TECHNICAL REPORT

ISO/TR 230-9

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Test code for machine tools —

Part 9:
Estimation of measurement uncertainty for machine tool tests according to series ISO 230, basic equations

Code d'essai des machines-outils —

Partie 9: Estimation de l'incertitude de mesure pour les essais des machines-outils selon la série ISO 230, équations de base

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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is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.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 230-9 was prepared by Technical Committee ISO/TC 39, *Machine tools*, Subcommittee SC 2, *Test conditions for metal cutting machine tools*.

ISO 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 of numerically controlled axes*

— *Part 3: Determination of thermal effects*

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

— *Part 5: Determination of the noise emissions*

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

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

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

The following parts are under preparation:

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

Introduction

In this part of ISO 230 equations for the estimation of the measurement uncertainty are presented.

Annex C is the special annex for the estimation of the measurement uncertainty for ISO 230-2.

Test code for machine tools —

Part 9:
Estimation of measurement uncertainty for machine tool tests according to series ISO 230, basic equations

1 Scope

This part of ISO 230 provides information on a possible estimation of measurement uncertainties for measurements according to ISO 230.

The methods described here are aimed for practical use; therefore, standard uncertainties are mainly evaluated by type B evaluation (see Clause 4 and GUM).

Other methods complying with GUM may be used.

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 230-2:—[1)], *Test code for machine tools — Part 2: Determination of accuracy and repeatability of positioning numerically controlled axes*

ISO/TR 16015:2003, *Geometrical product specifications (GPS) — Systematic errors and contributions to measurement uncertainty of length measurement due to thermal influences*

ISO/TS 14253-2, *Geometrical Product Specifications (GPS) — Inspection by measurement of workpieces and measuring equipment — Part 2: Guide to the estimation of uncertainty in GPS measurement, in calibration of measuring equipment and in product verification*

Guide to the expression of certainty in measurement, (GUM). BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, 1st edition, 1993, corrected and reprinted in 1995

3 Terms, definitions and symbols

For the purposes of this part of ISO 230, the terms, definitions and symbols given in ISO 230-2 and GUM apply.

1) To be published. (Revision of ISO 230-2:1997)

4 Estimation of measurement uncertainty U

The estimation of the measurement uncertainty, U, follows GUM, ISO/TS 14253-2 and ISO/TR 16015.

The individual contributors to the measurement uncertainty have to be identified (for examples, see Annex C) and expressed as standard uncertainties, u_i.

The combined standard uncertainty, u_c, is calculated according to Equation (1):

$$u_c = \sqrt{u_r^2 + \sum u_i^2} \qquad (1)$$

where

u_c is the combined standard uncertainty, in micrometres (µm);

u_r is the sum of strongly positive correlated contributors, see Equation (2), in micrometres (µm);

u_i is the standard uncertainty of uncorrelated contributor, i, in micrometres (µm);

$$u_r = \sum u_j \qquad (2)$$

where u_j is the standard uncertainty of strongly positive correlated contributor, j, in micrometres (µm).

The measurement uncertainty U is calculated according to Equation (3), where the coverage factor k is set to 2.

$$U = k \cdot u_c \qquad (3)$$

where

U is the measurement uncertainty, in micrometres (µm);

k is the coverage factor,

$k = 2$

u_c is the combined standard uncertainty, in micrometres (µm);

A standard uncertainty u_i is obtained by statistical analysis of experimental data (type A evaluation) or by other means, such as knowledge, experience and scientific guess (type B evaluation).

If an estimation gives a possible range of $\pm a$ or $(a^+ - a^-)$ of a contributor, then the standard uncertainty u_i is given according to Equation (4), assuming a rectangular distribution.

$$u_i = \frac{a^+ - a^-}{2\sqrt{3}} \qquad (4)$$

where

u_i is the standard uncertainty;

a^+ is the upper limit of rectangular distribution;

a^- is the lower limit of rectangular distribution.

5 Estimation of the uncertainty of parameters, basic equations

In Clause 4, the black box method of the uncertainty estimation is used. For the parameters that are calculated from individual measurement runs, from mean values, from multiples of the standard deviation, and/or sums of those, the uncertainty estimates are obtained using transparent box method. Positioning accuracy, repeatability and reversal value are such parameters. This can be written generally as

$$Y = f(X_i) \tag{5}$$

where

Y is the parameter (e.g. repeatability, reversal value, positioning accuracy);

X_i is the measured value i.

The combined standard uncertainty u_c is then calculated according Equation (6):

$$u_c = \sqrt{u_r^2 + \sum \left(\frac{\delta Y}{\delta X_i} \cdot u_{Xi} \right)^2} \tag{6}$$

where

u_c is the combined standard uncertainty;

u_r is the sum of strongly positive correlated components, see Equation (7);

u_{Xi} is the standard uncertainty of uncorrelated component i.

$$u_r = \sum \frac{\delta Y}{\delta X_j} \cdot u_{Xj} \tag{7}$$

where u_{Xj} is the standard uncertainty of strongly positive correlated component j.

Annex A
(informative)

Measurement uncertainty of mean value

A.1 General

The mean value is defined by

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad \text{(A.1)}$$

where

$\bar{x}$ is the mean value;

x_i is the measured value i;

n is the number of measurements.

If the mean value is calculated from measurements x_i, having a measurement uncertainty u_{xi}, then the mean value has also an uncertainty.

A.2 Calculation of the measurement uncertainty of the mean value, $u(\bar{x})$

A.2.1 General

The measurement uncertainty of the mean value $u(\bar{x})$ depends on the correlation between the uncertainties of the single measurements u_{xi}.

A.2.2 Uncertainty of the mean value $u(\bar{x})$ for strongly positive correlated uncertainties u_{xj}

If the uncertainties of the single measurements u_{xj} are strongly positive correlated, their influences on the uncertainty of the mean value $u(\bar{x})$ are simple summed, according to Equation (7).

NOTE A possible misalignment of a measuring instrument does not change in a series of measurements. Then this uncertainty contributor does not change between repeated measurements, and is regarded as strongly positive correlated.

If Equations (6) and (7) are applied to Equation (A.1) for strongly positive correlated contributors, the result is

$$u(\bar{x}) = \sum \frac{\delta \bar{x}}{\delta x_j} \cdot u_{xj} \qquad \text{(A.2)}$$

where

$u(\bar{x})$ is uncertainty of the mean value for strongly positive correlated contributors;

$\bar{x}$ is the mean value;

x_j is the single measurement value;

u_{xj} is the strongly positive correlated measurement uncertainty contributor for measured value j.

The partial derivation of the mean value $\bar{x}$ to the single measurement value x_j is the following:

$$\frac{\delta \bar{x}}{\delta x_j} = \frac{1}{n} \tag{A.3}$$

It is assumed that the measurement uncertainty for the single measurement does not change, i.e.

$$u_{x1} = u_{x2} = \ldots = u_{xn} = u_x \tag{A.4}$$

Equations (A.3) and (A.4) are set into Equation (A.2), resulting in

$$\begin{aligned} u(\bar{x}) &= \frac{1}{n} \cdot u_{x1} + \frac{1}{n} \cdot u_{x2} + \ldots + \frac{1}{n} \cdot u_{xn} \\ u(\bar{x}) &= \frac{1}{n} \cdot u_x \cdot n \\ u(\bar{x}) &= u_x \end{aligned} \tag{A.5}$$

where

$u(\bar{x})$ is the uncertainty of the mean value for strongly positive correlated contributors;

u_x is the strongly positive correlated measurement uncertainty contributor for measured values.

Equation (A.5) tells us that the uncertainty of the mean value $u(\bar{x})$ is the uncertainty of the measured value u_x, if the uncertainty contributors are strongly positive correlated.

A.2.3 Uncertainty of mean value $u(\bar{x})$ for uncorrelated uncertainties u_{xi}

If the uncertainties of the individual measurements u_{xi} are not correlated, the square root of the squared sum is applied according to Equation (6), with $u_c = 0$.

NOTE The influence of an environmental thermal variation error, ETVE, in general will change from measurement value to measurement value. Therefore, this influence is regarded as uncorrelated.

If Equation (6) is applied to Equation (A.1) for uncorrelated contributors, the results is

$$u(\bar{x}) = \sqrt{\sum \left(\frac{\delta \bar{x}}{\delta x_i} \right)^2 \cdot u_{xi}^2} \tag{A.6}$$

où

$u(\bar{x})$ is the uncertainty of the mean value for non-correlated contributors;

$\bar{x}$ is the mean value;

x_i is the single measurement value;

u_{xi} is the non-correlated measurement uncertainty contributor for measured value i.

Equations (A.3) and (A.4) are set into Equation (A.6), resulting in

$$u(\bar{x}) = \sqrt{\left(\frac{u_{x1}}{n}\right)^2 + \left(\frac{u_{x2}}{n}\right)^2 + \ldots + \left(\frac{u_{xn}}{n}\right)^2}$$

$$u(\bar{x}) = u_x \cdot \sqrt{\left(\frac{1}{n^2}\right) \cdot n} \qquad \text{(A.7)}$$

$$u(\bar{x}) = \frac{1}{\sqrt{n}} \cdot u_x$$

The measurement uncertainty of the mean value is reduced by $\frac{1}{\sqrt{n}}$, if n is the number of repeated measurements, and if the uncertainties of the repeated measurements are uncorrelated.