Consideration of standardisation requirements for "vibration dosemeters"

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Abstract

Since International Standard ISO 8041 [1] was revised in 2005 new instruments have come onto the market that challenge the definition of vibration instrumentation that is provided by the standard. There are, for example, instruments with no direct display of results, with measurement controlled and displayed via short-range wireless and using low-cost micro-electro-mechanical systems (MEMS) transducers. The novel systems are available as both hand-arm and whole-body vibration measurement products. For hand-arm vibration there are devices that fit into or onto the hands of machine operators, or on machine handles that log vibration exposures. For whole-body vibration, seat-cushion accelerometers incorporate vibration-logging capabilities within the transducer.

The market for vibration measurement has also changed since 2005. Prior to 2005, most instruments available on the market were aimed at researchers or vibration specialists. For this market, precision and reliability of measurement is important. Today products are being sold for routine monitoring of vibration exposures; for this market there may be a reduced need for accurate measurement.

Can ISO 8041 be amended to provide flexibility to allow innovative instruments? Is there now a need to define a separate category of instruments called "vibration dosemeters", or are more fundamental changes required in our measurement standards ISO 5349-1 [2] and ISO 2631-1 [3] to allow for certain types of alternative measurement? This paper discusses the need for change in vibration instrumentation standards to account for the features being incorporated into modern instruments.

1 Background

ISO 8041:2005 provides a specification for vibration instrumentation for measuring human response to vibration. When this standard was developed the types of vibration instrumentation available could be put into two categories:

1. Multipart instruments – consisting of various separate elements such as pre-amplifiers, frequency analysers, post processors and display units, often used in research or specialist laboratories.
2. Single hand-held, portable instruments – dedicated processors for human-response to vibration measurement, complete with pre-amplification, frequency weighting and display.

ISO 8041:2005 allowed both categories of instrument; requiring the same level of specification for both. At that time the development of ISO 8041 was constrained by ISO 2631-1:1997 which defined tolerances on the frequency weightings for whole-body vibration. This meant that there was no means by which ISO 8041 could define lower specification instruments (for example type I and type II), since the basic signal processing required for achieving the required frequency weighting tolerances was a challenge that should not, or could not, be handled by low-specification instrumentation. In the recent 2010 amendment to ISO 2631-1 the tolerances specifications were replaced with a reference to ISO 8041.

Since ISO 8041:2005 was produced, new instruments have become available, that are likely to be used for "survey" style measurement and monitoring. They might have one or more of a range of features that were not allowed for in ISO 8041:2005, such as:

- No display of vibration magnitudes (results are downloaded for viewing on a dedicated reader or PC)
- Control and display of data via short-range wireless communication (bluetooth)
- Low-cost MEMS (Micro-Electro-Mechanical Systems) transducers
- Simplified outputs (such as time-averaged vibration total values)

Systems are available across both hand-arm and whole-body vibration measurement products. In hand-arm vibration there are devices that fit into or onto the hands of machine operators, or on machine handles that log vibration exposures. For whole-body vibration, seat-cushion accelerometers incorporate vibration-logging capabilities within the transducer and some monitoring systems are designed to be incorporated into seats.

The market for vibration measurement has also changed since 2005. Prior to 2005, most instruments available on the market were aimed at researchers or vibration specialists. For this market precision and reliability of measurement is important. Today in 2013, products are being sold for routine monitoring of vibration exposures. For this type of monitoring, is there a lower requirement for measurement precision? Do the purchasers of such instruments have lower expectations of measurement precision?

2 Definitions

In ISO 8041, Clause 3.1.15, “Vibration Measuring Instrumentation” is defined as a:

> *“… combination of a vibration transducer, signal processor and display, being any single instrument, or a collection of instruments, which is capable of measuring parameters relating to human response to vibration.”*

This is a very broad definition and may need to be refined if additional instrumentation types are standardised. For example, is there a requirement for a personal vibration exposure meter (PVEM)? Such a meter might be analogous to the personal sound exposure meter (PSEM) defined by IEC 61252:1997 [4] and often referred to informally as a “*noise dosemeter*”. The PVEM might have a definition:

> *Vibration measuring instrumentation, being a combination of a vibration transducer, signal processor and data integration and latching overload indication, capable of being fitted to a worker or vibrating machine in such a way that it measures the vibration exposure accumulated by an individual during a measurement period.*

Formally, for PSEMs, IEC 61252 defines a dose parameter, the sound exposure *E*, measured in units of Pa²hours. While this parameter is a requirement of IEC 61252, it is in practice rarely used, and the alternative basic measures of time-averaged sound level, $L_{\mathrm{Aeq},T}$ and exposure time *T* are used. These values can be extrapolated to provide the daily personal noise exposure estimate, $L_{\mathrm{EP,d}}$ required for comparison with daily exposure action and limit values.

With the exception of a dose parameter, modern vibration meters provide equivalent parameters to those used in PSEMs. Although it is not formally defined, the a_{eq} value is usually available along with a value for the measurement duration. From these two values either the instrument or the user can estimate a daily vibration exposure *A*(8) value.

3 Estimation of daily vibration exposure

It is useful to clarify how the term “estimation” or “estimate” is being used in this discussion. Assessments of daily exposure are regarded as estimates if the value given is not the result of a measurement made over a worker’s full working day. Examples of how estimates are made are:

1. A daily exposure value is extrapolated from vibration measurements made over periods shorter than a full working day, based on assessment (not necessarily measurements) of total daily exposure time.
2. As allowed in the EU Directive on Physical Agents [5] where:
   “*The assessment of the level of exposure may be carried out on the basis of an estimate based on information provided by the manufacturers concerning the level of emission from the work equipment used, and based on the observation of specific work practices or on measurement.”.*

Estimates of daily exposure are not necessarily poor assessments of exposure. The term is used here simply to reflect that the assessment includes some assumptions regarding either exposure levels or exposure times.

4 Tools for estimating daily vibration exposure

The tools used for the process of assessing personal daily exposure to vibration range from calculators (where the user enters predetermined values for exposure time and vibration magnitude) through to full personal exposure meters that measure vibration exposure directly. In between there are a variety of vibration meters and timers that measure one parameter of exposure, but require the user to enter additional data.

It may be useful to have a common understanding of the key elements of the different types of measurement and evaluation tools that are associated with the evaluation of daily vibration exposure.

Table 1 Key elements of systems used for assessing vibration magnitude, exposure time and daily vibration exposure

Name	Definition
Vibration Exposure Calculator	System for calculating daily vibration exposure values based on values of vibration magnitude and exposure duration

Name	Definition
Machine Operation Timer	Device for measuring the time for which a machine is operating (e.g. based on power take up or machine vibration)
Personal Vibration Exposure Timer	Device for measuring the time for which either a hand is in contact with a vibrating machine or the body is in contact with the seat (e.g. using a switch to detect contact times with the vibrating surface)
Human Vibration Indicator	Instrument that measures a vibration value but measurements cannot conform with ISO 5349 and/or ISO 2631 - due to, for example, the transducer position being away from the hand grip or away from the centre of the seat.
Human Vibration Meter	Instrument conforming to ISO 8041 for measuring vibration magnitudes in accordance with ISO 5349 and/or ISO 2631
Personal Human Vibration Exposure Meter (PVEM)	Instrument for measuring daily vibration exposures, based on a measurement that directly determines the vibration exposure of a worker.*
* No assumptions are made at this stage as to whether a PVEM fully meets the requirements of ISO instrumentation or vibration measurement standards. Such an instrument might, for example, make a measurement on the hand of an operator that has been shown to be (within acceptable tolerances) equivalent to a measurement in accordance with ISO 5349-1.	

All daily vibration exposure evaluation systems are broadly based on one or more of the elements in Table 1. For example, most instruments for hand-arm vibration measurement have the facility for estimating daily vibration exposure, by combining the measured acceleration value with a value entered for the exposure time: such meters are a combination of a *Human Vibration Meter* and a *Human Vibration Exposure Calculator*. Table 2 shows some examples of current devices and which elements, or instrument functions they have.

Table 2 Examples of instrument and their key functions (1 Euro coin shown for scale)

Instrument Example	Instrument functions
	☐ Vibration Exposure Calculator ☑ Machine Operation Timer ☐ Personal Vibration Exposure Timer ☐ Human Vibration indicator ☐ Human Vibration Meter ☐ Personal Human Vibration Exposure Meter (PVEM)
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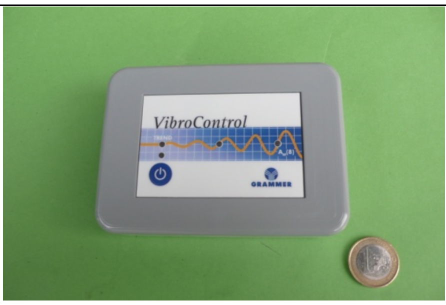
<tr><td>
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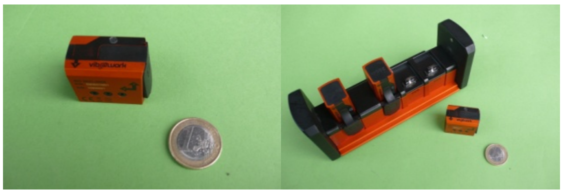	☑ Vibration Exposure Calculator ☑ Machine Operation Timer ☐ Personal Vibration Exposure Timer ☐ Human Vibration indicator ☑ Human Vibration Meter ☑ Personal Human Vibration Exposure Meter (PVEM)
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5 Issues for Standardisation

5.1 What should not be included in vibration standards?

Not all the key elements listed in Table 1 require instrumentation standardisation. If we consider the simple calculation of a vibration exposure value from a vibration exposure time and magnitude; this calculation is defined by a measurement standard (either ISO 5349-1 or ISO 2631-1) and does not require reference to an instrumentation standard.

For the measurement of tool usage time, we have a different problem. There may be a desire to standardise the output of tool timers; for example, it may be useful to distinguish clearly between *Machine Operation Timers* and *Personal Exposure Timers*. However, neither of these timer types measure vibration (even though devices may have the facility for taking an entered value for vibration magnitude and combining it with the measured usage time to report an estimate for daily vibration exposure). For this type of instrument we need to be careful that there is no confusion between timer devices and true vibration measurement devices. It is probably unwise to define an instrument that only measures duration of use or duration of exposure in a standard on vibration measurement devices.

Vibration instrumentation standards should only be applicable to instruments that make measurement of human vibration magnitudes. Additional facilities, as defined in Table 1, may be provided within a *Human Vibration Meter* (for example, where the vibration meter also measures personal exposure time or provides functionality for calculating vibration exposure). Where this is the case, the vibration instrumentation standard may incorporate some definition and test of these additional functions.

5.2 Instrumentation or measurement standard?

The *Personal Vibration Exposure Meter* (PVEM) that directly measures the vibration exposure of a worker may present particular problems for standardisation. In most (if not all) examples currently on the market, the manufacturers are able to conform to most parts of ISO 8041. Certainly the instruments currently available are electronically based on the requirements of ISO 8041, although they may have compromised some aspects of compliance to achieve the required functionality. Usually this compromise has been in the display requirements, which does not affect the instrument's ability to make good quality measurements.

The most significant compromise being made on instruments that might come under the definition of a PVEM, is that of the positioning and mounting of transducers. Both ISO 5349-1 and ISO 2631-1 are very specific about the requirements for the reference point for measurement. For hand-arm vibration ISO 5349-2 [6] recognises the practical difficulties of the defined reference locations and axes and provides practical advice that allows alternative locations to be used. ISO 5349-2 also provides advice on how transducers may be fixed to vibrating surfaces.

In recent years a number of interesting instruments have been produced that do not quite meet the requirements for mounting method or measurement location currently defined in measurement standards. For example:

- Whole-body measurement/monitoring systems permanently fitted to the seat, with the transducer to the side of the seat rather than directly under the driver,
- Hand-arm vibration systems that measure directly under the middle knuckle of the hand, but rely on the hand pressure to hold the transducer against the vibrating surface.

In both cases the instruments can claim to fully conform to ISO 8041, but the measurement is not fully compliant with the relevant measurement standard. In the case of measurement to the side of the seat, the vibration measurement is too remote from the correct measurement position, and these instruments have been categorised as "human vibration indicators" in Table 1 and Table 2.

Measurements of hand-arm vibration made under the palm of the hand, using hand-held transducer mounts are not advised by ISO 5349-2. It may, however, be argued that in many working environments, these measurement systems provide an evaluation of daily vibration exposure that is at least comparable with (if not better than) more traditional methods.

6 Transducer selection

Traditionally researchers have used piezo-electric or piezo-resistive transducers for measurement of human vibration. These devices require separate pre-amplification using dedicated amplifiers before the analysis stage of a measurement. The pre-amplification stage often allows for selectable amplification, giving an adjustable measurement range for the system. "Integrated Electronics Piezo Electric" (IEPE) sensors apply this pre-amplification stage within the transducer package, so there is no user-adjustment of the measurement range of the transducer. These transducers are convenient, as they provide a voltage output that is less susceptible to cable noise and requires less complex signal processing by the vibration meter. However, it is essential that the user select the transducer with the correct measurement range for the application.

One of the big technological changes in recent times, relating to human vibration measurement, has been the development and increased availability of compact, low-cost micro-electro-mechanical systems (MEMS) transducers. Manufacturers have been keen to use these transducers in place of traditional instrumentation transducers to produce lower-cost and more compact measurement systems and MEMS transducers are often the basis for lower-cost systems suitable for routine monitoring.

Like IEPE transducers, MEMS transducers, with their integrated pre-amplifiers, have to be carefully selected for the measurement tasks. Individual MEMS or IEPE transducers may be suitable for human vibration applications. However, transducers selected for general-purpose use may overload when high-level shocks are present in the vibration signal. This type of vibration is most commonly seen with hand-arm vibration measurement on impactive machines, but it can also be an issue with whole-body vibration shocks.

7 Is there a case for a reduced performance specification for PVEMs?

It has been argued that ISO 8041 should define different types of vibration meter, as was the case with the 1990 version of the standard [7]. Different instrument types would give two or more levels of measurement precision. We need to consider whether having a “survey grade” instrument that allows reduced precision is appropriate for PVEMs.

The value in allowing a lower precision instrument is in being able to reduce development and manufacturing costs by reducing the requirement for high-quality signal processing. However, for human vibration measurement, even the basic requirements of measurement present significant challenges to the instrument designer. For example in hand-arm vibration, the raw vibration signal is generally dominated by high-levels of vibration at high-frequencies while the frequency-weighted measurement recorded by the instrument is dependent upon accurate analysis of the lower-level, low-frequency signal components. There is therefore a fundamental requirement for human vibration meters to be able to handle large dynamic ranges, and this requirement is largely independent of meter precision. Modern instruments digitise vibration signals at the input, with signal analyses all software-based; this means that it is the dynamic range challenge that accounts for the major cost element in vibration meter electronics. At the current time, there does not appear to be a strong case for modifying ISO 8041 to allow for different types of meter.

With the transducer and its mounting, the concerns are different. We know that a low-cost MEMS transducer or a general purpose IEPE transducer are both capable of giving reliable results for many types of measurement. However, they are more susceptible to overload than traditional transducers when presented to shock vibration, either from a hand-held power tool or through a seat. Well-designed instruments will flag overloads, but may fail to give a reliable measurement result when overload occurs.

We might therefore apply different types of transducer to the measurement of different severities of vibrations. For example “routine” measurement on rotary machines and some rotary percussive tools might be adequately covered by IEPE or MEMS transducers while for impactive tools non-IEPE piezo-electric transducers are required. Similarly, routine measurement of whole-body vibration on a wide-range of road and off-road vehicles might be performed perfectly well with IEPE or MEMS transducers, but these may not be suitable for environments of very high shock such as small, fast boats.

8 Summary

The real difference between a traditional human vibration meter and those instruments being referred to as "vibration dosemeters" is difficult to define in terms of their respective requirements for signal processing. It is clear that there is a new category of instrument which we can refer to as personal vibration exposure meters (PVEMs). The question is: "Is there a need for new or modified standards for PVEMs?".

It is probably the case that any instrument for measuring vibration must be based on a core set of common specifications, which are already defined in ISO 8041:2005. There is also a strong case for relaxing requirements for some aspects of a vibration instrument that are not essential to an instrument designed to operate as a PVEM, most notably the display requirements. An instrument operating as a PVEM is also providing some functionality that is not a requirement of a traditional ISO 8041 vibration meter, notably the capability to present a measured personal exposure value. These modifications to ISO 8041 might be achieved by developing a part 2 to the standard.

The comparison with noise instrumentation is one we need to be careful about. The history of noise measurement is quite different to that of human vibration measurement and the personal sound exposure meter standard has its roots in a time when there were clear and unambiguous differences between a sound level meter and a noise dosemeter. The differences between modern integrating-averaging sound levels meters and personal sound exposure meters are now more related to how the instrument is used rather than what it measures.

Is the real difference between vibration meters and personal vibration exposure meters a matter of how the meter is used, rather than what is measured? If alternative measurement techniques can be proven to be valid, is it the measurement standards (rather than the instrumentation standards) that need to be modified to accommodate these new measurement techniques?

In many ways the really interesting aspect of "vibration dosemeters" is the innovation that manufacturers are putting into the development of new and exciting vibration measurement devices. While we need to ensure a consistency of measurement through the standardisation process, we do not want to inhibit the development of good, valid alternative measurement systems.

9 Acknowledgements

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10 Disclaimer

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[1] International Organization for Standardization, *ISO 8041:2005 Human response to vibration – Measuring Instrumentation,* ISO, 2005.

[2] International Organization for Standardization, *ISO 5349-1:2001 Mechanical Vibration and Shock – Evaluation of human exposure to hand-transmitted vibration – Part 1 General requirements,* ISO, 2001.

[3] International Organization for Standardization, *ISO 2631:1997/Amd 1:2010 Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration – Part 1: General requirements,* ISO, 1997.

[4] European Committee for Electrochemical Standardization, *EN 61252:1995/Amd 1:2001 Electroacoustics – Specifications for Personal Sound Exposure Meters,* 2001.

[5] European Parliament, Council, “DIRECTIVE 2002/44/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 June 2002 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration) ...,” *OJ L 177, 6.7.2002.*

[6] International Organization for Standardization, *ISO 5349-2:2001 Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration – Part 2: Practical guidance for measurement at the workplace.*

[7] International Organization for Standardization, *ISO 8041:1990 Human response to vibration -- Measuring instrumentation,* ISO 1990.