TECHNICAL REPORT

ISO/TR 230-8

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Test code for machine tools —

Part 8:
Determination of vibration levels

Code d'essai des machines-outils —

Partie 8: Détermination des niveaux de vibration

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

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/TR 230-8 was prepared by Technical Committee ISO/TC 39, *Machine tools*, Subcommittee SC 2, *Test conditions for metal cutting machine tools*.

ISO/TR 230 consists of the following parts, under the general title *Test code for machine tools*:

— *Part 1: Geometric accuracy of machines operating under no-load or finishing conditions*

— *Part 2: Determination of accuracy and repeatability of positioning numerically controlled axes*

— *Part 3: Determination of thermal effects*

— *Part 4: Circular tests for numerically controlled machine tools*

— *Part 5: Determination of the noise emission*

— *Part 6: Determination of positioning accuracy on body and face diagonals (Diagonal displacement tests)*

— *Part 7: Geometric accuracy of axes of rotation*

— *Part 8: Determination of vibration levels* [Technical Report]

— *Part 9: Estimation of measurement uncertainty for machine tool tests according to series ISO 230, basic equations* [Technical Report]

Introduction

The purpose of ISO 230 is to standardize methods of testing the performance of machine tools, generally without their tooling[1)], and excluding portable power tools. This part of ISO 230 establishes general procedures for the assessment of machine tool vibration.

The need for vibration control is recognized in order that those types of vibration that produce undesirable effects can be mitigated. These effects are identified principally as:

— unacceptable cutting performance with regard to surface finish and accuracy;

— premature wear or damage of machine components;

— reduced tool life;

— unacceptable noise level;

— physiological harm to operators.

Of these, only the first is considered to lie within the scope of this part of ISO 230, although the other effects may well occur incidentally. (Noise is covered by ISO 230-5, and the effect of vibration on operators is covered by ISO 2631-1.) For the most part, this necessarily limits this part of ISO 230 to the problems of vibrations that are generated between tool and workpiece.

Although this part of ISO 230 is in the form of a Technical Report, a number of acceptance tests are proposed within it. These take on the appearance of "standard tests" to be found in other parts of the 230 series. These tests may be used in this way, but, being less rigorous in their formulation, they do not carry the authority that a test in accordance with an International Standard would have.

1) In some cases, practical considerations require that real or dummy tooling and workpieces be used (see 7.1.1, 7.2.1, 7.4 and 8.3).

Test code for machine tools —

Part 8: Determination of vibration levels

1 Scope

This part of ISO 230 is concerned with the different types of vibration that can occur between the tool-holding part and the workpiece-holding part of a machine tool. (For simplicity, these will generally be referred to as "tool" and "workpiece", respectively.) These are vibrations that can adversely influence the production of both an acceptable surface finish and an accurate workpiece.

It is not aimed primarily at those who have expertise in vibration analysis and who routinely carry out such work in research and development environments. It does not, therefore, replace standard textbooks on the subject (see the Bibliography). It is, however, intended for manufacturers and users alike with general engineering knowledge in order to enhance their understanding of the causes of vibration by providing an overview of the relevant background theory.

It also provides basic measurement procedures for evaluating certain types of vibration problems that can beset a machine tool:

— vibrations occurring as a result of mechanical unbalance;

— vibrations generated by the operation of the machine's linear slides;

— vibrations transmitted to the machine by external forces;

— vibrations generated by the cutting process including self-excited vibrations (chatter).

Additionally, this report discusses the application of artificial vibration excitation for the purpose of structural analysis. For further information on how to use this part of ISO 230, see Annex A.

NOTE Other sources of vibration (e.g. the instability of drive systems, the use of ancillary equipment or the effects of worn bearings) are discussed briefly, but a detailed analysis of their vibration generating mechanisms is not given.

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 230-1, *Test code for machine tools — Geometric accuracy of machines operating under no-load or finishing conditions*

ISO 230-5, *Test code for machine tools — Determination of the noise emission*

ISO 1925:2001, *Mechanical vibration — Balancing — Vocabulary*

ISO 1940-1:2003, *Mechanical vibration — Balance quality requirements for rotors in a constant (rigid) state — Part 1: Specification and verification of balance tolerances*

ISO 2041:1990, *Vibration and shock — Vocabulary*

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

ISO 2954, *Mechanical vibration of rotating and reciprocating machinery — Requirements for instruments for measuring vibration severity*

ISO 5348:1998, *Mechanical vibration and shock — Mechanical mounting of accelerometers*

ISO 6103, *Bonded abrasive products — Permissible unbalances of grinding wheels as delivered — Static testing*

ISO 15641, *Milling cutters for high speed machining — Safety requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1925, ISO 2041 and the following apply.

3.1
absolute vibration
vibration value measured with an inertial transducer at a single point

3.2
absorber
damper
device for reducing the magnitude of a shock or **vibration** by energy dissipation methods

[ISO 2041:1990, definition 2.114]

3.3
accelerance
vibration quantified by its acceleration per unit excitation force

NOTE See Table 1 in ISO 2041.

3.4
aliasing error
erroneous result in digital analysis of signals caused by having the maximum frequency of the [measured] signal greater than one-half the value of the sampling frequency

[ISO 2041:1990, definition 5.8]

3.5
amount of unbalance
product of the **unbalance mass** and the distance of its centre of mass from the shaft axis

[ISO 1925:2001, definition 3.3]

NOTE This is sometimes referred to as the “residual unbalance” (e.g. in ISO 1940-1). It is measured in mass-length units, e.g. gram millimetres (g·mm).

3.6
amplitude
peak vibration value
maximum value of a sinusoidal **vibration**

[ISO 2041:1990, definition 2.33]

NOTE This is sometimes called vector amplitude to distinguish it from other senses of the term "amplitude", and it is sometimes called single amplitude, or peak amplitude, to distinguish it from double amplitude, which, for a simple harmonic vibration, is the same as the total excursion or peak-to-peak value. The use of the terms "double amplitude" and "single amplitude" is deprecated.

3.7
angular frequency
circular frequency
product of the frequency of a sinusoidal quantity and the factor 2π

[ISO 2041:1990, definition 2.30]

NOTE 1 The unit of circular frequency is the radian per unit of time.

NOTE 2 Angular or circular frequency occurs at the rate at which any vibration signal (or part of a vibration signal) repeats its pattern. It is measured in radians/s and is usually represented by the symbol "ω".

3.8
antinode
point, line or surface in a standing wave where some characteristic of the wave field has a maximum value

[ISO 2041:1990, definition 2.47]

EXAMPLE A point or line on the surface of a machine tool whose amplitude of vibration (at a particular frequency) is greater than that at any adjacent points or lines.

3.9
antiresonance
system in forced oscillation in which any change at a given point, however small, in the frequency of excitation causes an increase in a response at this point

NOTE 1 The above specification defines a response *minimum*, but not necessarily a response *zero*.

NOTE 2 Adapted from ISO 2041:1990, definition 2.74.

3.10
averaging
process chosen to determine a single representative value for a set of data

NOTE In connection with *sine wave analysis*, averaging refers to the arithmetic mean signal level in one half of a sine wave and is defined in Annex B. In connection with *data sampling*, various techniques are available. Vector averaging, for example, not only takes the mean of the signal level but also takes account of its phase relative to some reference frequency (e.g. the excitation frequency). This technique ensures that any signal content that is unrelated to the frequency of interest, and consequently of an undetermined phase for each sample, is rapidly diminished through cancelling as the averaging takes place. This effective enhancer of signal-to-noise ratio also provides a useful diagnostic tool for identifying vibration sources.

3.11
bandwidth
range of frequencies (usually expressed in hertz) where the amplitude exceeds a particular threshold level, or limits within which the power spectrum is considered

NOTE This should not be confused with the same term used in digital communication theory for expressing a data transmission rate in bits/s.

3.12
beats
periodic variations in the amplitude of an oscillation resulting from the combination of two oscillations of slightly different frequencies

NOTE 1 The beats occur at the difference frequency.

NOTE 2 Adapted from ISO 2041:1990, definition 2.28.

3.13
broadband measurement
measuring process where the total **vibration** power is integrated over the frequency range of interest

3.14
centre of mass
that point associated with a body which has the property that an imaginary particle placed at this point with a mass equal to the mass of a given material system has a first moment with respect to any plane equal to the corresponding first moment of the system

NOTE This term is sometimes referred to as “centre of inertia” and for most practical situations it is synonymous with “centre of gravity”.

[ISO 2041:1990, definition 1.31]

3.15
chatter
self-excited regenerative relative **vibrations** between the tool and workpiece during the cutting process, precipitating an unstable machining condition

NOTE See also 5.4.

3.16
coherence function
that fraction of the total power in a response signal that is identified with an individual source component

3.17
coupled modes
modes of **vibration** that are not independent but which influence one another because of energy transfer from one to another

[ISO 2041:1990, definition 2.53]

3.18
critical damping
⟨single degree-of-freedom system⟩ amount of viscous damping that corresponds to the limiting condition between an oscillatory and a non-oscillatory transient state of free **vibration**

[ISO 2041:1990, definition 2.85]

3.19
cycle
complete range of states or values through which a periodic phenomenon or function passes before repeating itself identically

[ISO 2041:1990, definition 2.22]

3.20
damping
dissipation of energy with time

NOTE Adapted from ISO 2041:1990, definition 2.79.

3.21
damping ratio
⟨system with linear viscous damping⟩ ratio of the actual damping coefficient to the critical damping coefficient

NOTE Adapted from ISO 2041:1990, definition 2.86.

3.22
degrees-of-freedom
number of degrees of freedom of a mechanical system equal to the minimum number of independent generalized coordinates required to define completely the configuration of the system at any instant of time

[ISO 2041:1990, definition 1.26]

3.23
distributed system
continuous system
system having an infinite number of possible independent configurations

[ISO 2041:1990, definition 1.29]

NOTE Machine tools generally fall into this category as the mass as well as the stiffness are not located at individual points but distributed over the whole structure.

3.24
dynamic compliance
reciprocal of **dynamic stiffness**

NOTE This is quite often referred to as “flexibility”. Typical units are µm/N.

3.25
dynamic stiffness
ratio of change of force to change of displacement under dynamic conditions

NOTE 1 See also ISO 2041:1990, definition 1.54.

NOTE 2 At low frequencies, the dynamic stiffness approximates to the static stiffness. At high frequencies, the response tends towards zero and the dynamic stiffness tends towards infinity. At intermediate frequencies, where resonances occur, the dynamic stiffness can drop to a very low value. Units of stiffness are expressed in force per displacement, e.g. N/µm.

3.26
dynamic vibration absorber
device for reducing **vibrations** of a primary system over a desired frequency range by the transfer of energy to an auxiliary system in resonance so tuned that the force exerted by the auxiliary system is opposite in phase to the force acting on the primary system

[ISO 2041:1990, definition 2.116]

NOTE Dynamic vibration absorbers may be damped or undamped, but damping is not the primary purpose.

3.27
FFT
fast Fourier transform
process where the computing times of complex multiplications and additions are greatly reduced

[ISO 2041:1990, definition 5.23]

NOTE 1 For more details, see ISO 2041:1990, A.18 to A.22.

NOTE 2 An FFT is a mathematical algorithm enabling vibration-analysis equipment to perform at high speed and thus appear to function in “real time”.

3.28
forced vibration
steady-state **vibration** caused by a steady-state excitation

[ISO 2041:1990, definition 2.16]

NOTE 1 Transient vibrations are not considered.

NOTE 2 The vibration (for linear systems) has the same frequencies as the excitation.

3.29
foundation
structure that supports a mechanical system and that may be fixed in a specified frame or it may undergo a motion that provides excitation for the supported system

[ISO 2041:1990, definition 1.23]

3.30
Fourier analysis
mathematical procedure for determining the coefficients and phase angles of the components of the **Fourier series** for a given waveform

3.31
Fourier series
series which expresses the values of a periodic function in terms of discrete frequency components that are harmonically related to each other

[ISO 2041:1990, definition A.18]

NOTE See the notes to the reference in ISO 2041:1990, A.18, for a mathematical description.

3.32
free vibration
vibration that occurs after the removal of excitation or restraint

[ISO 2041:1990, definition 2.17]

NOTE The system vibrates at natural frequencies of the system.

3.33
frequency
reciprocal of the fundamental period, being the smallest increment of the independent variable of a periodic quantity [time] for which the function repeats itself

NOTE 1 Adapted from ISO 2041:1990, definitions 2.23 and 2.24.

NOTE 2 The frequency is the rate at which any vibration signal (or part of a vibration signal) repeats its pattern and is measured in hertz (Hz), which is the number of cycles per second.

3.34
frequency response
output signal expressed as a function of the **frequency** of the input signal

NOTE 1 On a machine tool the frequency response is often limited to the expression of the ratio of the relative displacement between tool and workpiece (output signal) to the excitation force (input signal). See also 4.3 *et seq*. The magnitude of the frequency response is equivalent to the dynamic compliance. The frequency response is, however, a complex quantity and requires two numbers to define it fully: either “magnitude” and “phase”, or “real part” and “imaginary part”. In some texts the term “receptance” is used synonymously with “response”.

NOTE 2 The frequency response is usually given graphically by curves showing the relationship of the output signal and, where applicable, phase shift or phase angle as a function of frequency.

NOTE 3 Adapted from ISO 2041:1990, definition B.13.

3.35
fundamental frequency
⟨periodic quantity⟩ reciprocal of the fundamental period

[ISO 2041:1990, definition 2.25]

3.36
harmonic
⟨periodic quantity⟩ sinusoid, the **frequency** of which is an integral multiple of the **fundamental frequency**

[ISO 2041:1990, definition 2.26]

NOTE 1 The term “overtone” has frequently been used in place of “harmonic”, the n^{th} harmonic being called the $(n\text{-}1)^{th}$ overtone.

NOTE 2 In English, the first overtone and the second harmonic are each twice the frequency of the fundamental. In French, the distinction between harmonic and overtone does not exist, and the second harmonic is twice the frequency of the fundamental. The term “overtone” is now deprecated to reduce ambiguity in the numbering of the components of a periodic quantity.

3.37
harmonic distortion
⟨periodic wave⟩ amount of vibrational energy existing at second and subsequent harmonic frequencies compared with the total vibrational energy present

3.38
imaginary part
that part of the displacement frequency response that is in quadrature (90° out-of-phase) with the excitation

NOTE For a simple vibration system, the imaginary part reaches a maximum at the undamped natural frequency.

3.39
impulse

integral with respect to time of a force taken over the time during which the force is applied, which, for a constant force, is the product of the force and the time during which the force is applied

[ISO 2041:1990, definition 3.6]

NOTE The “impulsive” force may act over a very short time and change rapidly during the event, often reaching a very high instantaneous value. Typical examples are a hammer blow or a rapidly accelerating machine slide. Impulses are measured in units of force multiplied by time, e.g. N·s.

3.40
inertial cross-talk
displacements perpendicular to the intended direction of motion owing to a lateral offset between the driving force and the centre of mass, which lead to tilt motions during acceleration and deceleration

3.41
instrumented hammer
hammer incorporating a force transducer that is capable of transmitting a broadband frequency response of the impact delivered by the hammer when used to strike a structure

3.42
linear system
system in which the response is proportional to the magnitude of the excitation

[ISO 2041:1990, definition 1.21]

3.43
mass eccentricity
distance between the centre of mass of a rigid rotor and the shaft axis

[ISO 1925:2001, definition 2.11]

3.44
mobility
complex ratio of the velocity, taken at a point in a mechanical system, to the force taken at the same or another point in the system, during simple harmonic motion

[ISO 2041:1990, definition 1.50]

3.45
modal mass
equivalent mass in a single degree-of-freedom system for a particular mode

3.46
mode of vibration
⟨system undergoing vibration⟩ mode of vibration designates the characteristic pattern of nodes and antinodes assumed by the system in which the motion of every particle, for a particular frequency, is simple harmonic (for linear systems) or has corresponding decay patterns

[ISO 2041:1990, definition 2.48]

NOTE In a machine tool, individual modes of vibration are characterized by the different relative movements of the basic structural elements. For a particular frequency at any point in time, the instantaneous disposition of these elements will determine the characteristic modal shape for that frequency.

3.47
modulation, amplitude and **frequency**
periodic wave whose amplitude and/or frequency is itself varying as a result of an imposed signal. Modulated signals are characterized by the presence of side-band frequencies

3.48
multi-degree-of-freedom system
system for which two or more co-ordinates are required to define completely the configuration of the system at any instant

[ISO 2041:1990, definition 1.28]

3.49
narrow-band measurement
measuring process where the **vibration** power over a specified narrow bandwidth of frequencies is measured

3.50
natural frequency
frequency of the free **vibration** of a damped linear system

[ISO 2041:1990, definition 2.81]

EXAMPLE The frequency at which a structure will vibrate freely when all forced vibration is removed, which in practice is the damped natural frequency. (The undamped natural frequency occurs when the phase shift is 90°.)

3.51
node
point, line or surface in a standing wave where some characteristic of the wave field has essentially zero amplitude

EXAMPLE A point or line of little or minimal movement between two parts of the machine, which, at any given instant, are moving in opposite directions.

[ISO 2041:1990, definition 2.46]

3.52
non-linearity
property of a system in which the response is specifically not proportional to the magnitude of the excitation.

NOTE Systems with non-linear stiffness are usually identified either as “stiffening” or “softening”.

3.53
oscillation
variation, usually with time, of the magnitude of a quantity with respect to a specified reference when the magnitude is alternately greater and smaller than some mean value

[ISO 2041:1990, definition 1.8]

3.54
peak-to-peak vibration value
algebraic difference between the extreme values of the **vibration**

[ISO 2041:1990, definition 2.35]

EXAMPLE The total “displacement” movement of the vibration.

NOTE This is twice the amplitude and is sometimes also referred to as “double amplitude”. This term is non-preferred and loses its relevance for velocity and acceleration vibration signals.

3.55
period
fundamental period

smallest increment of the independent variable of a periodic quantity for which the function repeats itself

[ISO 2041:1990, definition 2.23]

3.56
periodic force
periodic motion
periodic quantity, the values of which recur for certain equal increments of the independent variable (time)

[ISO 2041:1990, definition 2.2]

EXAMPLE Exciting force or motion that repeats its wave pattern at a regular rate.

NOTE The waveform is not necessarily sinusoidal; the force or motion is characterized by its frequency components.

3.57
phase
phase angle
fractional part of a period through which a sinusoidal **vibration** has advanced as measured from a value of the independent variable as a reference

[ISO 2041:1990, definition 2.31]

EXAMPLE The angular delay between two otherwise similar vibration signals.

NOTE This delay is either measured in degrees in terms of the vibration period (which is counted as 360°) or in radians. Thus, two vibrations moving in opposite directions to each other at the same instant are 180° or π radians out of phase.

3.58
power spectrum
spectrum of mean-squared spectral density values

[ISO 2041:1990, definition 5.2]