AN INTRODUCTION TO ISO 8041 HUMAN RESPONSE TO VIBRATION — MEASURING INSTRUMENTATION

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1 INTRODUCTION

In July 2005 the UK introduced the Control of Vibration at Work Regulations (CVWR) 2005 in response to the requirements of European Directive 2002/44/EC. The EU Directive and the CVWR 2005 have produced a growing demand for human vibration measurement and there are now an increasing number of “simple” vibration instruments available on the market.

International Standards ISO 8041 is intended to support the standards defining the human-response to vibration measurement methods, ISO 2631 for whole-body vibration and ISO 5349 for hand-arm vibration. Since 1990, ISO 8041 has provided a base document for human response to vibration instrument manufacturers and most current instruments claim conformance with this standard. However, concerns that ISO 8041 was inadequate for measurement of hand-arm vibration on percussive tools, and a substantial revision of ISO 2631-1 meant that a revision of ISO 8041 was necessary.

The revision of ISO 8041 was issued in 2005. The revision introduces a more thorough and more demanding specification for vibration instruments and defines a full range of pattern evaluation and verification tests.

2 NEED FOR REVISION OF ISO 8041

2.1 Frequency weightings prior to 1997

ISO 2631 has a number of parts for different applications, Up until the revision in 1997; the version we used was ISO 2631/1-1985, which had two frequency “dependencies” (equal sensitivity curves) for vertical and transverse whole-body vibration directions. A further two frequency dependencies were defined in other parts of this standard: ISO 2631-2:1989 and ISO 2631/3-1985.

ISO 5349 was first published in 1986, and defined a single frequency weighting as a straight-line function based on third-octave bands from 6.3 to 1250 Hz.

These four dependencies were rationalised into the five smooth-curved frequency-weightings defined in ISO 8041:1990:
1. Vertical direction (z-axis),
2. Lateral directions (x- and y-axes),
3. Combined vertical and lateral exposure, mainly for building vibration issues where subjects may be either sat/standing or lying (W-B combined),
4. Low-frequency motion, mainly for motion sickness studies.
5. Hand-arm vibration

2.2 Revision of ISO 2631

In 1995 an extensive revision of ISO 2631 part 1 was published. The revision followed the lead provided by an earlier British Standard, BS 6841:1987, and introduced a series of frequency weightings for different types of vibration exposure. The two principal whole-body weightings for z and x/y axes were replaced by the five weightings: Wc, Wd, We, Wj and Wk and the motion sickness weighting Wf was also included in part 1.

In addition, revisions of ISO 2631 part 2 and ISO 2631 part 4 have introduced new weightings Wm for building vibration (to replace the old whole-body combined weighting) and Wb for railway vibration (taken directly from the British Standard BS 6841:1987).

There are now a total of 9 human response frequency weightings shown in Figure 1 (including the hand-arm frequency weighting):

Wb	Vertical whole body vibration, *z*-axis seated, standing or recumbent person, based on ISO 2631-4
Wc	Horizontal whole body vibration, *x*-axis seat back, seated person, based on ISO 2631-1
Wd	Horizontal whole body vibration, *x*- or *y*-axis seated, standing or recumbent person, based on ISO 2631-1
We	Rotational whole body vibration, all directions, seated person, based on ISO 2631-1
Wf	Vertical whole body vibration, *z*-axis motion sickness, seated or standing person, based on ISO 2631-1
Wh	Hand-arm vibration, all directions, based on ISO 5349-1
Wj	Vertical head vibration, *x*-axis recumbent person, based on ISO 2631-1
Wk	Vertical whole body vibration, *z*-axis seated, standing or recumbent person, based on ISO 2631-1
Wm	Whole-body vibration in buildings, all directions, based on ISO 2631-2

The full revision of ISO 8041 needed to consider the new parameters such as vibration dose value (VDV), motion sickness dose value (MSDV), maximum transient vibration value (MTVV) and vibration total value. It also needed to address the other concerns, such as that meters conforming to ISO 8041 might have very limited measurement ranges, seriously affecting their ability to measure hand-arm vibration on percussive tools accurately.

A Standard on instrumentation also needed to deal with electromagnetic compatibility (EMC), measurement uncertainty pattern evaluation, verification and field calibration; all issues that had not been a part of the original version of the standard.

2.3 Revision of ISO 5349

In 2001 a revision of ISO 5439 was published, as ISO 5349-1:2001, alongside a new part 2 document ISO 5349-2:2001 on practical workplace measurement. While this revision did not change the frequency weighting, or the basic measurement method, it did introduce the reporting of a total vibration value, representing the combined vibration magnitude from all three axes. ISO 5349-2 also highlighted the problems of measurement of hand-arm vibration, particularly on percussive machines and the importance of good, rigid, accelerometer mounting systems.

2.4 Objectives for the revision of ISO 8041

The introduction of new frequency weightings in the 1997 revision of ISO 2631, meant that ISO 8041:1990 was out-of-date. As a temporary fix, an amendment to ISO8041:1990 was issued in 1999. However, this amendment only dealt with changes resulting directly from changes to the frequency weightings; other issues needed to await a full revision.

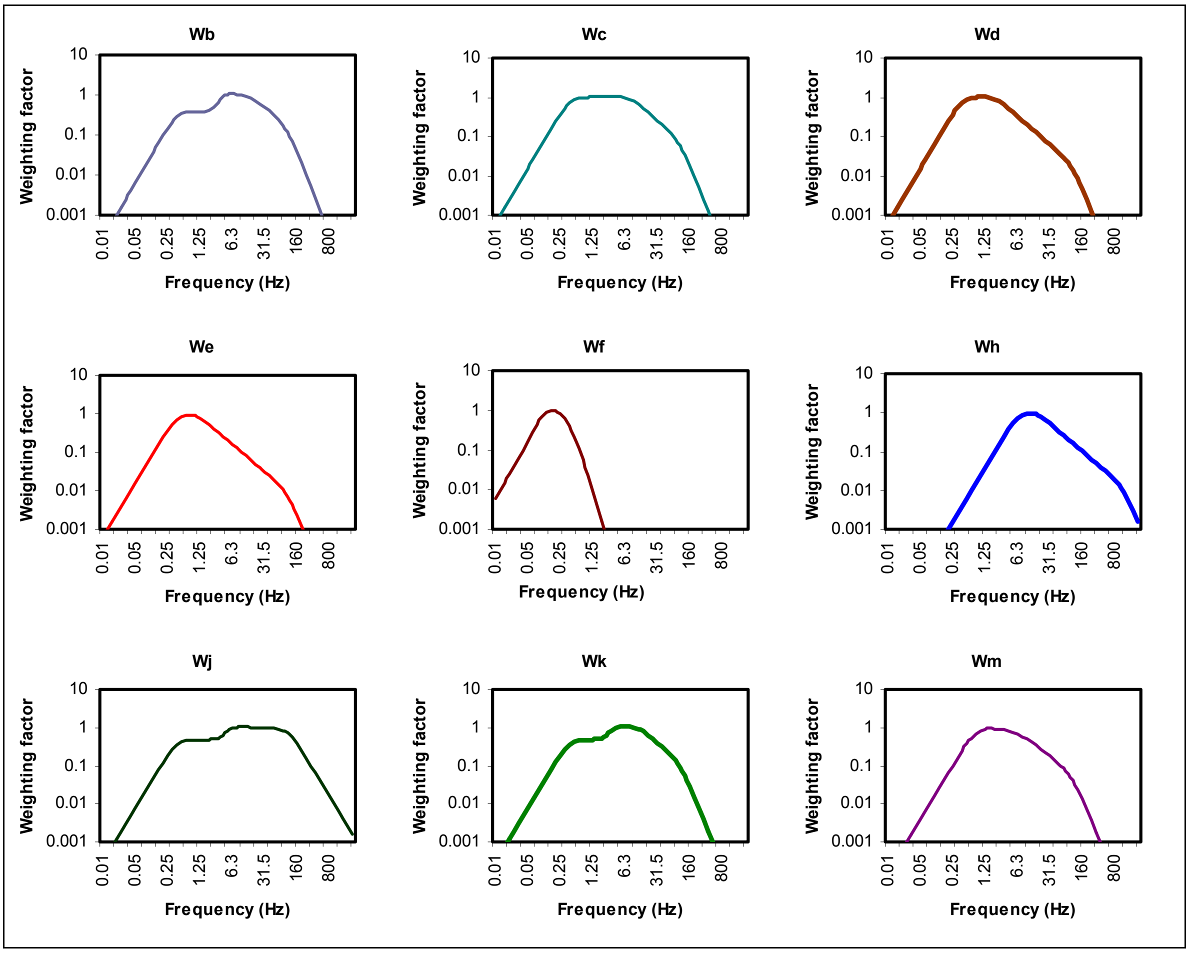

Figure 1 Frequency weightings from ISO 2631-1:1997 and ISO 5349:2001

3 REVISION ISSUES

3.1 Number of instrument classes

ISO 8041:1990 defined two classes of human vibration instrument, type 1 and type 2, with type 1 requiring conformance to a generally tighter specification. The case for having multiple types is based on the assumption that less expensive instrumentation can be constructed that will produce results with slightly higher uncertainties associated with them. However, for human vibration measurement, a greatest potential for very large errors comes from the inability of a meter to handle the large measurement ranges, and for instrument manufactures, the greatest cost element comes from producing a meter that has a large measurement range.

After much discussion, it was agreed that the revision of ISO 8041 would have just one type, with a minimum measurement range that was capable of handling the majority of measurement situations.

3.2 Testing hierarchy

An instrument standard needs to provide a base specification for instruments, and also tests to confirm that the instrument achieves the required specification.

It is essential that an instrument design be confirmed to be capable of meeting the full instrument specification, including environmental tests, EMC tests and detailed measurement performance.

However, full evaluation of an instrument testing is expensive, and is not appropriate for testing of batches of instruments, or for annual or bi-annual calibrations by the instrument user.

The revision of ISO 8041 includes the basic specification for a human-response to vibration instrument, and a hierarchy of 3 levels of testing. The first level is the pattern evaluation; this is the testing required for production instruments, which will demonstrate that an instrument design is capable of meeting the required specification. The second level is intended for routine testing of instruments, and also for one-off instruments (typically of the type constructed by researcher, from combinations of other equipment such as charge-amplifiers, data recorders and frequency analysers or data processors). This second level does not consider aspects such as EMC or environmental testing and has a reduced the number of measurement performance tests. The final level is a field check, to be performed by users before and after sets of measurements, to verify basic functionality and sensitivities.

3.3 Calibrators

As with noise, a portable field human-vibration instrument relies on a field calibrator to check the instrument sensitivities, and to validate that the meter is working correctly. Unlike noise, there is no standard specification for human-vibration instrument field calibrators.

To allow field-testing of instrument, ISO 8041 revision has introduced an informative specification for field calibrators. It is hoped that this specification will develop in future revisions.

3.4 Measurement range

The dynamic range required for hand-arm vibration measurement is potentially very large, and the frequency weighting shape means that it is common to have vibration signals dominated by high-frequency short-duration vibration components, where the lower-frequency components are important contributors to the overall frequency weighted result.

Whole-body vibration is less sensitive to problems of measurement range than hand-arm vibration. However, intermittent shocks often occur in whole-body vibration, and for measures such as MTVV and VDV is its important that these shocks are measured accurately.

ISO 8041:1990 allowed meters with ranges of much less than 40dB to claim conformance with the specification. Such meters are easily overloaded by impulsive signals, and if the sensitivity is reduced, to avoid overload, a lot of important low-frequency information is lost in the instrument's noise floor.

ISO 8041:2005 now requires a measurement range of at least 60dB for both hand-arm and whole-body applications. This requirement is within the capability of modern instruments and will ensure that all instruments are capable of performing good human response to vibration measurements on most machinery types.

3.5 Impulse and phase response

The objective for specification and assessment of performance of a instrument, is to specify only the features and measurement parameters that are required on all instruments of that type and test the instrument using only those required features. Instrument manufacturers may choose to provide additional functionality, but the test standard should not force the inclusion of features purely so that the meter can be tested.

For human vibration meters, one characteristic that is important for some types of measurement, but unfortunately cannot be directly tested using the required measurement parameters and instrument facilities is the phase response.

The majority of human-response to vibration measurements are long-term r.m.s measurements. As such they are relatively insensitive to phase response. However, where the meter is designed to measure parameters such as VDV, peak and MTVV, then the result may be dependent on the phase response.

Figure 2 illustrates the problem. The upper graph shows a fundamental and harmonic signal combined to give a resultant wave form, there is no phase shift between the zero crossing of the fundamental and a zero-crossing of the harmonic signal. The resultant wave has a maximum value close to 1. The lower graph introduces a 45-degree phase shift between the fundamental and its harmonic. In this case, the resultant wave has different shape, and a maximum value well over 1.

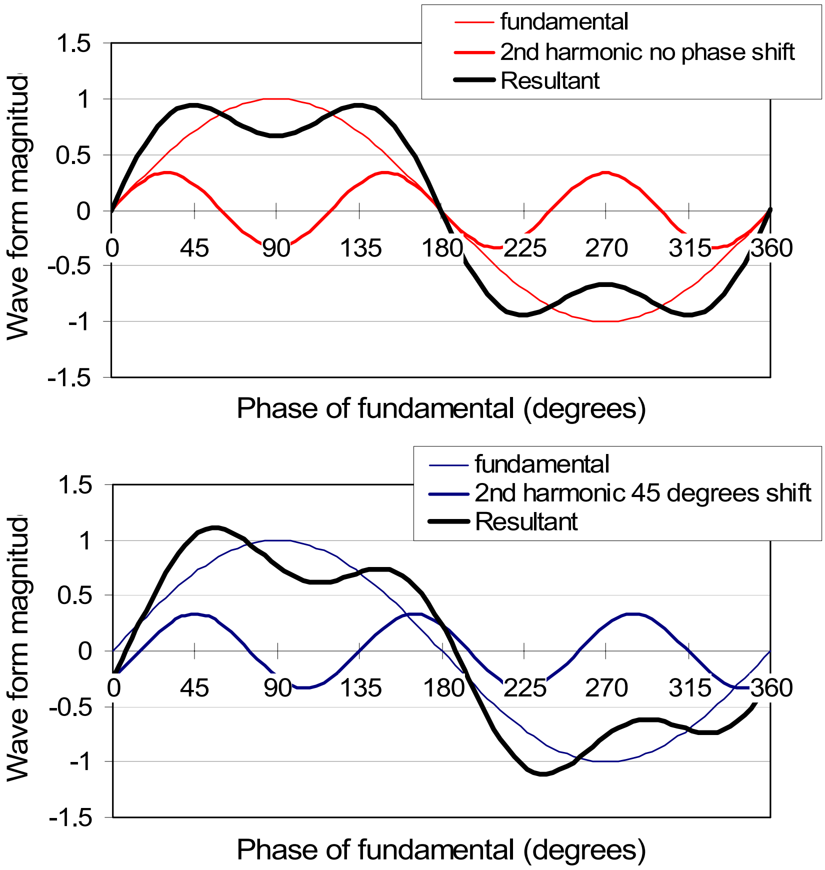

Figure 2 Illustration of phase-shift errors.

While modern instruments can be designed to have very well controlled phase responses, there is a particular problem with human response that results from the severe slopes of the frequency weightings that occur within the main parts of the frequency ranges.

Human-response to vibration frequency weightings are defined by a series of equations, that define both magnitude and phase of the frequency weightings. The weightings are based on simple analogue filter functions, to ensure that they can be easily incorporated into instrumentation. However, modern digital instruments are capable of being designed with any arbitrary phase response, and there is a real possibility that manufacturers might chose to build an instrument with zero phase response (i.e. a filter that does not introduce any phase change across the whole of the human-response frequency range).

Figure 3 shows the magnitude and phase response for the Wk frequency weighting as defined by ISO 2631:1997. As can be seen, the phase changes rapidly as frequency changes, and these changes in phase occur across the entire frequency range. As Figure 2 illustrated, phase response will have an impact on the maximum frequency-weighted values, and consequently on any parameters that are sensitive to these maximum values, such as VDV, MTVV and peak. Any error in the phase response will introduce errors in measurement of these parameters.

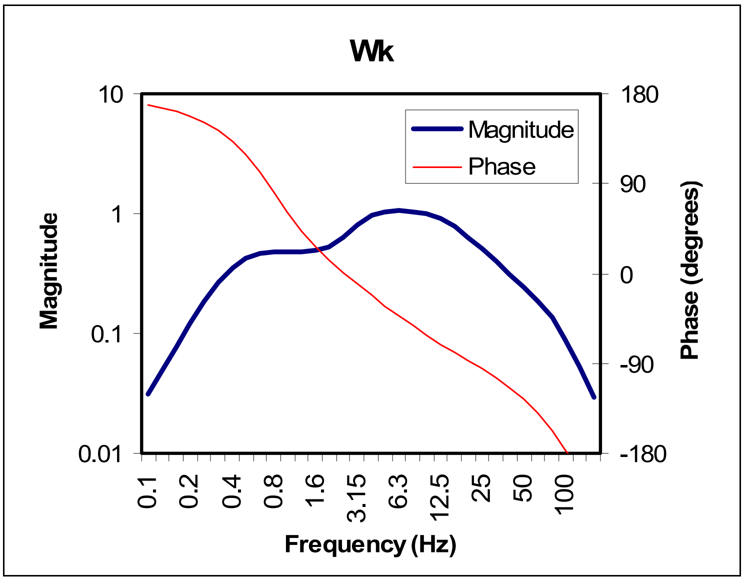

Figure 3 Magnitude and phase response for weighting Wk

The revision of ISO 8041 needed to include some testing of phase response. However, there is no requirement for a human vibration meter to indicate phase, therefore any test needed to be an indirect test. The test developed is based on a saw-tooth waveform. A saw-tooth has been chosen as signal that includes a fundamental signal and its second harmonic. The maximum values of this combination of signals will be very sensitive to phase changes, and therefore provides the best signal to detect phase errors indirectly, by observing their impact on measured parameters.

A second method for testing has also been included as an optional method. This method seeks to evaluate the “characteristic phase deviation” (CPD), a value that is used to specify tolerances on the phase errors (the CPD recognises that the absolute phase error is not important, it is actually the rate of change of phase-shift error with frequency that is important).

3.6 Mounting systems

The errors from poor mounting systems can easily be much larger than errors from any other sources. A poor mounting system introduce a significant resonance, well inside the measurement frequency range. This is a particular problem for hand-arm vibration measurement, where the mounting has to fix on to a small structure, and provide a mount that is rigid for frequencies above 1500 Hz.

ISO 8041:1990 did not deal with transducer mounting systems, and concentrated on the performance of the instrument electronics, and (to a limited degree) the performance of the vibration transducer. However, often a mounting system is included as part of an instrument package, and the reliability of some mounting systems being supplied in this way is questionable.

ISO 8041:2005 has introduced an optional test of hand-arm vibration transducer mountings. It is based on a simple, single axis shaker tests, illustrated in Figure 4. These are designed to establish that the mounts are capable of fixing transducers firmly to a handle and, will provide good performance over the necessary frequency range.

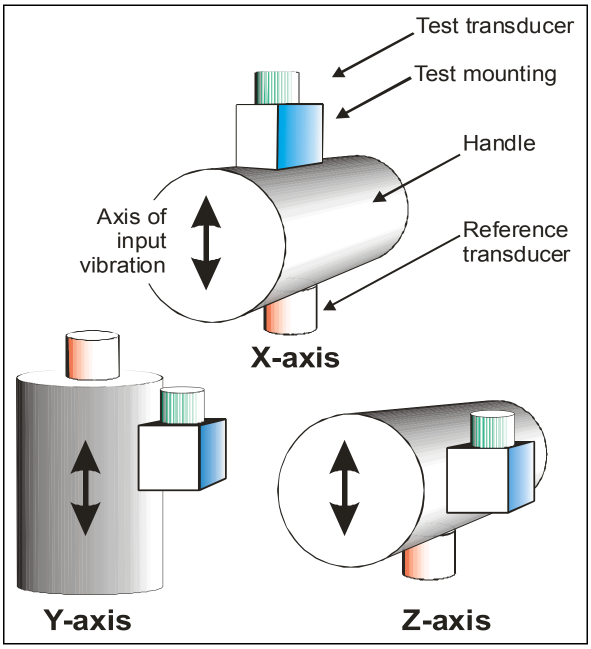

Figure 4 Mounting tests

3.7 Uncertainty

In common with other new instrumentation and calibration standards, ISO 8041:2005 needed to account for the uncertainty of measurement during testing in all the specifications and tests. All tolerances given in the revised standard include an allowance for the uncertainty of measurement of a given performance parameter and an allowance for the permitted variation in the performance of the instrument.

One important issue affecting the uncertainty of testing is the uncertainty of the calibration of reference vibration transducers. The primary and secondary calibration of vibration transducers is defined by the ISO 16063 series. These define tests and tolerances on calibration procedures. In human vibration measurement we never use these calibration tests, but the performance of our instrumentation must be related back to these standards.

The frequency ranges covered by human-response to vibration extends to very low frequencies that are actually well below the frequency ranges for which accepted calibration methods exist. Motion-sickness measurement is a big problem. The lowest frequency for which ISO 16063 tests are developed is about 0.4Hz; the same frequency as the upper end of the motion-sickness frequency range.

Generally calibration checks for transducers used for motion sickness measurements have been based on the method of inverting the transducer, to generate a 2g change in output. While this dc-method has been accepted as being a reliable check of the measurement systems, it is not a test that can be relied on as a true test of the sensitivities of transducer and instrumentation in the frequency range of the measurement. For this reason, ISO 8041:2005 requires that calibration checks be carried out at a frequency that is within the measurement frequency range.

4 CONCLUSIONS

ISO 8041:2005 was published in Spring 2005. Currently most instruments available for measurement are based on the older 1990 version of the standard, and its 1999 amendment. However, in time instruments based on the revision will become available, improving the reliability of human vibration measurement.

5 REFERENCES

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