

Confirmed

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British Standard Method for
**Measurement of body vibration transmitted
to the operator of earth-moving machinery**

[ISO title: Earth-moving machinery — Operator seat — Transmitted vibration]

Méthode de mesure des vibrations transmises au corps du conducteur d'engins de terrassement

Verfahren zur Messung der auf den Fahrer von Erdbaumaschinen übertragenen Körpervibration

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National foreword

This British Standard has been prepared under the direction of the Road Engineering Standards Committee and is identical with ISO 7096 'Earth-moving machinery – Operator seat – Transmitted vibration' published in 1982 by the International Organization for Standardization (ISO).

ISO 7096 was produced as a result of international discussion in which the UK took an active part.

Terminology and conventions. The text of the international standard has been approved as suitable for publication as a British Standard without deviation. Some terminology and certain conventions are not identical with those used in British Standards; attention is especially drawn to the following.

The comma has been used as a decimal marker. In British Standards it is current practice to use a full point on the baseline as the decimal marker.

Wherever the words 'International Standard' appear, referring to this standard, they should be read as 'British Standard'.

Cross-references

International standard	Corresponding British Standard
ISO 5353-1978	BS 5631 : 1978 Specification for earth-moving machinery – seat index point (Identical)
ISO 6165-1978	BS 5718 : 1979 Glossary of terms for basic types of earth-moving machinery (Identical)

There are no corresponding British Standards for ISO 2041, ISO 2631 and IEC 225. The Technical Committee has reviewed the provisions of these standards to which reference is made in clause 3, and has decided that they are acceptable for use in conjunction with this standard. Related British Standards for ISO 2041 and ISO 2631 are BS 3015 'Glossary of terms relating to mechanical vibration and shock' and DD 32 'Guide to the evaluation of human exposure to whole-body vibration' respectively. ISO 4865 is in course of preparation.

Compliance with a British Standard does not in itself confer immunity from legal obligations.

British Standard Method for

Measurement of body vibration transmitted to the operator of earth-moving machinery

1 Scope

This International Standard specifies a method for the measurement, evaluation and acceptance level of the whole body vibration transmitted through the seat to the operator during laboratory simulated machine vertical vibration.

2 Field of application

This International Standard is applicable to seats fitted to earth-moving machines within specified machine classes, each class defined as a group of machines having similar vibration characteristics. See table 2.

3 References

ISO 2041, *Vibration and shock — Vocabulary*.

ISO 2631, *Guide for the evaluation of human exposure to whole-body vibration*.

ISO 4865, *Analog analysis and presentation of vibration and shock data*.¹⁾

ISO 5353, *Earth-moving machinery — Seat index point*.

ISO 6165, *Earth-moving machinery — Basic types — Vocabulary*.

IEC Publication 225, *Octave, half-octave and third octave band filters intended for the analysis of sounds and vibrations*.

IRIG Document 106, Inter Range Instrumentation Group, *Magnetic tape recorder, reproducer standards*.

4 General

The laboratory simulated machine vertical vibration, specified as the test input to the operator seat, is based on representative measured data from machines in typical hard working condi-

tions. The test input for a machine class is a representative envelope for the machines within the class, therefore the laboratory test is more severe than the typical vibration environment of any specific machine.

The specification of procedures, instruments and evaluation methods allows the measurements to be made and reported with an acceptable precision.

The vibration is evaluated in accordance with ISO 2631. The procedure includes means of weighting the vibration level at different frequencies to account for the frequency sensitivity of the human operator.

NOTE — The vibration felt by the operator's feet on the platform or control pedals or by his hands on the steering wheel or control levers is not evaluated in this International Standard.

5 Definitions

The terminology used in this International Standard is generally in accordance with ISO 2041. Additional definitions applicable to this International Standard are given below.

5.1 whole body vibration : Vibration transmitted to the body as a whole through the buttocks of a seated operator.

5.2 operator seat : That portion of the machine provided for the purpose of supporting the buttocks of the seated operator, including the seat suspension system.

5.3 frequency analysis : Process of arriving at a quantitative description of the amplitude of a vibration as a function of frequency.

5.4 measuring period : The time duration in which vibration data for analysis is obtained.

1) At present at the stage of draft.

6 Symbols and abbreviations

a	= instantaneous acceleration
a_f	= rms value of 1/3 octave acceleration having centre frequency f
a_w	= frequency weighted acceleration signal
a_{wf}	= weighted rms acceleration calculated as described in 7.4.1, 7.4.2, or 7.4.3
a_{wfb}	= a_{wf} at the base of the seat (see 7.2.2)
a_{wfs}	= a_{wf} at the seat disc (see 7.2.1)
B_e	= resolution bandwidth of a frequency analysis, in hertz
f	= frequency
T	= analysis time duration, in seconds
W_f	= frequency dependent, dimensionless weighting factor
g	= acceleration of gravity, by international agreement equal to 9,80665 m/s ² at sea level
rms	= root-mean-square
PSD	= Power Spectral Density expressed as mean square acceleration per unit bandwidth in metres per second squared, squared per hertz
PDF	= Probability Density Function of acceleration amplitudes
SIP	= Seat Index Point (see ISO 5353)

7 Instruments

The instruments and analysis specifications are for vibration tests of seats in the laboratory on a vibration test stand. Specifications given as (* *) are additions only for the purpose of extending the specifications to apply to field tests of machines.

7.1 Acceleration transducers

Vibration transmitted to the operator shall be sensed by an acceleration transducer (accelerometer) in the mounting device described in 7.2.1. The accelerometer, together with its associated amplifier, shall be capable of measuring rms acceleration levels ranging from 0,1 to 10 m/s² with a crest factor as great as 6. The accelerometer and amplifier, with proper

calibration for the test, shall be capable of an accuracy of at least $\pm 2,5\%$ of the actual rms vibration levels in the frequency range from 0,8 to 40 Hz (* and at least $\pm 6,0\%$ of the actual rms vibration levels in the frequency range from 40 to 80 Hz *) as calculated from the instrument specifications and the actual test conditions. The resonant frequency of the accelerometer shall be greater than 300 Hz. The accelerometer shall sustain instantaneous acceleration levels up to 100 m/s² without damage.

Vibration at the seat mounting base shall be sensed by an accelerometer of the same type, having a similar signal-to-noise ratio in this application, and capable of the preceding specifications.

7.2 Transducer mounting

7.2.1 Vibration transmitted to the operator

The accelerometer for sensing vibration transmitted to the operator shall be attached near the centre of a thin disc 250 ± 50 mm in diameter placed between the seated operator and the seat cushion. Either a rigid or semi-rigid disc may be used; however, the semi-rigid disc is recommended, especially for soft or highly contoured cushions. The resonance arising from the disc must be above the range of measured frequencies. Disc designs are shown in figures 1 and 2. Either disc shall be placed on the seat so that the accelerometer is located midway between the ischial tuberosities and is aligned parallel to the measurement axis a_z (see figure 3). The disc shall be taped or similarly attached to the cushion to maintain its location.

7.2.2 Vibration at the seat mounting base

The vibration at the base of the seat shall be sensed by an accelerometer attached to a rigid portion of the test stand or seat mounting base. The accelerometer shall be located within the vertical projection of the seat cushion, not more than 100 mm from the vertical, longitudinal plane through the centre of the seat, and shall be aligned parallel to the measurement axis a_z (see figure 3).

If the vibration test stand is of the pivoting type suggested in figure 5 (see 8.1), the seat mounting base accelerometer shall be the same distance (± 20 mm) from the pivot as the seat disc accelerometer.

7.3 Electronic tape recorders

The electrical signals generated by the transducers may be recorded on magnetic tape for later analysis. The magnetic tape recorder, with proper calibration for the test, shall be capable of a replay accuracy of at least $\pm 3\%$ of the rms value of the total signal within the frequency range from 1 to 80 Hz, as calculated from the instrument specifications and the actual test conditions. The tape recorder should meet current IRIG¹⁾ standards for alignment and distortion characteristics.

1) Inter Range Instrumentation Group

7.4 Frequency weighting

Frequency weighting may be achieved in any of three ways : by digital analysis of the acceleration into constant bandwidth levels, weighting the levels in individual bands and recombination; by analysis of the acceleration into 1/3 octave band levels, weighting the levels in individual bands and recombination; or by direct use of electrical filters in a broadband method. The three methods are described below in decreasing order of accuracy (accuracy as resulting from practical considerations of analysis equipment).

7.4.1 Constant bandwidth method

Each vibration tape recording, or vibration signal where a tape recorder is not used, shall be analyzed into constant bandwidth acceleration levels over the frequency range from 1 to 20 Hz (* to 80 Hz *) by appropriate digital methods (see ISO 4865). The sampling time, T (in seconds), and resolution bandwidth, B_e (in hertz), shall satisfy the following :

$$2 B_e T > 140 \quad B_e < 0,3 \text{ Hz}$$

The mean square value of the digitized time data (time domain) should be compared to the mean square value of the spectral estimate (frequency domain). If these values differ, then the analysis procedure should be reviewed and corrected as necessary for possible errors such as improper scaling, wrong correction factor for the data time window (sampling window), or programme errors.

The constant bandwidth rms levels shall each be multiplied by a weighting factor calculated for each centre frequency from figure 4 for a_z (vertical) vibration. A weighted acceleration value, a_{wf} , shall be calculated as the square root of the sum of the squares of the weighted constant bandwidth levels over the range 1 to 20 Hz (* to 80 Hz *).

7.4.2 One-third octave bandwidth method

Each vibration tape recording, or vibration signal where a tape recorder is not used, shall be analyzed into 1/3 octave component accelerations for the centre frequencies of table 1. (The centre frequencies of table 1 are an extrapolation of IEC Publication 225.) The rms value of each component, a_f , shall be averaged over the duration specified for the measurement. The 1/3 octave values shall each be multiplied by the weighting factors, W_f , listed in table 1, and a weighted acceleration value, a_{wf} , calculated for each recording as follows :

(* 80 *)

$$a_{wf} = \left[\sum_{f=1}^{20} W_f^2 \times a_f^2 \right]^{1/2}$$

To satisfy the following,

$$2 B_e T > 140$$

the minimum sampling time, T , is 300 s.

7.4.3 Broadband method

This method, if employed for direct indication of the weighted vibration, shall consist of an electronic weighting network incorporated between the transducer and a time integration stage. The weighting network shall have an insertion loss conforming to the curve in figure 4 for a_z (vertical) vibration. The loss shall not deviate from the curve by more than ± 1 dB for frequencies between 1,1 Hz and 10 Hz, and ± 2 dB at any other frequency. The integration stage shall be capable of indicating the integral of the square of weighted acceleration, a_w , for the time period of the test run T . That is,

$$(a_{wf})^2 = \frac{1}{T} \int_{t=0}^T a_w^2 dt$$

The minimum sampling time, T , is 300 s.

7.5 Calibration

7.5.1 General

Operating manuals or other literature furnished by the instrument manufacturer should be reviewed for both recommended operation of the instrument and precautions to be observed. The entire measurement and analysis system should be regularly calibrated by technically trained instrumentation personnel following manufacturer's recommendations for the adjustment and application of individual components.

Acceleration transducers should be calibrated in accordance with a suitable recognized calibration method¹⁾. In particular, the calibration procedures should ensure that the acceleration sensitivity varies less than $\pm 2,5$ % of a mean value over the frequency range of 0 to 40 Hz and less than $\pm 6,0$ % of a mean value over the frequency range of 0 to 80 Hz.

The effects of ambient temperature and humidity on the performance of all instruments shall be known. Instruments shall be operated within the temperature limits at which the required accuracy can be expected.

7.5.2 For tests

It is strongly recommended that technically trained personnel select the instrumentation for the actual test conditions and

1) Additional information will be given in a forthcoming International Standard.

that the tests be conducted only by qualified persons trained in the current techniques of random vibration measurement and analysis.

Multi-instrument measurement systems shall be checked for proper signal levels, terminating impedances, and cable lengths.

The general procedures described in the tilting support method¹⁾ for static calibration of acceleration transducers should be used to obtain overall system acceleration sensitivity. Tilting the sensitive axis of the transducer from the vertical through an angle of 180° in the field of gravity provides a peak-to-peak change in the output representing a 19,61 m/s² (2g) change in input acceleration. The sensitive axis of the accelerometer should be aligned with the vertical and the 180° inverted position to within ± 4°, and the peak-to-peak change in output voltage should be measured to within ± 0,5 %. Calibration should be made and recorded before and after each test series and at reasonable intervals during any extended test series. Each calibration shall be compared to the internal electronic calibration of the overall instrument system.

The transducer used to measure the vibration transmitted to the operator need not be removed from the mounting disc (see 7.2.1) provided the sensitive axis of the transducer can be located within the prescribed tolerance. Zero hertz frequency response of the instrumentation system is required for this calibration procedure.

An internal electronic calibration of the overall instrument system shall be checked immediately before and after each test run, and corrections made as necessary to maintain the required test accuracy.

The output from each accelerometer amplifier shall be nulled by proper balancing and zeroing techniques while the accelerometers are in the test position between the seat and the seated operator and on the seat mounting base or test stand.

The null or zero value of the overall instrument system shall be recorded immediately before and after each test run.

8 Vibration test stand

8.1 Physical characteristics

The minimum required facility is an electro-hydraulic feedback control system with an a_z degree of freedom. The system shall have dynamic response capable of driving the mounting base of the loaded seat in accordance with the defined test spectra.

The transfer function characteristics of the facility may be compensated for during the synthesis of the command input signal in order that a_z output PSD and PDF requirements are satisfied at the seat mounting base. Any appropriate digital or analog

method may be used to generate the command signal providing that the output PSD and PDF requirements are satisfied at the seat mounting base.

The moving portion of the vibration test stand shall consist of a platform to provide for the seat mounting base and flat floor space for operator foot support. The stand shall be constrained to travel in an essentially vertical direction and shall be free from resonances and non-linearities, which would distort the output vibration beyond the correction capability of signal compensation.

If the platform is carried on an arm, as shown in figure 5, the radius from the arm pivot to the SIP shall be at least 2 000 mm.

8.2 Safety recommendations

The vibration test stand should have fail-safe provisions capable of automatic shut-down when the seat mounting base acceleration exceeds 15 m/s² for any reason. It is preferred that this provision be a hydraulic means, such as a supply pressure relief valve and/or a load-limiting valve across the piston of the actuator cylinder. If an acceleration transducer is used as the sensor for safety purposes, its signal should be passed through a low pass filter with a 20 Hz cut-off frequency to avoid automatic shut-down from high frequency components beyond the hydraulic capability of the test stand. If the test stand is not of the hydraulic type, adequate safety devices should be used.

The pump and/or servo-valves should be sized to limit the test stand velocity to 1,3 m/s, and the accumulator should be of the minimum size required to provide the proper system response.

Fail-safe shut-down switches should be provided to both the person in the test seat and the operator of the test facility. The shut-down switches should shut down the hydraulic power supply and actuate a valve to release the system hydraulic pressure.

In all tests, the excitation vibration should be increased slowly to allow the test to be terminated at the request of the person in the seat.

8.3 Technical characteristics

The following technical characteristics are only for the purpose of assisting in the selection of a vibration test stand.

Maximum dynamic thrust force = $1,5 \times \text{mass (platform, seat and subject)}$.

Working frequency range = 0,5 to 20 Hz.

Piston stroke = 175 mm minimum (allowance for variable level at 0 Hz should be in addition to 175 mm).

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