Mechanical vibration, guidance, instrumentation, calibration and measurement

In this instrumentation corner article, Martin Armstrong, a founder member of the IOA M&I Committee, discusses mechanical vibration and the human response to it in respect of health, safety and comfort.

By Martin Armstrong

For the past 12 years, the members of the Measurement and Instrumentation (M&I) Group have provided articles for Acoustics Bulletin that looked into interesting corners of many aspects of measurements and instrumentation, and the metrics used in evaluating human exposure to sound and vibration.

From the IOA members page: *The mission of the M&I Group committee is to advance the science of measurement of both sound and vibration and to explain the instrumentation required to achieve this goal, not only to the IOA membership but the wider public as well.*

As shown in the title, this article addresses the subject of vibration, specifically, **mechanical vibration**, not necessarily in the order listed. A short reminder; the international committee for vibration is the ISO Technical Committee No 108, Mechanical vibration, shock and condition monitoring. Here in the UK the BSI committee is GME/21, Mechanical vibration and shock and condition monitoring. There is also CEN, the European Committee for Standardization, which is an association that brings together the national standardisation bodies of 34 European countries, with an agreement on technical cooperation between ISO and CEN (Vienna agreement).

With the current Covid 19 pandemic situation, no face-to-face meetings are taking place, and the latest information issued October from ISO was that virtual only meetings are extended to 31January 2022. For the past two years, the loss of the normal interaction at working groups has hindered the pace of progress. The formation of new working groups covering transducer calibration and human response to vibration instrumentation has left a gap in the wider considerations of mechanical vibration.

In this article, the emphasis is to consider human response to vibration, both for health and safety and comfort. Mechanical vibration measurements, a_h, a_k, a_d and a_b are the time-averaged weighted acceleration values in ms^{-2}. The frequency ranges are 8 Hz to 1000 Hz for HA and 0.5 Hz to 80 Hz for WB. The three orthogonal directions are nowadays measured concurrently, this was not always the case in the past. Values are in general linearly time averaged with the eight hour average, daily working time, used to evaluate compliance with the Health and Safety at Work Directive, see SI 1093:2005. Intermittent or transient vibrations encountered are sources of complaint and of adverse comment, and being non stationary require dose or peak value measurements.

Calibration

Starting at the beginning of the measurement trail, devices for measuring shock and vibration have been described in many ways in documents, e.g. pickups, sensors and probes. In 1996, a resolution was passed in TC 108 that, in future, the term 'transducer' should be used in describing shock and vibration measuring devices. Unfortunately, some companies still use the term 'sensor' in their literature.

At that time, transducer calibration was covered by the ISO 5347 *Calibration of vibration and shock pick-ups series*.
A complete rethink took place with a new ISO 16063 series and over time the earlier series has been replaced though work is still ongoing.

Such standards are periodically under review, which is the case with BS EN ISO 16063-21:2016: *Methods for the calibration of vibration and shock transducers. Part 21: Vibration calibration by comparison to a reference transducer* which incorporated amendment 1.

An amendment 2 was expected to be published in 2021. The total frequency range now extended from 0.1Hz to 20k Hz, more informative text and revised figures showing different configurations. Standard back-to-back, fixture using a transfer transducer and an exciter with built-in transducer.

All 15P member[1] countries voted positive in November 2020 to this amendment 2. However, there were so many comments, many beyond the amendment, that the final text has been delayed. As it is now out of allocated time it could be cancelled and need to be restarted.

It is important in measurements to be able to make *in situ* checks to verify that the instrumentation is performing correctly. There is BS ISO 16063-44:2018 *Methods* P36

for the calibration of vibration and shock transducers. Part 44: Calibration of field vibration calibrators. This is an important standard to provide traceability of a specified reference vibration value at the reference frequency at the measurement point. This document specifies the instrumentation and procedures to be used in performing the calibration of field vibration calibrators (FVCs).This calibration document states: *'It is not applicable to FVCs used for the calibration of transducers. These are covered by ISO 16063 21.'*

Related standards in the 16063 series to be aware of are Part 31:2009: *Testing of transverse vibration sensitivity* and Part 34:2019: *Testing of sensitivity at fixed temperature.* Such transducer data provided by the supplier of the instrumentation is important in evaluating uncertainty budgets in any measurement.

Human response to vibration

Here there are two strands:

1. standardising the parameter to be measured; and as required,
2. standardising the values to be specified and the instrumentation to perform such measurements.

The frequency ranges are listed above as in ISO 5349-1 for hand-arm and in ISO 2631-1 for whole body. There is nothing changed on that front and the instrument standard BS EN ISO 8041-1:2017 *Human response to vibration – Measuring instrumentation, Part 1: General purpose vibration meters* specifies the requirements for pattern evaluation, or validation, periodic verification and *in situ* checks, and the specification of vibration calibrators for *in situ* checks. Prior to, and following a measurement or series of measurements *in situ*, checks act to verify the instrument's basic calibration and functionality. This should not be omitted.

As mentioned, the changes in the structure of the ISO TC 108 subcommittee from 2017 with new Working Groups for calibration and human response to vibration, with the inevitable overlap of time scales, has given rise to anomalies that will need correcting or understanding.

When a complete revision of ISO 8041, to supersede ENV 28041:1993 was undertaken, it was of concern that there was no specification for a field calibrator, unlike in acoustics. When ISO 8041 was published in 2005, it had a normative Annex A, 'Specification for vibration field calibrator'. In this annex calibration within the scope of ISO 16063-21 is the method, at the reference vibration values and frequencies for the relevant application. Now there is a calibration standard, ISO 16063-44:2018 for the FVC. However, it was published after the latest issue of ISO 8041-1:2017 where there is no change to Annex A.

In May, a first edition of ISO 80412: *Human response to vibration - Measuring instrumentation - Part 2: Personal vibration exposure meters (PVEM)* was published. This fits in well with the health and safety hierarchy to give the true working day exposure values. Personal vibration exposure meters as a logging measuring instrument measure over a long period of time (e.g. a whole working shift) and are used unattended, without measurement personnel present, so that the measurements can include artifacts, measurement errors and also periods without vibration.

It specifies two parts allowing for fixed, temporary wired or wireless interface between the vibration input and the display of the measurement. The logging, signal processing and operator detection systems can be split between the two parts. Note: PD CEN ISO/TR 19644:2018 gives guidance on the assessment of daily vibration exposure at the workplace, of different methods employed, according to the requirements of health and safety where the PVEM has a prominent role.

ISO 8041-2:2021 relies on the pattern evaluation, validation and periodic verification tests, as well as the *in situ* checks, specified in ISO 8041-1:2017. Unfortunately, there is no reference to using ISO 16063-44 which was published in 2018 to calibrate the FVC. BSI has not published it as BS EN ISO 8041-2 as the importance of traceable calibration checks in the field needs to be clarified. A national foreword is to be added to address this situation.

Guidance on measurements

Guidance documents, whether as standards, from the Health and Safety Executive or trade institutions are a mixed bag. Care needs to be taken to ensure measurements being used meet a measurement standard.

In what I call 'the first division' are those directly associated with a measurement Standard. An example is BS EN ISO 5349-2: *Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration – Part 2: Practical guidance for measurement at the workplace*. This part of ISO 5349 provides practical guidelines to perform P38

References

[1] Participating members are called P members, as opposed to observing members, who are called O members. Each technical committee has different numbers of countries participating and it is against that number that those voting in favour are equated. For a project to be approved there must be more than 66.66% P members in favour.

measurements correctly and to develop an effective strategy for measurement of hand-transmitted vibration at the workplace.

Another standard, this time covering whole-body comfort assessment, is BS 6472-1:2008 *Guide to evaluation of human exposure to vibrations in buildings – Vibration sources other than blasting.* The measurements are according to ISO 2631-1and ISO 2631-4 with the instrument standard ISO 8041. The parameters are weighted acceleration Wb and Wd and the vibration dose value (VDV).An earlier standard BS 6841:1987is broadly the same. Therefore, any assessment from a measurement has standardisation of the measuring equipment as well as traceability to an accurate calibration at the reference vibration values and frequencies using an FVC.

The next tier could be to use data obtained with instrumentation complying with a Standard, plus other parameters. PR CEN/TR 15350, *Mechanical vibration – Guideline for the assessment of exposure to hand-transmitted vibration* using available information including that provided by manufacturers of machinery is one example. It is based on the requirements and guidance given in EN ISO 5349 1and EN ISO 5349 2 but instead of measuring the vibration magnitudes at the specific workplaces, the methods in this document use existing vibration values from, for instance, the ISO 28927 series on hand-held portable power tools.

To assist in providing advice on safety at work, identifying vibration magnitudes and exposure times using different procedures, the PD CEN ISO/TR 19644:2018 *Human response to vibration. Guidance and terminology for instrumentation and equipment for assessment of daily exposure at the workplace according to the requirements of health and safety* covers different methods employed. The PVEMis an important tool in this regard.

Where a guidance document has a problem is where a parameter to be measured is not fully specified, or more than one objective is being addressed. BS 6472-2:2008: *Guide to evaluation of human exposure to vibration in buildings – Blast-induced vibration* is a case in point. The two normative documents listed are BS 6841and ISO 8041, which are specific to human response to vibration from 0.5 Hz to 80 Hz. The standard specifies peak particle velocity measurements (PPV),not r.m.s or VDV, but over a frequency range from from 4.5 Hz to 250 Hz. So basically, the origins here of the vibration in buildings is a legacy document from BS 7385-2: *Evaluation and measurement for vibration in buildings Part 2. Guide to damage levels from ground borne vibration* and not human response to vibration. BS 7385 gives the lowest frequencies expected as 1Hz and the highest 1000 Hz with a more limited range of 4 Hz to 250 Hz being usually encountered.

Further to this it is generally the use of velocity transducers, or geophones, which are typically used for building damage. They operate above their resonance frequency, which is where the 4.5 Hz comes from as the lowest frequency. In fact, as this is the 3dB damping point accurate measurements commence around an octave above this frequency.

In fact, in many instances, this guidance document is often taken as a measurement document and referred to by equipment manufacturers. Though BS 6472-2 is for blast-induced vibration it is used to cover many transient vibrations such as pile-driving. It is a guidance document and while it refers to BS 6841and ISO 8041 for human response to vibration it needs better guidance on human exposure to vibration in buildings to ensure it is the response of humans to vibrations between 0.5 Hz and 80 Hz being evaluated.

A revised PPV model

Do any of the human response to vibration weightings in ISO 2631 provide the means of converting the acceleration to a velocity? In BS 6472-2 it is stated that the typical range of vibration frequencies for blast-induced vibrations is from 5 Hz to 40 Hz.

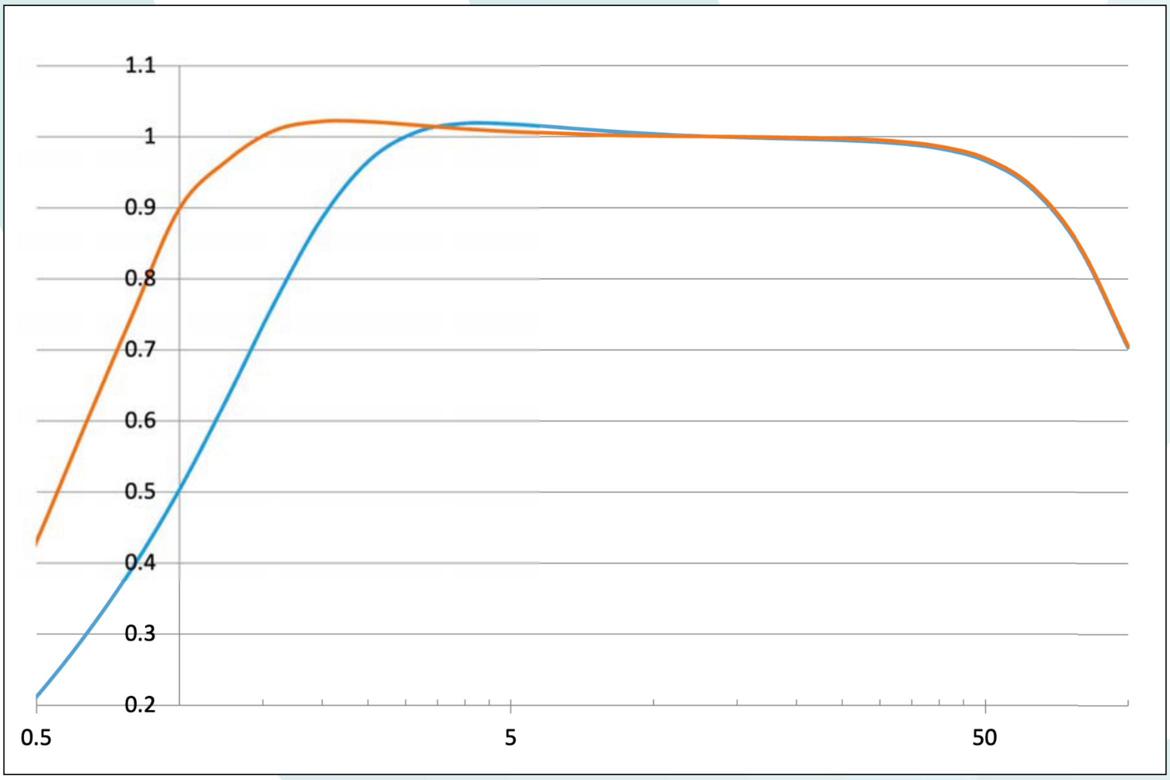
In reality it is possible to measure the human response to vibration with PPV by using an instrument meeting the BS EN ISO 8041-1 standard, selecting the W_d or W_e weightings (see Tables B.3 and B.4) on all three channels, and selecting the term frequency-weighted values 3.1.5.8 – peak vibration value, would measure particle velocity. The resultant displayed value will be in m/s^2 acceleration but velocity weighted.

So where does weighting Wd meet the requirement of integrating the acceleration to velocity? The a-v transition is at 2 Hz, ideal to both meet the requirements of human vibration and velocity in the range for particle velocity. In fact, W_e has an a-v transition at 1Hz and, therefore, could be more suitable but not all instruments incorporate this weighting.

All that is needed is to apply a conversion from the weighted acceleration value instrument display to a velocity value in mm/s. The whole-body vibration at the reference vibration value is $1 m/s^2$ at the reference frequency of 100 rad/s (15.915Hz) which is a velocity of 10 mm/s.

The weighted acceleration factor for W_d, at the reference frequency is 0.1262 and such that a conversion

Table 5 from BS EN ISO 8041-1: velocity response for W_d and W_e weightings for an input vibration



factor of 79.24 results in an error of less than 0.1% when recording the vibration value in mm/s.

In calibrating such an instrument with weighting W_d, according to the Periodic procedure 12.1 in BS EN ISO 8041-1, as required in Table 5 at the 1/3 Octave frequency of 12.5 Hz and 1 m/s² (12.64 mm/s) the calculated value would be 12.65.

The weighted acceleration factor for W_e, at the reference frequency is 0.06288, such that a conversion factor of 159.0 results in an error of less than 0.1% when recording the vibration value in mm/s.

In calibrating such an instrument with weighting W_e, according to the Periodic procedure 12.1 in BS EN ISO 8041-1, as required in Table 5, at the 1/3 Octave frequency of 12.5 Hz and 1 m/s² (12.64 mm/s) the calculated value would be 12.65.

Is it a way forward? Only time will tell though the relevant BSI committee GME/21/6/4 has not yet put forward a proposal to revise BS 6472-2, though there is a proposal to revise BS 6472-1.

Conclusions

A new issue of the transducer calibration standard ISO 16063-21 is unlikely to be published shortly. The problem is that the comments from the committee exceeded the original objective of the Amendment 2. If the work is expanded to the entire document then additional support for a revised project will be required as it is currently flagged as in a critical phase as being out of time.

A national foreword will be incorporated in the publication of BS EN ISO 8041-2. It has been agreed and the BSI publications team should complete this process shortly.

At present, the ISO committee WG33, covering human response to vibration instrumentation, has no project to follow on from ISO 8041-2 and could disband.

About the author:

Martin Armstrong is a founder member of the M&I Committee, been a member of BSI and ISO committees for 30 years and having been retired for 20 years is now retiring a second time.