Shaken or stirred? I'm reviewing the situation to think it out again

By Martin Armstrong

Sound and vibration are two of the physical agents that have been much in the news, mainly in relation to health and safety at work. As a physical agent, affecting humans, any vibration can be characterised in two main groups. As an intermittent or impact (shock) or a continuous vibration (vibration) which may be variable. People recognise and respond in different ways.

Mechanical vibration and shock does not necessarily refer to machinery though most vibrations in the world are man-made. However, earthquakes and wind-induced vibration are environmental sources of mechanical vibration as opposed to acoustic vibrations.

Vibration standards are produced by ISO (International Organisation for Standardization) and given in documents produced by the technical committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*. Currently within TC 108 several working groups cover subjects applicable to the whole field of mechanical vibration, such as WG1-Terminology, WG 23-Vibration and shock isolation, WG24-Condition assessment of structural systems from dynamic response measurements and WG 28-Vibration Materials. A draft international standards (DIS), available for comment at BSI and for voting with a deadline of 29th January 2016, is ISO/DIS 2041:2015, *Mechanical vibration, shock and condition monitoring – Vocabulary*.

The vibration standards portfolio directly impacts the health, well-being and quality of life of the society at large. The standards have many constituencies from users to Government to manufacturers to the general public. It is critical to develop international standards that reflect a balanced approach accounting for the impact on all of our constituencies. The experts on the working groups are very proud of the quality of this portfolio and the procedures in place to guide good practice. A bad standard is worse than none at all and can often reflect the interests of one or two groups at the expense of others. Existing standards that date from the 1990s or even earlier do not necessarily reflect P34

There are several ISO/TC 108 sub-committees which are paralleled by UK National Committees within the British Standards Institution, BS/GME/21:	
SC 2	Measurement and evaluation of mechanical vibration and shock as applied to machines, vehicles, and structures; GME/21/5
SC 3	Use and calibration of shock and vibration measuring instruments; GME/21/2
SC 4	Human exposure to mechanical vibration and shock; GME/21/6 and 3
SC 5	Condition monitoring and diagnostics of machines; GME/21/7
SC 6	Vibration and shock generating systems; GME/21/2.

P32

current methodologies, and it takes time from identifying a project to issuing a standard, often several years. The number of experts available to work on standards is not unlimited. No standard is fit for purpose unless all the terms are fully documented. The starting point for vibration is the standard BS ISO 2041:2009, *Mechanical vibration, shock and condition monitoring - Vocabulary*. This is regularly reviewed as additional parameters and metrics are incorporated in other standards. Vocabulary standards are specific to the work of sub-committee on human response to vibration in BS ISO 5805:1997, *Human exposure - Vocabulary* and condition monitoring in BS ISO 13372:2012, *Condition monitoring and diagnostics of machines - Vocabulary*.

Undoubtedly, of most interest to IOA members are the standards work of SC3 and SC4. This article is an opportunity to provide an update of current standards and with regard to the title to think it out again in reviewing the situation. There are working groups (WGs) actively reviewing existing standards and planning new work items in each sub-committee and members may be assigned to more than one WG.

In many instances international standards are published by BSI with the prefix BS. A standard originating from the European Committee for Standardization (CEN), designated as a European Standard (EN), CEN member countries must comply with the stipulation that the standard is given the status of a national standard. On occasion an international standard may be given a BS number even where it does not fit in with UK practices of measurement. A case being BS ISO 2631-1:1997 +A1:2010 issued by BSI in 2011 where the National Forward states the following, "Technical Committee, GME/21/6, draws attention to the guidance given in BS 6841:1987 (Guide to measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock) that offers clearer and more consistent provisions regarding the evaluation of whole-body vibration with respect to human responses". The publishing by BSI was to meet the requirement of the frequency weightings that are included in the UK Health and Safety Regulations 2005 (Statutory Instrument 2005 No. 1093) whereas BS 6841 specifies Wb for z axis measurements.

As noted earlier, ISO/TC 108 is the technical committee standardizing mechanical vibration. Where there may be a need for a vibration standard within Europe, which is the responsibility of CEN, then a joint committee under the Vienna agreement is set-up with typically ISO taking the lead. The resulting standard is issued by both ISO and CEN (EN ISO).

ISO/TC 108/SC 4, *Human exposure to mechanical vibration and shock*, comprises the following WG's:	
WG 3	Hand transmitted vibration
WG 5	Biodynamic modelling
WG 8	Vibrotactile perception
WG 9	Application of ISO 2631-1 to railway vehicles
WG 12	Evaluation of vibration transmissibility of gloves
WG 13	Evaluation of human exposure to whole-body vibration
WG 14	Posture related to whole-body vibration
WG 16	Revision of ISO 5805:1997, Vocabulary
WG 17	Cold provocation tests
WG 18	Laboratory evaluation of marine seat shock isolation.

ISO/TC 108/SC 3, *Use and calibration of shock and vibration measuring instruments*, comprises the following WGs:	
WG 1	Human response to vibration – Measuring instrumentation
WG 6	Calibration of vibration and shock transducers.

So where to start? First of all to start at the beginning. Traceability to physical vibration is paramount and the standards covered by SC 3/WG 6 provide the traceability for sensitivity and the procedures for documenting other important parameters. The earlier standard series ISO 5347 series, dating from the 1990s, needed a complete overhaul and a new numbering sequence. The ISO 16063 series of standards is concerned with methods for the calibration of vibration and shock transducers under both standard laboratory conditions and in the field. The numbering sequence is Part 1 the basis concepts, Part 1X the primary calibration standards (reference transducers), Part 2X calibration by comparison to a reference transducer (working transducers), Part 3X tertiary parameter (transverse sensitivity, resonance) and Part 4X (seismometers, laser vibrometers and field calibrators).

For a wide range of end users, the ability to perform a calibration check on site before commencing any measurement, the use of a calibrator is important. As opposed to the field of acoustics there is no standard for a 'hand-held' calibrator. A step forward was introduced in Annex A in ISO 8041:2005, with reference frequencies and magnitudes tabulated, and a note directing the calibration of the field calibrator to use the procedure in ISO 16063-21. WG 6 has commenced work on a calibration standard to be designated ISO 16063 Part 44: *Calibration of field vibration calibrators*.

As an observation I have a split opinion as to the on-site "calibration" of a measuring instrument as in general instruments have a calibration certificate which is traceable to a calibration laboratory. This is a subject often debated in standards meetings. An in-situ check or verification is good practice prior to or following a measurement.

Of interest to all is the cost of the periodic calibrations such instrumentation that has prompted the current revision of ISO 8041:2005. This has also brought to the fore the advances in transducer technology where integrated MEMS transducers have become more common in place of piezoelectric transducers. Therefore electrical testing for periodic testing is being supplanted by vibration testing to include the transducer.

This brings me to the work being undertaken by SC 3/WG 1. The revision of ISO 8041 *Human response to vibration – Measuring instrumentation*, mentioned above, is nearing completion with a new Annex to inform users on the expanded uncertainty applicable in a measurement budget.

The next step in SC 3/WG 1 is the development of a standard for what are commonly called dose meters. This standard has the title of *Human response to vibration – Personal vibration exposure meter*, referred to as a PVEM. There will also be a Technical Report (TR) on instrumentation and equipment for assessment of the daily vibration exposure in the workplace, shortly to be registered as a preliminary work item (PWI).

Experience shows that there is a lack of awareness of the measurement uncertainty in the field of vibration measurement. DIN published in August 2015 the specification DIN SPEC 45660-2 *Leitfaden zum - 3 - Umgang mit der Unsicherheit in der Akustik und Schwingungstechnik - Teil 2: Unsicherheit schwingungstechnischer Größen*. It describes the fundamentals of the measurement uncertainty in the field of vibration measurement and gives several examples of how to use it in practice. An English translation *Guide for dealing with uncertainty in acoustics and vibration - Part 2: Uncertainty of vibration quantities* is expected to be published in February 2016.

There will therefore be guidance to consider the overall the uncertainty of the measurement incorporation the uncertainty of the site measurement and the measuring instrument.

In the UK there are few BS standards in vibration measurement, as in general international standards are renumbered. As BSI is a P-Member of ISO/TC 108, there being 19 P-Members around the world, the UK is very involved in the working groups. However, where the required measurement parameter is not included, be it a weighting or a metric, then a British Standard is developed. Such a standard is BS 6472:2008. This is now under revision as the current guidance incorporated had been derived

from historical data where W_g was the weighting used and not enough accumulated experience using the weighting W_b was available in 2008.

As mentioned above, within ISO/TC 108/SC 3/WG 1 a TR is under development to provide clarity regarding the limitations that can be expected when using different instrumentation and equipment for the assessment of daily vibration exposure in the workplace. Differences between instrumentation and equipment features lead to results of varying reliability. By defining guidance and terminology this TR will help the measurement process. Health and Safety Control of Vibration at Work Regulation (Statutory Instrument 2005 No. 1093) sets the exposure limit values and action values for hand-arm and whole-body vibration. There are many routes to arriving at the exposure assessment. There is no clear best practice to cover the different approaches or guidance. Be it by direct measurement on the worker, pattern of work from direct measurement, manufacturers published data with estimated usage or timing the duration of tool operating times (tool timers). Each path brings a different level of uncertainty to the assessment The TR will provide guidance and terminology for instrumentation and equipment for the assessment of daily vibration exposure in the workplace according to the requirements of health and safety.

So far, though not having mentioned it, it is the root mean square (RMS) acceleration in ms^{-2} that is the vibration value documented, either band limited or weighted with band limiting. For human response to vibration this is the case for health and safety at work regulations. However, where vibration has a large crest factor, and comfort is being assessed, then the parameter to be derived is the root mean quad (RMQ) over the period of measurement and recorded as the Vibration Dose Value (VDV) with a value in $ms^{-1.75}$. As noted above, Wb is the appropriate weighting used for comfort, specified in railway applications, fixed guideway transport systems and in the UK for vertical motion. Use BS 6472-1:2008, *Guide to evaluation of human exposure to vibration in buildings, Part 1: Vibration sources other than blasting* for such assessment. This standard is currently under review.

To complete the mechanical vibration picture velocity, directly measured or derived from acceleration, is the parameter mainly used in machinery monitoring. Vibration severity is retained for instruments making repeated measurements for trend monitoring that are not based on modern analogue to digital conversion and numerical calculation of RMS. BS ISO 2954:2012, *Mechanical vibration of rotating and reciprocating machinery -Requirements for instruments for measuring vibration severity* is the standard in this case.

Velocity in the form of Peak Particle Velocity (PPV) is often specified for human response assessment for blasting. However, PPV is also used for other shock type vibrations such as pile driving whilst not being covered by a standard. In fact there is no standard setting out the band limiting frequencies, the band limiting filter characteristics or tolerance limits to ensure consistent measurements. The UK standard for PPV measurements in buildings is BS 6472-2:2008, *Guide to evaluation of human exposure to vibration in buildings, Part 2: Blast-induced vibration*.

As in Fagin's song in *Oliver*, having reviewed the situation, maybe on further consideration I'd better think it out again.

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