INTERNATIONAL STANDARD

ISO 2631-5

First edition
2004-02-15

Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration —

Part 5:
Method for evaluation of vibration containing multiple shocks

Vibrations et chocs mécaniques — Évaluation de l'exposition des individus à des vibrations globales du corps —

Partie 5: Méthode d'évaluation des vibrations contenant des chocs répétés

Reference number
ISO 2631-5:2004(E)

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Published in Switzerland

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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 2631-5 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration and shock*, Subcommittee SC 4, *Human exposure to mechanical vibration and shock*.

ISO 2631 consists of the following parts, under the general title *Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration*:

— *Part 1: General requirements*

— *Part 2: Vibration in buildings (1 Hz to 80 Hz)*

— *Part 4: Guidelines for the evaluation of the effects of vibration and rotational motion on passenger and crew comfort in fixed-guideway transport systems*

— *Part 5: Method for evaluation of vibration containing multiple shocks*

Introduction

The purpose of this part of ISO 2631 is to define a method of quantifying whole-body vibration containing multiple shocks in relation to human health. Examples of conditions that result in vibration containing multiple shocks include, but are not limited to, machinery travelling over rough surfaces, small boats in rough sea, aircraft in buffeting, presses and mechanical hammers.

Adverse effects on the lumbar spine are the dominating health risks of long-term exposure to vibration containing multiple shocks. Therefore, this part of ISO 2631 is basically concerned with the lumbar spine response. Annex A provides guidance on assessment of adverse health effects.

The assessment method described in this part of ISO 2631 is based on the predicted response of the bony vertebral endplate (hard tissue) in an individual who is in good physical condition with no evidence of spinal pathology and who is maintaining an upright unsupported posture. However, the assessment method and related models described in this part of ISO 2631 have not been epidemiologically validated.

Annex A provides guidance on assessment of health effects of multiple shocks. Annex B discusses the effects of multiple shocks and the posture on the intervertebral disc (soft tissue). Annex C gives information on the background of the calculation of spinal response in the vertical direction (z-direction). Annex D includes a software calibration check and an example of a computor program that can be used for the calculation of the vibration dose.

Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration —

Part 5: Method for evaluation of vibration containing multiple shocks

1 Scope

This part of ISO 2631 addresses human exposure to mechanical multiple shocks measured at the seat pad when a person is seated.

The adverse health effects of prolonged exposure to vibration that includes multiple shocks are related to dose measures. The method described in this part of ISO 2631 is generally applicable in cases where adverse health effects in the lumbar spine are concerned.

The calculation of the lumbar spine response described in this part of ISO 2631 assumes that the person subjected to the vibration is seated in an upright position and does not voluntarily rise from the seat during the exposure. Different postures can result in different responses in the spine.

The limitations of the lumbar spine response models used in this part of ISO 2631 are given in 5.2. Caution is necessary when applying the method to extreme shock conditions.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 2041, *Vibration and shock — Vocabulary*

ISO 2631-1:1997, *Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration — Part 1: General requirements*

ISO 5805, *Mechanical vibration and shock — Human exposure — Vocabulary*

3 Terms and definitions, symbols and subscripts

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 2041 and ISO 5805 apply.

3.2 Symbols and subscripts

3.2.1 Symbols

a	acceleration
A	peak acceleration
c	constant
D	acceleration dose
f	frequency
m	dose coefficient
R	factor
s	displacement
S	compressive stress
t	time
u	model acceleration term
v	velocity
w, W	model coefficients
ζ	critical damping ratio
ω	angular frequency

3.2.2 Subscripts

d	daily, as in duration of daily exposure t_{d}
e	equivalent, as in equivalent static compressive stress S_{e}
i, j	counter
k	counter (x, y or z)
l	lumbar
m	measured, as in measurement period t_{m}
n	natural, as in natural frequency f_{n}
s	seat
u	ultimate, as in ultimate stress S_{u}
x, y, z	reference axes

4 Vibration measurement

Vibration measurement, including the direction of measurement, location of transducers, duration of measurement, and reporting of vibration conditions, shall follow the requirements included in ISO 2631-1:1997, Clause 5. See also ISO 8041 for instrumentation specification, and ISO 10326-1 for information on the location of measurements on the seat and on design of the seat pad. During data collection, the subject shall remain seated and belted and shall not voluntarily rise from the seat.

For measurement of vibration including multiple shocks, it is important that the sign of acceleration signals (positive, negative) is correctly recorded.

The sampling rate for the x- and y-directions shall be appropriated to the analysis of an 80 Hz signal. Because of the requirements associated with the z-direction model, a sampling rate in the z-direction that is a multiple of 160 samples per second is recommended.

The duration of the measurement shall be sufficient to ensure that the multiple shocks are typical of the exposures that are being assessed.

5 Determination of the spinal response acceleration dose

5.1 General

The determination of the spinal response acceleration dose involves the following steps:

— calculation of the human response of the spine;

— counting of number and magnitudes of peaks;

— calculation of an acceleration dose by application of a dose model related to the Palmgren-Miner fatigue theory.

5.2 Computation of spinal response

5.2.1 General

Predictive models are used to estimate the lumbar spine accelerations (a_{lx}, a_{ly}, a_{lz}) in the x-, y- and z-directions in response to accelerations measured at the seat pad (a_{sx}, a_{sy}, a_{sz}) along the same basicentric axes. Two such models are provided below.

NOTE Other models than those given below for calculation of the spinal response, often more refined and complex, are used and developed in research. This is important for further development and should be encouraged.

5.2.2 Spinal response in horizontal directions (x-axis or y-axis)

In the x- and y-axes, the spinal response is approximately linear and is represented by a single-degree-of-freedom (SDOF) lumped-parameter model, having the following characteristics:

— natural frequency, $f_n = 2{,}125$ Hz ($\omega_n = 13{,}35\ s^{-1}$);

— critical damping ratio, $\zeta = 0{,}22$.

The lumbar spine response, a_{lk}, in metres per second squared, is calculated from the equation of motion of a SDOF system:

$$a_{lk}(t) = 2\,\zeta\,\omega_n(v_{sk} - v_{lk}) + \omega_n^2(s_{sk} - s_{lk}) \tag{1}$$

where

k is x or y;

s_{sk} and s_{lk} are the displacement time histories in the seat and in the spine;

v_{sk} and v_{lk} are the velocity time histories in the seat and in the spine.

The values for the SDOF resonance frequency and damping ratio given above, result in the following values for the multipliers in Equation (1): $2\,\zeta\,\omega_n = 5{,}87\ s^{-1}$ and $\omega_n^2 = 178\ s^{-2}$.

5.2.3 Spinal response in vertical direction (z-axis)

In the z-direction, the spinal response is non-linear and is represented by a recurrent neural network model.

The basis for this modelling technique is discussed in Annex C. Lumbar spine z-axis acceleration, a_{lz}, in metres per second squared, is predicted using the following equations:

$$a_{lz}(t) = \sum_{j=1}^{7} W_j u_j(t) + W_8 \qquad (2)$$

$$u_j(t) = \tanh\left[\sum_{i=1}^{4} w_{ji} a_{lz}(t-i) + \sum_{i=5}^{12} w_{ji} a_{sz}(t-i+4) + w_{j13}\right] \qquad (3)$$

The model coefficients in Equations (2) and (3) are specific to a sampling rate of 160 per second. Therefore, data collected at a different sampling rate shall be resampled to 160 samples per second.

The values to be used for W_j in Equation (2) and w_{ji} in Equation (3) are given in Tables 1 and 2.

NOTE The degree of precision indicated by the number of digits in the figures in Tables 1 and 2 is related to the neural network technology and should not be taken as an indication of an extremely high accuracy in the assessment.

Table 1 — z-axis model coefficients for Equation (2)

W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8
57,96539	52,32773	49,78227	53,16885	56,02619	−27,79550	72,34446	21,51959

Table 2 — z-axis model coefficients for Equation (3)

j	1	2	3	4	5	6	7
w_{j1}	0,00130	0,01841	−0,00336	0,01471	0,00174	0,00137	0,00145
w_{j2}	−0,00646	−0,00565	−0,00539	0,01544	−0,00542	0,00381	0,00497
w_{j3}	−0,00091	−0,02073	0,00708	−0,00091	0,00255	−0,00216	0,01001
w_{j4}	0,00898	−0,02626	0,00438	−0,00595	−0,00774	−0,00034	0,01283
w_{j5}	0,00201	0,00579	0,00330	−0,00065	−0,00459	−0,00417	−0,00468
w_{j6}	0,00158	0,00859	0,00166	0,00490	−0,00546	0,00057	−0,00797
w_{j7}	0,00361	0,00490	0,00452	0,00079	−0,00604	−0,00638	−0,00529
w_{j8}	0,00167	−0,00098	0,00743	0,00795	−0,01095	0,00627	−0,00341
w_{j9}	−0,00078	−0,00261	0,00771	0,00600	−0,00908	0,00504	0,00135
w_{j10}	−0,00405	−0,00210	0,00520	0,00176	−0,00465	−0,00198	0,00451
w_{j11}	−0,00563	0,00218	−0,00105	0,00195	0,00296	−0,00190	0,00306
w_{j12}	−0,00372	0,00037	−0,00045	−0,00197	0,00289	−0,00448	0,00216
w_{j13}	−0,31088	−0,95883	−0,67105	0,14423	0,04063	0,07029	1,03300

5.3 Calculation of acceleration dose

The acceleration dose, D_k, in metres per second squared, in the k-direction is defined as

$$D_k = \left[\sum_i A_{ik}^6 \right]^{1/6} \quad (4)$$

where

A_{ik} is the i^{th} peak of the response acceleration $a_{\text{l}k}(t)$;

$k = x$, y or z.

A peak is defined here as the maximum absolute value of the response acceleration between two consecutive zero crossings. For the x- and y-directions, peaks in positive and negative directions shall be counted. For the z-direction, only positive peaks shall be counted (compression of the spine is of primary interest for exposure severity).

In calculating the dose, peaks of a considerably lower (by a factor of three or more) magnitude than the highest peak will not significantly contribute to the value associated with the 6th power term in Equation (4) and may therefore be neglected.

For assessment of health effects, it is useful to determine the average daily dose, $D_{k\text{d}}$, in metres per second squared, to which a person will be exposed, using the following equation:

$$D_{k\text{d}} = D_k \left[\frac{t_\text{d}}{t_\text{m}} \right]^{1/6} \quad (5)$$

where

t_d is the duration of the daily exposure;

t_m is the period over which D_k has been measured.

Equation (5) may be used when the total daily exposure can be represented by a single measurement period. When the daily vibration exposure consists of two or more (n) periods of different magnitudes, the acceleration dose, in metres per second squared, for the total daily exposure shall be calculated as follows:

$$D_{k\text{d}} = \left[\sum_{j=1}^{n} D_{kj}^6 \frac{t_{\text{d}j}}{t_{\text{m}j}} \right]^{1/6} \quad (6)$$

where

$t_{\text{d}j}$ is the duration of the daily exposure to condition j;

$t_{\text{m}j}$ is the period over which D_{kj} has been measured.

5.4 Flowchart for calculation of the acceleration dose

The procedure for calculation of the acceleration dose is illustrated by the flowchart in Figure 1.

Guidance for development of programs for calculation of response and dose is given in Annex D.

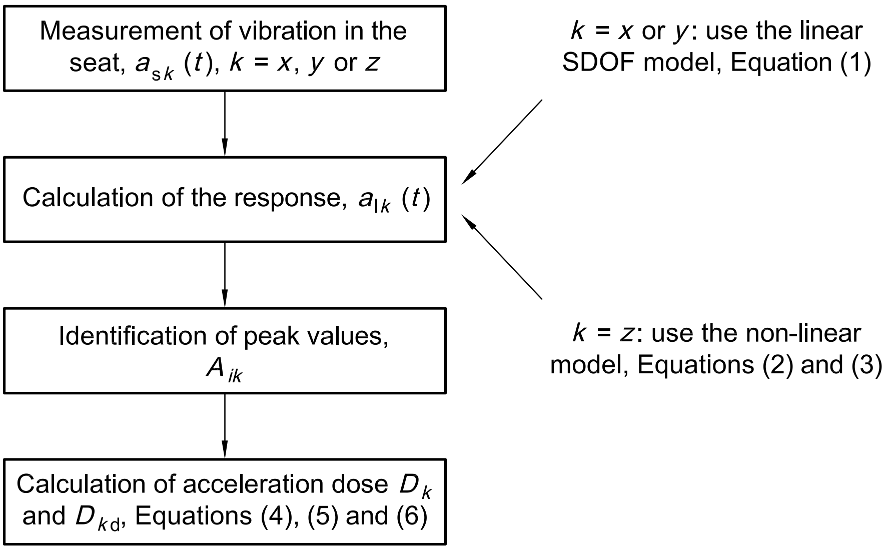

Figure 1 — Flowchart for acceleration dose calculation

5.5 Relationship between acceleration dose and adverse health effects

Guidance on assessment of the adverse health effects from the knowledge of the acceleration dose for multiple shocks is given in Annex A. The response calculations as given in this part of ISO 2631 are related to the prediction of the response of the bony vertebral endplate (hard tissue). Effects of multiple shocks and the posture on the intervertebral disc (soft tissue) are discussed in Annex B.