TECHNICAL REPORT

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Test code for machine tools —

Part 11: **Measuring instruments suitable for machine tool geometry tests**

Code d'essai des machines-outils —

Partie 11: Instruments de mesure compatibles avec les essais de géométrie des machines-outils

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 39, *Machine tools,* Subcommittee SC 2, *Test conditions for metal cutting machine tools*.

A list of all parts in the ISO 230 series can be found on the ISO website.

Introduction

The purpose of this document is to provide information for instruments and equipment for testing machine tools as specified in the ISO 230 series (except ISO 230-5 and ISO/TR 230-8), and in machine-specific standards of ISO/TC 39/SC 2, test conditions for metal cutting machine tools.

The main parts of this document have been transferred from ISO 230-1:1996, Annex A, which is no longer part of ISO 230-1. Newly developed measuring instruments, like special purpose measuring instruments in Clause 12, have been added to this document as well as special application examples in Clause 13.

The concept of measuring uncertainty has been implemented. Uncertainty contributors for measuring instruments and measuring procedures are listed in Annex D to improve reliability of test results. In addition, Annex A addresses checking devices for instruments applied in the workshop and Annex C addresses influences of supporting systems.

Additional information for existing ISO and national standards for measuring equipment is included in Annex B.

This document and ISO 230-1:2012 together cover the entire content of ISO 230-1:1996, with updated instruments and concepts.

Test code for machine tools —

Part 11:
Measuring instruments suitable for machine tool geometry tests

1 Scope

The aim of this document is to document the characteristics of precision measuring instruments for testing the geometric accuracy of machine tools, operating either under no-load or under quasi-static conditions.

Where necessary, reference is made to the appropriate International Standards.

The measuring instruments for operational testing of machine tools [vibrations (ISO/TR 230-8), noise (ISO 230-5), stick-slip motion of components, etc.] as well as instruments for checking of other characteristics of machine tools (speeds, feeds, temperature) are not covered in this document. The measuring instruments for checking of workpiece geometry (size, form, etc.) are not covered by this document either.

This document has list style construction for ease of search and identification of each instrument's characteristics.

Sources of uncertainty of instruments and measurements are described in this document for more accurate measurement procedures.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
calibration
operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties, and in a second step, uses this information to establish a relation for obtaining a measurement result from an indication

Note 1 to entry: A calibration may be expressed by a statement, calibration function, calibration diagram, calibration curve, or calibration table. In some cases, it may consist of an additive or multiplicative correction of the indication with associated measurement uncertainty.

Note 2 to entry: Calibration should not be confused with adjustment of a measuring system, often mistakenly called "self-calibration", nor with verification of calibration.

Note 3 to entry: Often, the first step alone in the above definition is perceived as being calibration.

[SOURCE: JCGM 200:2012, 2.39]

3.2
measuring range
set of values of measurands for which the error of a measuring instrument is intended to lie within specified limits

Note 1 to entry: Error is determined in relation to a conventional true value.

[SOURCE: ISO 14978:2006, 3.36]

3.3
accuracy
closeness of agreement between a measured quantity value and a true quantity value of a measurand

Note 1 to entry: The concept “measurement accuracy” is not a quantity and is not given a numerical quantity value. A measurement is said to be more accurate when it offers a smaller measurement error.

Note 2 to entry: The term “measurement accuracy” should not be used for measurement trueness and the term “measurement precision” should not be used for ‘measurement accuracy’, which, however, is related to both these concepts.

Note 3 to entry: “Measurement accuracy” is sometimes understood as closeness of agreement between measured quantity values that are being attributed to the measurand.

[SOURCE: JCGM 200:2012, 2.13]

3.4
linearity
degree of insignificance on deviation from the linear relation between the input signal and the output signal[20]

3.5
repeatability
measuring precision under a set of repeatability conditions of measurement

Note 1 to entry: These conditions include

— reduction to a minimum of the variations due to the observer,

— the same measurement procedure,

— the same observer,

— the same measuring equipment, used under the same conditions,

— the same location, and

— repetition over a short period of time.

Note 2 to entry: Repeatability can be expressed quantitatively in terms of the dispersion characteristics of the indications.

3.6
frequency response
a state where the amplitude ratio of an output signal to the input signal and the phase difference between the two are varied as a function of sinusoidal input signal frequency[20]

3.7
measuring force
<load> force applied by the stylus of an indicator or recorder to the feature being measured

3.8
operating environment
atmosphere or environment in which the object is placed during testing[20]

3.9
stability
property of a measuring instrument, whereby its metrological properties remain constant in time

Note 1 to entry: Stability may be quantified in several ways.

EXAMPLE 1 In terms of the duration of a time interval over which a metrological property changes less than a stated amount.

EXAMPLE 2 In terms of the change of a property over a stated time interval.

[SOURCE: JCGM 200:2012, 4.19]

3.10
correction
compensation for an estimated systematic effect

Note 1 to entry: See ISO/IEC Guide 98-3:2008, 3.2.3, for an explanation of “systematic effect”.

Note 2 to entry: The compensation value(s) can take different forms, such as a constant addition or multiplication, or multiple values obtained from a table.

[SOURCE: JCGM 200:2012, 2.53]

3.11
measuring instrument
device used for making measurements, alone or in conjunction with one or more supplementary devices

Note 1 to entry: A measuring instrument that can be used alone is a measuring system.

[SOURCE: JCGM 200:2012, 3.1]

3.12
measuring transducer
device, used in measurement, that provides an output quantity having a specified relation to the input quantity

[SOURCE: JCGM 200:2012, 3.7]

3.13
measuring system
set of one or more measuring instruments and often other devices, including any reagent and supply, assembled and adopted to give information used to generate measured quantity values within specified intervals for quantities of specified kinds

[SOURCE: JCGM 200:2012, 3.2]

3.14
sensor
element of a measuring system that is directly affected by the phenomenon, body or substance carrying the quantity to be measured

EXAMPLE Sensing coil of a platinum resistance thermometer, rotor of a turbine flow meter, Bourdon tube of a pressure gauge, float of a level-measuring instrument, photocell of a spectrometer, thermotropic liquid crystal which changes colour as a function of temperature.

Note 1 to entry: In some fields, the term “detector” is used for this concept.

[SOURCE: JCGM 200:2012, 3.8]

3.15
detector
device or substance that indicates the presence of a phenomenon, body, or substance when a threshold value of an associated quantity is exceeded

EXAMPLE Halogen leak detector, litmus paper.

Note 1 to entry: In some fields, the term “detector” is used for the concept of sensor.

[SOURCE: JCGM 200:2012, 3.9]

3.16
sensitivity
quotient of the change in the indication of a measuring system and the corresponding change in a value of a quantity being measured

Note 1 to entry: Sensitivity of a measuring system can depend on the value of the quantity being measured.

Note 2 to entry: The change considered in a value of a quantity being measured needs to be large compared with the resolution.

[SOURCE: JCGM 200:2012, 4.12]

3.17
resolution
smallest change, in a quantity being measured that causes a perceptible change in the corresponding indication

Note 1 to entry: Resolution can depend on, for example, noise (internal or external) or friction. It can also depend on the value of a quantity being measured.

[SOURCE: JCGM 200:2012, 4.14]

3.18
instrumental drift
continuous or incremental change over time in indication, due to changes in metrological properties of a measuring instrument

Note 1 to entry: Instrumental drift is related neither to a change in a quantity being measured nor to a change of any recognized influence quantity.

[SOURCE: JCGM 200:2012, 4.21]

3.19
optical measuring instrument
instruments, measuring physical, geometrical or material properties based on optical principles, such as photometry, interferometry, geometrical optics, holography, or refractometry[14].

EXAMPLE one-coordinate and multi-coordinate measuring machines, surface-measuring instruments, numerical measuring instruments for machine control, autocollimators, telescopes, contour-measuring instruments.

3.20
maximum permissible error
MPE
<for a metrological characteristic> extreme value of an error of a metrological characteristic permitted by specifications, regulations, etc. for a given piece of measuring equipment

[SOURCE: ISO 14978:2006, 3.21, modified — The domain has been added and “errors” has been changed to “error”.]

3.21
measuring precision
closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions

Note 1 to entry: Measurement precision is usually expressed numerically by measures of imprecision, such as standard deviation, variance, or coefficient of variation under the specified conditions of measurement.

Note 2 to entry: The specified condition can be, for example, repeatability conditions of measurement, intermediate precision condition of measurement, or reproducibility condition of measurement (see ISO 5725-1. 1994).

Note 3 to entry: Measurement precision is used to define measurement repeatability, intermediate measurement precision, and measured reproducibility.

Note 4 to entry: Sometimes "measurement precision" is erroneously used to mean measurement accuracy.

[SOURCE: JCGM 200:2012, 2.15]

4 Preliminary remarks

4.1 Measuring units

The units for the following features are:

— displacement, distance and linear deviations: mm or µm;

— angles: degrees or a ratio;

— angular deviation: µm/m or ″ (arc seconds); and

— linear compliance: µm/N.

4.2 Uncertainty of measuring instrument

4.2.1 General

Uncertainty of measuring instrument is a component of combined measurement uncertainty (JCGM 200:2012, 4.24). The instrument uncertainty should be small enough to assess the system performance. The uncertainty of the measurement including the instrument uncertainty should be considered according to ISO 14253-1 ("decision rules") when it is used to check system performance against specifications. However, if the measurement uncertainty is less than 10 % of the specification limit, it is common industrial practice to decide on the conformance or non-conformance based on the indicated measurement value.

Measuring equipment should not be used until it has been allowed to stabilize at the ambient temperature, and stability maintained during the test procedure.

Care should be taken to prevent disturbance to the equipment caused by vibrations, magnetic fields, electrical interference, etc.

General uncertainty contributors are indicated in Table 1 (see also ISO 14253-2). Annex D describes relationship between the instruments and uncertainty contributors. Simple explanation of uncertainty contributors related to the measuring instruments and set-up procedures are described in the following clauses.

Table 1 — List of uncertainty contributors

1. Environment	**2. Measuring equipment**
Absolute temperature (4.2.2.1)	Stability (4.2.3.1)
Temperature spatial gradient (4.2.2.2)	Scale mark quality (4.2.3.2)
Temperature time variance (4.2.2.2)	Temperature expansion coefficient (4.2.3.3)
Vibration/noise (4.2.2.3)	Thermal conductivity (4.2.3.4)
Humidity (4.2.2.4)	Uncertainty of the calibration (4.2.3.5)
Contamination (4.2.2.5)	Resolution of the main scale (analogue or digital) (4.2.3.6)
Ambient pressure (4.2.2.6)	Time since last calibration (4.2.3.7)
Air composition (4.2.2.7)	Magnification, electrical or mechanical (4.2.3.8)
Air flow (4.2.2.7)	Wavelength error (4.2.3.9)
Gravity (4.2.2.8)	Zero-point stability (4.2.3.10)
Electromagnetic interference (4.2.2.9)	Measuring force stability/absolute force (4.2.3.11)
Supply air pressure (e.g. air bearings) (4.2.2.10)	Hysteresis (4.2.3.12)
Heat radiation (4.2.2.11)	Probe system, Tip radius, Form deviation of tip (4.2.3.13)
Instrument thermal equilibrium (4.2.2.12)	Stiffness/rigidity (4.2.3.14)
	Linear coefficient for thermal expansion (4.2.3.15)
	Temperature stability/sensitivity (4.2.3.16)
	Parallaxes (4.2.3.17)
	Interpolation system, error wavelength (4.2.3.18)
	Interpolation resolution (4.2.3.19)
3. Measurement setup and procedure	**4. Software and calculations**
Cosine errors and sine errors (4.2.4.1)	Rounding/Quantification (4.2.5.1)
Abbe principle (4.2.4.2)	Algorithms (4.2.5.2)
Temperature sensitivity (4.2.4.3)	Sampling (4.2.5.3)
Stiffness/rigidity (4.2.4.4)	Filtering (4.2.5.4)
Stiffness of the probe system (4.2.4.5)	Correction of algorithm/Certification of algorithm (4.2.5.5)
Optical aperture (4.2.3.6)	Interpolation/extrapolation (4.2.5.6)
Interaction between standard and setup (4.2.4.7)	
Warming up (4.2.4.8)	
Conditioning (4.2.4.9)	
Number of measurements (4.2.4.10)	
Order of measurements (4.2.4.11)	
Duration of measurements (4.2.4.12)	
Alignment (4.2.4.13)	
Choice of reference — reference item (standard) (4.2.4.14)	
Choice of apparatus (4.2.4.15)	
Strategy (4.2.4.16)	
Fixturing (4.2.4.17)	
Number of points (4.2.4.18)	
Probing principle and strategy (4.2.4.19)	

Table 1 *(continued)*

Alignment of probing system (4.2.4.20)	
Reversal measurements (4.2.4.21)	
Multiple redundancy, error separation (4.2.4.22)	

4.2.2 Environment factors

4.2.2.1 Reference temperature

Standard reference temperature for machine tool measurements is 20 °C (see ISO 1). Deviations from this temperature, either in absolute terms or due to temporal and spatial temperature gradients, results in linear expansion and/or bending of the measuring equipment, the measurement set-up and the object being measured. The influence of temperature deviations on the length is given by Formula (1).

$$\Delta L = \Delta T \times \alpha \times L \qquad (1)$$

where

ΔT is the relevant temperature deviation from 20 °C;

α is the temperature expansion coefficient of the material;

L is the effective length under consideration (see ISO 14253-2:2011, 8.4.8.1).

See also 4.2.3.3 and ISO/TR 16015.

4.2.2.2 Temperature gradient/variance

The existence of temperature gradients implies that portions of the environment will not be at the same mean temperature such that the consequences of mean temperatures other than 20 °C will be different in different locations in a room. Additional complexity is created when these temperature gradients change in time (see also ISO 230-3:2007, Annex D).

4.2.2.3 Vibration/noise

Vibration/noise from internal of machine tool system under test or from external sources causes relative displacement between the measuring instrument and the target machine surface. Such vibration also affects the supporting device of the instrument. Acoustic noise sometimes excites vibration that affects the instrument (see also ISO/TR 230-8).

4.2.2.4 Humidity

Length measurement using laser interferometer is affected by the change of the laser wavelength due to the change in the relative humidity of air, in which the laser beam passes. For example, 30 % change in relative humidity of air causes 1 µm/m change in length measurement.

4.2.2.5 Contamination

Dust, rust, oil, chemical materials and other unwanted small particles in the workshop can disturb precise contact between the instrument and target work surface. Surface contamination on optical parts can affect optical performance such as polarization, wavelength change, etc.

4.2.2.6 Ambient pressure

Length measurement using laser interferometer is affected by the change of the laser wavelength due to the change in pressure of air, in which the laser beam passes. For example, 330 Pa change in absolute air pressure causes 1 µm/m change in length measurement.

4.2.2.7 Air flow/air composition

The flow rate and velocity of the ambient air are of prime importance in the control of temperature variation and temperature gradients of the machine components. Also, such air characteristics affect the wavelength of the laser and, consequently, the length measurement when laser interferometer is used. The local air density change directly influences the length unit (see 4.2.2.4, 4.2.2.6 and also ISO 230-3:2007, Annex D).

4.2.2.8 Gravity

See 4.2.3.14.

4.2.2.9 Electromagnetic interference

Electromagnetic fields induced by surrounding power electronic facilities can contaminate the accuracy, stability and instrumental drift of an electronic measuring instrument. Sensors using magnetic effect such as scale, limit sensor, and inductive gauges can be influenced. It can affect sensor itself, connecting cable, amplifier and power source.

4.2.2.10 Supply air pressure (air bearing)

Air gauge, linear motion instruments with air bearing are operated by pressurized supply air in the workshop. The variance of air pressure can influence the air gauge stability, gap of air bearings, and motion accuracy. Content of moisture in the supply air can also induce rust.

4.2.2.11 Heat radiation

Heat generated by the machine environment can affect the measuring instrument and its supporting system. Such radiation can be guarded by a reflective material cover such as an aluminium sheet.

4.2.2.12 Instrument thermal equilibrium

Temperature of the instrument placed on the target surface of the machine should be as close as possible to the machine temperature. The difference between these induces local deformation of instrument, thermally-induced changes in readings, etc.

4.2.2.13 EVE (Environmental Variation Error)

Environmental variation (such as temperature variation, air density variation, ground vibration) influences the measurement device and/or the machine tool under test causing environmental variation error (EVE) (see also ISO/TR 230-9:2005, C.2.5). This environmental variation error (EVE) can be checked by setting up the measurement equipment on the machine tool under test and looking at the change of readout during the time necessary to do the test. The location of EVE test is selected in order to recognize the largest influence from EVE on the geometrical test concerned. Figure 1 shows an example of EVE on laser angle measurement. The data indicate the variance within 120 seconds. The total EVE value is about 1 arc-second (see 4.2.2.2, 4.2.2.3, 4.2.2.6 and 4.2.2.7).