Kommission Arbeitsschutz und Normung

KAN Position Paper on EN ISO 8041:2005: "Human response to vibration – Measuring instrumentation"

Contents

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1. Introduction

Owing to the EU Vibration Directive 2002/44/EC, which has now been transposed into national laws and regulations, measurement of vibration exposure at workplaces is becoming increasingly important. Measuring instruments conforming to EN ISO 8041 must be employed for the measurements required for risk assessment in accordance with accepted good practice. This requirement is derived from the 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) and ISO 2631-1 (Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration – Part 1: General requirements) measurement standards specified in the EU directive, which respectively require and recommend the use of a measuring instrument conforming to EN ISO 8041. Also, numerous test standards for the determining of vibration emission, such as ISO 20643 (Mechanical vibration – Hand-held and hand-guided machinery – Principles for evaluation of vibration emission), make reference to EN ISO 8041 with regard to the requirements placed upon the test and measurement equipment.

EN ISO 8041 specifies characteristics and tolerance limits for instruments employed for the evaluation of human exposure to vibration, and contains provisions for a multi-level system of traceable calibrations and tests. These extend from pattern evaluation and periodic verification testing to in-situ checks. In-situ checks are often described in the measurement standards as calibration prior to measurement.

Development of the standard began as early as 1977. The ISO/DIS 8041 draft standard was published in 1984 and the European prestandard ENV 28041 in 1993, with an amendment in 2001. The development from analogue to digital technology necessitated a comprehensive revision in 2005. This revision remains the current version and is based primarily upon Parts 1 to 3 of the EN 61672 sound level meter standard. This is the reason for certain provisions in the standard not being beneficial or entailing considerable cost in their implementation.

In addition, the market has responded more swiftly than the standards sector, and now offers a large number of dosemeters of varying quality, particularly for whole-body vibration. As yet, EN ISO 8041 does not contain provisions governing dosemeters. As a result, simple vibration indicators which are sold as dosemeters may result in the risk being underestimated.

In the light of this issue, OSH experts from all stakeholders met under the overall lead of the Commission for OH&S and Standardization (KAN) in order to obtain the opinion of the OSH sector on potential problems associated with the application of EN ISO 8041. The points of criticism and proposals for improvement expressed in the discussions between the experts are summarized below.

In order to provide users with a proper, consistent guide to the application of EN ISO 8041 until the desired revision of ISO 8041 – the underlying international standard – a reduced, practicable verification test (intermediate test) is also described in the annex.

2. Problems associated with the application of EN ISO 8041

Text in EN ISO 8041	Criticism	Explanation
Figure 1 — Overview of the basic functional path output of a vibration measurement instrument or measurement system	The schematic illustrations of a vibration meter are too restrictive for modern vibration measurement systems; e.g., IEPE transducers normally do not give access to the internal pre-amplifier, so that testing via Key 5 in Figure 1 does not include the pre-amplifier. Declare them as "examples".	The requirements and test conditions vary as a function of the technical form taken by the instrument. In instrumentation systems employing IEPE transducers, the integral preamplifier within the transducer is not tested electrically. The electrical input (No. 5) is not accessible in the case of IEPE transducers. As a result, overload indication, band limiting and linearity cannot be tested in this case in the first section of the signal path.
Table 1 — Reference vibration values and frequencies Hand-transmitted: only 500 rad/s (79,58 Hz) Whole-body: 100 rad/s (15,915 Hz) Low-frequency whole-body: 2,5 rad/s (0,3979 Hz) **Table A.1** Hand-arm: 79,577 Hz and 159,155 Hz	Calibration check frequencies within ISO 8041 must be brought into line. Low-cost calibrators for the calibration check frequencies stated, particularly for 15,915 Hz, are not available on the market. Only the following frequencies should be employed for reference and calibration check signals: Hand-arm 1 000 rad/s, whole-body 200 rad/s with adjustment of the test procedure.	For whole-body vibration in particular, the test frequency is too low; a second frequency should be permitted as an alternative (e.g. 200 rad/s = 31,85 Hz), as with hand-arm vibration. The provisions in the measurement standards governing "in-situ calibration" require that a transportable instrument be available. The level of the test amplitude should lie in the mid-range of the measurement range. "In-situ calibration" for the low-frequency range of 0,3979 Hz is unrealistic and may be possible only during laboratory testing (refer also to the comments on testing and calibration, see page 9).
Table 1 and **Table A.1** Hand-arm: 10 m/s^2 Whole-body: 1 m/s^2	Unrealistically low calibration amplitudes are specified.	

Text in EN ISO 8041	Criticism	Explanation
5.6 Frequency weightings and frequency responses	The requirement for a band-limiting filter and a separate frequency weighting filter is restrictive.	In digital technology, separate band-limiting and weighting filters are not necessary.
5.7 Amplitude linearity Over the full extent of all the measurement ranges, the linearity error shall not exceed 6 % of the input value.	The stated linearity error of 6 % is too strict a requirement, since with the fourth power-based vibration dose value (VDV), it is extremely difficult to remain within the linear operating range.	A further requirement is that concerning the amplitude linearity, including that of the accelerometer. Since, in practice, the transducers must be adapted to the measurement tasks, observance of the requirement is difficult, particularly for the low-frequency range.
5.7 Amplitude linearity On the reference measurement range and at the reference frequency, the linear operating range shall be at least 60 dB.	Charge amplifiers do not possess the required linear operating range of 60 dB in all measurement ranges. Where measurement ranges are switchable, "at least 40 dB" is sufficient. Transducers with integral charge amplifiers (IEPEs) would have to be tested mechanically over 60 dB, since the electrical input of the charge amplifier is not accessible.	As explained under Point 1, the scope for the testing of instruments with IEPEs is limited owing to the technical constraints. Where measurement ranges are switchable, a minimum requirement of 40 dB with an overlap of 20 dB is perfectly adequate. A minimum requirement of 60 dB would effectively rule out the combination of piezoelectric accelerometers and charge amplifiers. Charge amplifiers offer considerable benefits for many measuring chains, particularly those used for laboratory tests. A further requirement is that concerning the amplitude linearity, including that of the accelerometer. Since, in practice, the transducers must be adapted to the measurement tasks,
5.7 Amplitude linearity For instruments with multiple and manually selected measurement ranges, the overlap of vibration values indicated on adjacent measurement ranges shall be at least 40 dB.	Overlap ranges must be reviewed; on manually selected measurement ranges, they are too great; recommendation: at least 20 dB.	

Text in EN ISO 8041	Criticism	Explanation
		observance of the requirement is difficult, particularly for the low-frequency range. The transducers available on the market and suitable for such measurements possess a typical amplitude frequency response error in the relevant frequency range of 5 % with respect to the calibration point. At a required linear operating range of 60 dB and in consideration of the above amplitude response, this would require an error over the entire measurement chain (calibrator, sensor, instrument) of approximately 0,001 % of the full-scale value of the measurement range.
5.9 Signal-burst response Fig. 2	It is essential that the measurement does not start <u>within</u> a signal burst, therefore a pre-trigger (start time, Key 2 in Figure 2) is specified. However, there is no requirement given for a synchronizing feature. Give requirements for a synchronizing feature (interface) between the vibration meter and a signal generator. Or make sure by other, simpler means that the measurement starts well before the 1st signal burst begins.	The reason for the start times (0,2 s, 1 s, 40 s) required here is that the settling times of the integral filters within the instrument should generally be allowed to pass. For this purpose, however, synchronization with the signal generator is absolutely essential. Such a function is, however, not required anywhere else. It is not justifiable to force the manufacturer to provide this function purely because of this test item.

Text in EN ISO 8041	Criticism	Explanation
5.10 Overload indication When a vibration meter is used to measure running r.m.s. time-weighted vibration values, the overload indicator shall remain on while the overload condition exists and for any period during which the overload condition affects the displayed measurement (a period equivalent to the integration time for linear running r.m.s. acceleration values or twice the integration time for exponential averaging).	Measurements need not always to be discarded if short overloads took place. It is, however, up to the measuring personnel to decide on the validity of the measurement. Add a Note: It is useful that the vibration meter is able to indicate how long (in relation to the measurement duration) in each channel overload took place.	During very long measurement durations, it can be useful to know the number and duration of the overload conditions, since they provide an indication of the validity of the measurement result.
5.10 Overload indication … Following the overload, the indicator shall remain on for a further 1 s for hand-arm vibration, 8 s for whole-body and low-frequency whole-body applications.	The duration of the overload indication should be formulated as a minimum value as in 5.11.	
5.13 Running r.m.s. acceleration Table 10	For human eyes, it is impossible to read decay times of (0,124 ± 0,005) s. Actually, an electric output equivalent to the display is not compulsory (see 5.3). Explain how the measurement is to be performed.	

Text in EN ISO 8041	Criticism	Explanation
5.16 Electrical cross-talk Where an instrument provides simultaneous signal inputs for more than one axis (or channel) of vibration, then the response on any one channel to a signal on any of the other input channels shall be less than 0,5 % of the input signal magnitude.	The mechanical cross-talk of triaxial transducers normally is higher than 0,5 %. Give some information concerning transducer-internal cross-talk of multi-axial transducers.	The requirement is tested only electrically, and should therefore be limited to the electrical part. For triaxial accelerometers, the limit value should be specified separately, e.g. < 5 %.
11 Testing and calibration	Measurement systems often consist of several components which can be tested separately. IEPE transducers, for instance, are an example of components for which only a "global" test result can be achieved. Give an advise how to calculate the total error of a measurement system consisting of n components: $\varepsilon_{\text{tot}} = \sqrt{\sum_{i=1}^{n} \varepsilon_i^2}$ Additionally, a calibration of the complete measurement system with one amplitude and at one frequency shall be performed.	Regarding the <u>verification tests</u>: The requirement/effort entailed for verification tests is too great. In consideration of the diversity of instruments, these are likely to be once-off approvals. It may therefore be feared that the time expenditure required for verification testing and the associated costs will be very high. This could entice many users to forgo regular verification testing or could result in increased costs for the entire measurement, since these costs are added to the final charge. Given that even the manufacturers do not consider this outlay necessary, it is doubtful whether users will actually observe the statutory minimum requirement. Regarding <u>in-situ checks:</u> The required calibrating devices are not yet available on the

Text in EN ISO 8041	Criticism	Explanation
		market (as is already mentioned in the standard). Manufacturers state that such calibrating devices could be fabricated, but that the low production runs would make them unreasonably expensive. The consequence would be either that such calibrations would not be performed, with a detrimental impact upon the quality of measurements, or that the costs of measurements would rise significantly. It must also be pointed out that measurements are not generally performed under "laboratory conditions", but under industrial conditions. The calibration devices should therefore not only be affordable, but also robust, easy to transport and easy to operate. The alternative solution referred to in the standard is in our view not practicable and could generally not therefore be performed. (Refer to the alternative calibration frequency for whole-body vibration of 200 rad/s = 31,85 Hz, Table A.1)

Text in EN ISO 8041	Criticism	Explanation
Table 13 Summary of performance characteristics and test requirements	The scale of verification testing is too great, involves too much effort and is therefore too expensive; a reduced verification test (intermediate test) should be included as a fourth set of tests in a dedicated section and in Table 13, and the reasons for its performance stated in Clause 11.	A proposal can be found in the annex of this position paper. (see page 14)
12.3 Submission for testing The vibration instrument shall be submitted for testing together with its documentation and all items or accessories that are identified in the instrument documentation as integral components of the complete instrument in its configuration for normal use. Examples of additional items or accessories include an accelerometer, mounting device and cable.	The pattern evaluation applies only for certain combinations of transducer and instrument.	For hand-arm vibration, in particular, different accelerometers need to be employed according to the item under assessment. Equally, the transducers are the only items requiring more frequent replacement, owing to mechanical wear. Separate calibration of the accelerometer and the electrical part of the instrument is therefore the only practicable solution. This permits more frequent verification testing of the transducers, since they are the only parts subject to mechanical wear.

Text in EN ISO 8041	Criticism	Explanation
12.10.1, 13.9 Electrical tests of amplitude linearity On the reference measurement range, the value of the test frequency input signal shall be increased in the increments specified in Table 14 from the specified lower boundary of this measurement range up to the input signal value that causes the first indication of overload.	"Specified lower boundary" is ambiguous. Define "measurement range" in Clause 3 and clearly distinguish from "linear operating range".	How the "lower boundary of this measurement range" is to be specified is not defined. From 3.1, it could be understood that the lower boundary of the linear operating range is meant here. This would also be logical.
12 Pattern evaluation **13 Verification test**	The performance of some tests is not formulated clearly, making them ambiguous, for example 5.9, 5.13, 12.10.1, see above. Section 13.3, final sentence: "vibration transducers are similar". "Similar" is not defined more closely.	For example 5.13: Table 10 requires that following switching-off of the signal at the input, it be checked that the displayed value has decayed to 10 % of the initial value within (0,124 ± 0,005) s. This test cannot be performed, since sensible refresh rates for the display are in the order of (0,2 to 0,5) s. In addition, a verification test approaches a pattern test in extent. If it is assumed that the majority of users possess multiple transducers with different properties for different measurement tasks and that each verification test is valid for only a single instrument/transducer combination, the costs of a

Text in EN ISO 8041	Criticism	Explanation
		verification test can rapidly be expected to exceed the purchase costs.
Annex B Frequency weightings	The tolerances of the weighting filters are unnecessarily low, for example for IIR filtering, and are in conflict with a 4-digit display.	This criticism may not be relevant, since the annexes in question are informative only.
Table E.1 Vibration transducer specifications Maximum unweighted shock acceleration 30000 m/s^2 (up to 50000 m/s^2 for pneumatic hammers)	The shock duration T should be stated as $T \geq 5/f_n$, where f_n is the resonant frequency of the transducer when mounted in accordance with ISO 5347-14 "Methods for the calibration of vibration and shock pick-ups – Part 14: Resonance frequency testing of undamped accelerometers on a steel block". Insert Note 3: The overall dynamic range can be covered by multiple accelerometers.	
Table E.1	Transducer manufacturers do not always give the sensitivity at the reference frequencies acc. to ISO 8041. Add a row "Sensitivity at the relevant reference frequency acc. to Table 1".	

3. Proposal for practicable verification testing of vibration instruments according to EN ISO 8041 – reduced verification test (intermediate test)

3.1. Introduction

With respect to calibration and testing of a measuring instrument according to EN ISO 8041:2005, distinction is made between three cases.

A.) Pattern evaluation

"...tests necessary to demonstrate conformance of a vibration instrument to all mandatory specifications of this International Standard, along with the test methods to be used."

B.) Verification test

"...details of the tests necessary for verification of conformance of a vibration instrument to the specifications of this International Standard, together with the test methods to be used." "...periodically (e.g. ... every 1 or 2 years thereafter)"

C.) In-situ check

"In-situ checks are intended for application in the field prior to or following a measurement or series of measurements. They act as a check of the instrument's basic calibration and functionality."

The scope of testing in each case is listed in EN ISO 8041, Clause 11, Table 13, "Summary of performance characteristics and test requirements".

"Pattern evaluation" encompasses all tests necessary to demonstrate compliance of a vibration instrument with the technical requirements of this standard. It will generally be performed by the manufacturer before the instrument type is placed on the market.

The "verification test" describes regular calibration of the vibration measuring instrument, as is generally commissioned by the end user of the instrument from a test laboratory (calibration laboratory). The verification test encompasses the greater part of the tests required for the pattern evaluation. Owing to the technical diversity of the instruments available on the market, automation of the necessary measurements and verifications is virtually impossible. The measured values must therefore be recorded and documented largely manually, which is very time-consuming and correspondingly expensive.

"In-situ testing" describes a function check by the end user of the instrument prior to the performance of measurement.

A further, simplified, practicable "reduced verification test" ("intermediate test") is proposed below which has the objective of identifying an instrument which is adequately calibrated for the intended applications and is suitable for the purpose, at a cost reasonable for the calibration laboratories and affordable for the end user.

This simplified test procedure is described below as a reduced verification test (intermediate test).

3.2. Test procedure for the "reduced verification test"

A simplified test method is proposed in this section. This test method is based upon the current EN ISO 8041 but limits its tests to the needs corresponding to the specific applications of the end user.

In order for the effort of testing to be reduced, it is assumed that an end user does not generally use the full measurement scope of an acceleration measuring instrument according to EN ISO 8041, but only a limited range of applications. For three typical applications, measurement programmes are therefore proposed for calibration and verification testing which contain only the tests of the vibration measurement instrument which are relevant to the application concerned.

- Each test procedure comprises the mechanical test of the accelerometer and instrument, constituting a measurement chain together with suitable weighting filters for the application in question.
- The test conditions are based closely upon EN ISO 8041.
- The validity of the verification test as stated on the calibration certificate must therefore be limited to the application for which testing was performed.

Where necessary, the end user can also commission testing of system configurations which differ from the typical applications. The objective in all cases, however, is for testing to be performed only of the measurement chain configuration which is actually used by the end user.

Proposed measurement programmes:

1. **Calibration of a 3-channel vibration measurement chain for whole-body human vibration exposure**
2. **Calibration of a 3-channel vibration measurement chain for whole-body vibration in buildings**
3. **Calibration of a 3-channel vibration measurement chain for hand-arm vibration**

3.3. General content of the measurement programmes:

Calibration objects:

3-axis (or three 1-axis) accelerometer together with an instrument forming a measurement chain for the measurement and direct display of frequency-weighted accelerations according to EN ISO 8041 (frequency weightings W_b, W_c, W_d, W_f, W_h, W_j, W_k, W_m).

Calibration procedure:

- Mechanical calibration of the measurement chain with sinusoidal signals of defined amplitude and frequency, determining of the transmission factor of the measurement chain as a whole, of the level linearity and of the frequency response

Mechanical calibrations:

- **Adjustment to reference frequency:** determining and adjustment of the transmission factors of the measurement chain at the reference frequency and acceleration in conjunction with a selected weighting filter per channel,
- **Level linearity at the reference frequency:** determining of the level linearity for all measurement channels within a measurement range (level range 40 dB),
- **Calibration of the frequency response:** determining of the deviation of the measurement chain from the desired display value at fixed frequencies (in consideration of the tolerance limit frequencies of the weighting filters) in the relevant specified frequency ranges, for each channel, with one specified weighting within a specified measurement range, comparison with the permissible tolerances.

3.4. Parameters for measurements for mechanical calibration of measurement chains

The data constitute **useful standard methods**; deviations of the weightings are possible, particularly under Point 1.

1. Verification of a 3-channel vibration measurement chain for whole-body human vibration exposure

Weightings according to EN ISO 8041:	**W_b, W_c, W_d, W_j, W_k**		
Reference frequency:	**15,915 Hz**		
Reference acceleration:	**1,00 m/s²**		
Mechanical amplitude linearity:	**0,1 m/s² to 10 m/s² at 15,915 Hz**		
Frequency range for the frequency response:	**0,5 Hz to 160 Hz**		
Number of fixed frequencies:	**13**		
Preferred frequency weighting filters:	**X axis**	**Channel 1**	**W_d**
	Y axis	**Channel 2**	**W_d**
	Z axis	**Channel 3**	**W_k**

2. Verification test of a 3-channel vibration measurement chain for whole-body vibration in buildings

Weightings according to EN ISO 8041:	**W_m**		
Reference frequency:	**15,915 Hz**		
Reference acceleration:	**1,00 m/s²**		
Mechanical amplitude linearity:	**0,1 m/s² to 10 m/s² at 15,915 Hz**		
Frequency range for the frequency response:	**0,5 Hz to 160 Hz**		
Number of fixed frequencies:	**13**		
Preferred frequency weighting filters:	**X axis**	**Channel 1**	**W_m**
	Y axis	**Channel 2**	**W_m**
	Z axis	**Channel 3**	**W_m**

3. Verification test of a 3-channel vibration measurement chain for hand-arm vibration

Weightings according to EN ISO 8041:	**W_h**		
Reference frequency:	**79,58 Hz**		
Reference acceleration:	**10,00 m/s²**		
Mechanical amplitude linearity:	**1 m/s² to 100 m/s² at 79,58 Hz**		
Frequency range for the frequency response:	**8 Hz to 2000 Hz**		
Number of fixed frequencies:	**13**		
Preferred frequency weighting filters:	**X axis**	**Channel 1**	**W_h**
	Y axis	**Channel 2**	**W_h**
	Z axis	**Channel 3**	**W_h**

Annex: Experts involved

The following experts were involved in the expert discussion during which the position paper was formulated:

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