cost of the complete system dramatically.

ISO 5349-2 mentions that contact force measurement should be used to detect when the worker's hands first make contact to the vibrating surface and also when contact is broken. With the development of the new very small MEMS sensors it became possible to locate the force sensor right next to the vibration accelerometer. This solution allows the user to automatically obtain information about the period while the hand is in contact with the vibrating surface and to evaluate the total contact time per day.

1. Introduction

1.1. Characteristics of hand-arm vibration

Mechanical vibration signals are usually complex and may be the result of the construction of the device, structural defects or its usage. During human contact with the surface of the vibrating machine, mechanical vibrations are transmitted directly to the human body, affecting the individual tissues or even the whole body. Vibration that affects humans is called human vibration and is divided into whole-body and hand-arm vibration.

In practice, the most dangerous are hand-arm vibrations which can cause pathological changes in the nervous, vascular (cardiovascular) and osteoarticular system. Hand-arm vibration occurs when one or both of the upper limbs is in contact with a vibrating surface. Typical sources of such vibration are any kind of hand tools that generate vibration, steering wheels and levers to control vehicles. The characteristic feature of hand-arm vibration is their **variability in time** (Griffin, 1990). Therefore, very often, measurement results depend on the point in time that measurement takes place. This is a very important feature that defines both the test methods and measurements describing this kind of vibration. This variability in time influences another significant factor in determining the body's response to the vibration which is the exposure time (duration of exposure to vibration).

1.2. White fingers disease

Changes in the human body resulting from contact with mechanical vibrations are recognized as an occupational disease called “vibration syndrome” (or “vibration disease”). The most frequent form of vibration disease is caused by hand-arm vibrations and occurs in a form of vascular disorder characterized by low blood circulation in the fingers (Kolarzyk, 2008). The symptoms manifest by the fading fingertips of one or more fingers, commonly named as “white finger disease”. Nowadays, medicine still cannot cure white finger disease so treatment of this syndrome is symptomatic. Therefore, the only effective way to avoid vibration disease is by prevention. The obligation of the protection of workers has been given to employers who often have problems with finding an effective way to fulfil this duty. This is because the common methods of prevention such as rotation of workers at hazardous tasks or changing the power tools are often not possible due to a lack of workforce or limits in the budget. Neither do anti-vibration gloves solve this problem as there is no way to measure their real efficiency in the field. For these serious reasons, a **more effective way of prevention is expected and awaited**.

Photo 1 White fingers caused by vibration disease

1.3. Human vibration meters

Currently measurements are made using vibration level meters often called 'vibration dose meters' equipped with vibration acceleration sensors. Not every vibration meter is suitable for measuring the vibration affecting humans, which is why the ISO 8041 helps in the selection process defining the parameters of a human vibration meter. According to ISO 8041, the meter should meet certain minimum requirements including:

- displaying the weighted averaged acceleration values for the period of measurement,
- displaying band-limited averaged acceleration values for the period of measurement,

- displaying the time of measurement,
- the option of entering the sensitivity of the sensor,
- the option of measurement of peak values,
- measurement with one of the frequency-weighting filters (Wb, Wc, Wd, We, Wf, Wh, Wj, Wk, Wm),
- required measurement ranges,
- linearity error in the measurement range is not greater than 6%,
- display of distortion – exceedance of the measuring range (overload).

In practice, the majority of human vibration meters use piezoelectric accelerometers whose operation is based on the fact that mechanical stresses in the piezoelectric material cause an electric charge on its walls which are proportional to the acceleration acting on it. Unfortunately, major drawbacks of piezoelectric sensors include their **fragility**, **high price** and **DC-shift effect** problems. Exposing piezoelectric transducers to very high accelerations at high frequencies, for example on percussive tools having no damping system, can cause the generation of DC-shift, where the vibration signal is distorted such that a false low-frequency component appears in the vibration signal. The DC shift distortion occurs in the transducer and is due to excitation of transients which are too large for the transducer, overloading the piezoelectric system mechanically. For this reason any measurements showing signs of DC-shift should be disregarded (according to ISO 5349-2).

Disadvantages of piezoelectric accelerometers have created a barrier for the development of measurement methods and made them difficult and expensive causing exceptions in vibration law enforcement such as the use of clocks (tool timers) instead of human vibration meters.

1.4. SV107 the MEMS vibration sensor

In recent years accelerometers based on MEMS technology (Micro Electro-Mechanical Systems) became an alternative to piezoelectric sensors. MEMS transducers are widely used in micro-mechanical systems in the automotive, computer and audio-visual industries. Construction of MEMS is a moving mass of resistant boards, placed on a mechanical suspension system frame of reference. As a result of movement (such as vibration) there is a change in the capacitance between the moving and the fixed plates (which form capacitors).

The advantage of MEMS is that their dimensions that can vary from a few microns to millimetres which makes them a milestone in miniaturization. The list of the advantages of MEMS-based sensors is long and includes **low cost**, low power consumption, small size, **resistance to mechanical shocks**, full electromagnetic compatibility and **no DC-shift effect**.

The appearance of MEMS accelerometers broke the barrier created by piezoelectric accelerometers in hand-arm vibration measurements. First of all, it reduced the cost of the complete system. Secondly, their small size allowed them to be attached to human hands without any distraction to the performance of everyday activities even underneath anti-vibration gloves, therefore giving the true results of vibration exposure. Additionally, their size brought the opportunity to install a force sensor next to the accelerometer which enabled measurement of the contact force simultaneously to tri-axial acceleration assessment. This gives a strong basis for the creation of improved methods of hand-arm vibration assessment and new hand-arm vibration measurement standards.

Photo 2 Hand-arm vibration adapter with tri-axial MEMS sensor installed

1.5. Summary of the hand-arm vibration measurement technique according to ISO 5349

The fundamental parameter used in the evaluation of hand-arm vibration is the vector sum of tri-axial vibration called AEQ which is the basis for the calculation of daily exposure A(8). To identify the daily exposure it is necessary to identify all the sources of vibration, which means identifying all working modes of tools (e.g. drilling with hammer and without), and changes in the conditions of use of the device. This information is necessary for the proper organization of measurement and to include as many common tasks of the operator during which he is exposed to hand-arm vibration. Daily exposure should be calculated for each source of vibration.

After determining the sources of mechanical vibrations affecting the employee, the next step is to choose the most appropriate accelerometer mounting. According to ISO 5349, hand-arm vibration should be measured in place, or at the point of contact with the hand tool. The best location is the centre of the handle which is the most representative location. ISO 5349 suggests using lightweight sensors to reduce measurement errors. Measurements directly at the hand are performed using special adapters and measurement in all three axes is recommended.

Typical vibration exposure consists of short periods in which the operator is in contact with the tool. Measuring time should include a representative tool operation time and the measurement should **start from the moment the vibrating device is touched and should end when the contact is broken or the vibration stops** (ISO 5349-2:2001).

1.6. ISO 5349-2 about improved methods for the assessment of vibration risk

The evaluation of vibration exposure as described in ISO 5349-1 is solely based on the measurement of vibration magnitude at the grip zones or handles and exposure times. Additional factors, such as gripping and feed forces applied by the operator, the posture of the hand and arm, the direction of the vibration and the environmental conditions, etc. are not taken into consideration. ISO 5349-2, being an application of ISO 5349-1, does not define guidance to evaluate these additional factors. However, it is recognized that reporting of all relevant information is **important for the development of improved methods for the assessment of vibration risk** (ISO 5349-2:2001).

2. Testing object and measurement performance

2.1. SV 103 Personal Hand-Arm Vibration Exposure Level Meter

The study has been performed with the **SV 103** (Svantek Sp. Z o.o., 2014), SVANTEK's new vibration exposure level meter that meets ISO 8041:2005 and is designed to perform measurements in accordance to ISO 5349-1 and ISO 5349-2 with special adapters mounted on the operator's hand. Inside the hand adapter is the latest MEMS accelerometer and a contact force sensor.

Photo 3 SV 103 Hand-arm Vibration Exposure Meter

Contact forces act between the hand and the vibrating surface: the push/pull force and the gripping force. The need of simultaneous assessment of the contact forces and vibration magnitudes has been universally recognized and reflected in ISO 15230.

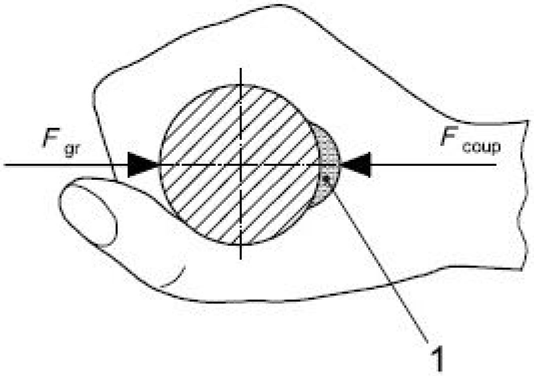


Figure 1 Examples of contact forces measurement given by ISO 15230

Both acceleration and contact force values are displayed clearly on the OLED screen which has very good visibility and contrast. During the measurement instrument was powered from its rechargeable batteries. The SV 103 was attached to the arm of the operator and the accelerometer was mounted on the hand. The cable was secured with a mounting band on the wrist not interfering with working activities.

2.2. The measurement task

The task was to drill four holes in a reinforced concrete block and this was performed by 3 operators. Each operator drilled first two holes without gloves and then two holes with ISO 10819:1996 certified anti-vibration gloves on. The task was performed with the hammer function of the drill enabled (a model DeWALT D25103 with a manufacturer stated vibration amplitude of 9.2 ms^{-2} in accordance to IEC 60745).

Photo 4 Typical mounting of SV 103 vibration exposure level meter on an operator's arm

3. Measurement results

3.1. Exposure time and daily exposure A(8)

The SV 103 vibration exposure level meter recorded the time history of the AEQ vector expressed in ms^{-2} and Contact Force expressed in Newtons (N) with logging step of 200 ms for each of the 3 tasks (Figures 2, 3, 4).The data was further analysed with SVANTEK's Supervisor software (Svantek Sp Z o.o., 2014).

Using tools provided by the software, the time history of contact force values was used to determine the time of exposure of the operators to mechanical vibrations from the drill.

Depending on the contact force values the following results have been obtained:

Operator	Force threshold N	Exposure time mm:ss	Vector AEQ ms^{-2}	A(8) ms^{-2}	Force Aver N
1	10	01:41	7.590	0.45	65.3
	20	01:31	7.963	0.45	70.9
2	10	02:23	8.659	0.61	93.7
	20	02:10	9.023	0.61	101.5
3	10	03:46	8.193	0.73	22.6
	20	01:43	9.246	0.55	29.5

Table 1 Measurement results for 3 tasks

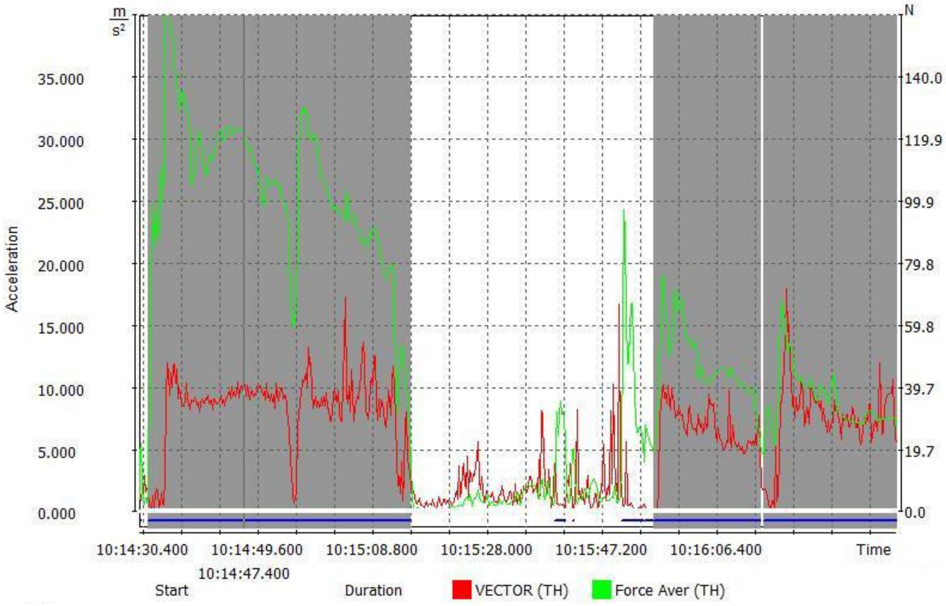


Figure 2 Time history of AEQ vector and Force (Operator 1)

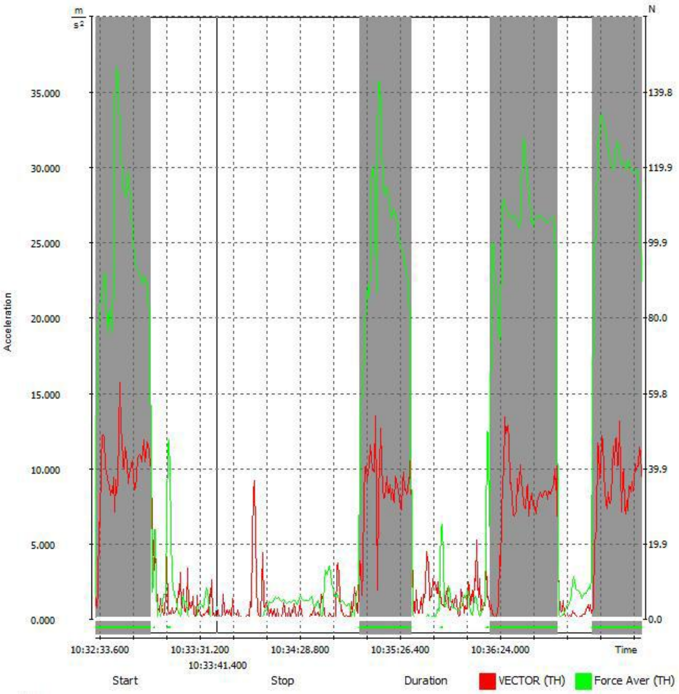


Figure 3 Time history of AEQ vector and Force (Operator 2)

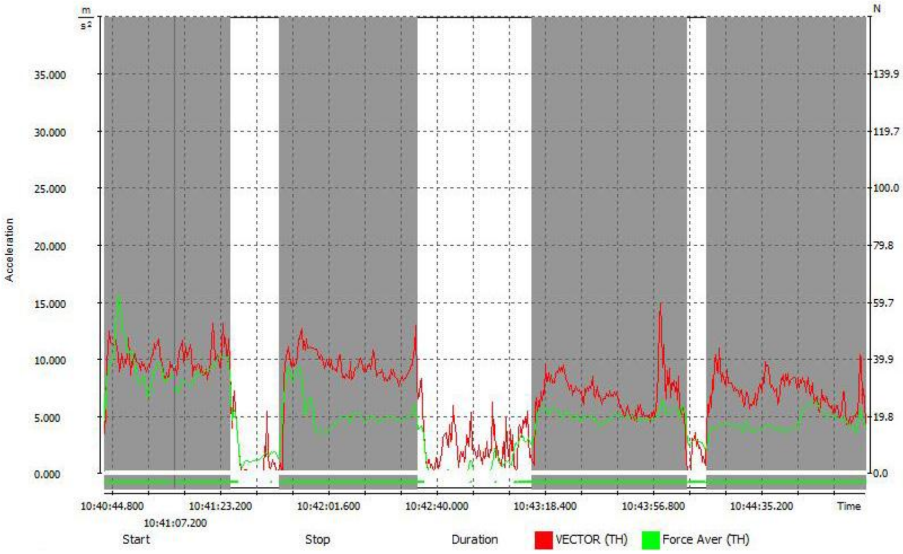
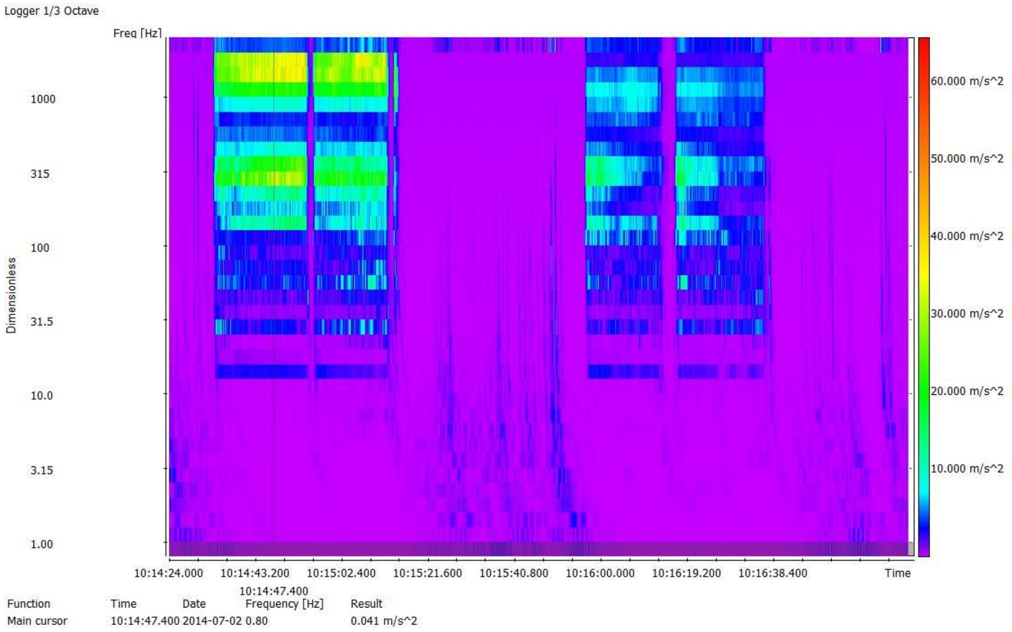


Figure 4 Time history of AEQ vector and Force (Operator 3)

3.2. Verification of exposure time with 1/3 octave analysis

Additionally, the 1/3 octave spectrogram was analysed to determine the repeatability of the frequency contents for the selected exposure times for each operator (Figures 5, 6, 7).



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Function      Time         Date       Frequency [Hz]   Result
Main cursor   10:14:47.400 2014-07-02 0.80             0.041 m/s^2
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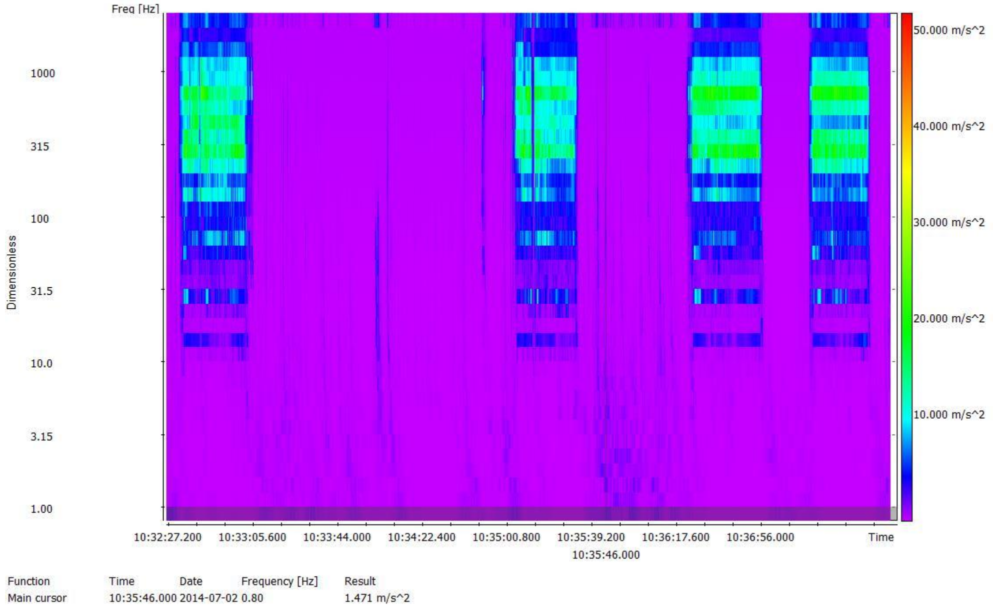
Figure 5 Spectrogram of 1/3 octave (Operator 1)



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Function      Time         Date       Frequency [Hz]   Result
Main cursor   10:35:46.000 2014-07-02 0.80             1.471 m/s^2
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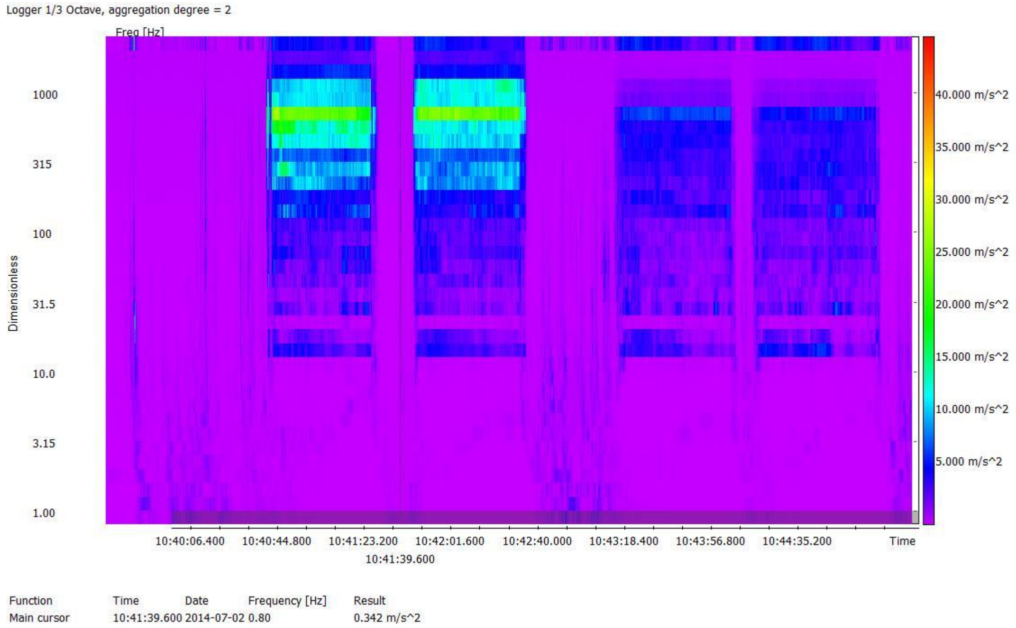
Figure 6 Spectrogram of 1/3 octave (Operator 2)



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Function      Time         Date       Frequency [Hz]   Result
Main cursor   10:41:39.600 2014-07-02 0.80             0.342 m/s^2
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Figure 7 Spectrogram of 1/3 octave (Operator 3)

4. Conclusions

The average contact force data analysis showed that Operator 2 used the biggest force whilst Operator 3 used the smallest amount of force when performing the task (Table 1). It is worth noting at this point that each operator’s posture was different – especially Operator 2, who leaned on the tool. This effect has been characterized in the Technical Report CEN/TR 16391:2012, which says: "Awkward and strained postures will tend to result in higher than necessary coupling-forces between the hand and the handle of the machine".

For each operator the daily exposure A(8) values were calculated based on exposure time indicated by the contact force thresholds. As per ISO 5349-2, short periods where the force values exceeded the threshold for less than 8 seconds were excluded from the calculation.

For operators 1 and 2 the threshold of 20 N appeared sufficient to determine exposure times but in the case of Operator 3 the force threshold of 20 N appeared too high as the time period excluded large amounts of the sample. The selection of a 10 N threshold appeared to be correct in this case. Based on this phenomenon the relation between average contact force and the contact force threshold has been revealed. According to the study, the value of the contact force threshold should be set significantly lower than the average value for the considered time period.

Results of A(8) for each operator show the relation between contact force values and vibration magnitudes and therefore contact force should be taken into consideration when evaluating the daily exposure.

The analysis of the 1/3 octave spectrogram proved selection of exposure times to be correct and additionally helped to evaluate the efficiency of anti-vibration gloves usage. The spectrogram clearly showed 4 activities for all operators, however the spectrum for Operators 1 and 3 contained lesser values on higher frequencies for the last two drills resulting from the use of anti-vibration gloves. The spectrogram for Operator 2 (Figure 6) showed all holes drilled at a similar frequency content despite the use of anti-vibration gloves. These results show that an increase of contact force may reduce the efficiency of anti-vibration gloves significantly.

5. Summary

Improved methods of hand-arm vibration exposure measurement have been defined by ISO 5349 as the ones using additional factors such as contact force in order to decrease the uncertainty of exposure time.

At the time the ISO standard was written it was practically impossible to perform force measurements together with tri-axial vibration measurements due to hardware limitations.

Contemporary, very small force transducers can be fitted right next to the MEMS-technology-based vibration accelerometer in a form of hand-arm adapter as specified by ISO 5349-2 and ISO 10819. With such an effective solution it became possible to perform continuous measurements through the whole working day which decreases the uncertainty of the sample limitation. The time-history of contact force values proved important in determining the true exposure time by simple selection of the force threshold level and this was backed up by the analysis of spectrograms.

For example, usage of the adapters in accordance to ISO 10819 allowed us to compare vibration results with and without anti-vibration gloves. Although the efficiency of anti-vibration gloves usage is not the topic of this study, the reduction of their efficiency at higher contact force values has been revealed.

Taking into account all these advantages and the new scope for possibilities, this improved method of hand-arm vibration measurement using the contact force detection is a milestone in hand-arm vibration measurements.

Simultaneous measurement of coupling forces and vibration is necessary because different coupling forces applied by operators on handheld vibrating tools influence differently the stage of transmission of vibration in the upper limbs. Coupling forces modify exposure to vibration and the health effects it causes. Moreover, the synergic impact of force and vibration on the cardiovascular system, nervous system and the joints and muscles should be considered (J.Malinowska-Borowska, 2012). Therefore, it is clear that **future evaluation of the occupational exposure limits for vibration, should also consider coupling forces exerted on vibrating tools.**

6. References

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