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Test code for machine tools —

Part 12:
Accuracy of finished test pieces

Code d'essai des machines-outils —

Partie 12: Exactitude des pièces d'essai finies

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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.

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).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of 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 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.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The purpose of the ISO 230 series is to standardize methods of testing the accuracy of machine tools, excluding portable power tools.

When a machine tool is used to repeatedly machine a single test piece in a mass production line, some machine tool users want to test cut that single test piece and check its geometric accuracy, as a part of acceptance tests for a machine tool. For machines machining multiple types of test pieces, standard test pieces should be used. The geometric error of the finished test piece can be caused by various error motions of a spindle, linear axes, rotary axes, or other mechanical components of a machine tool. A proper set of machining tests should be chosen such that it exhibits the influence of machine error motions for a machine tool user's possible machining applications. This document specifies a set of machining tests that can be used to assess the influence of various quasi-static error motions of a machine tool. This document is intended to supply minimum requirements for assessing the finish-cutting accuracy of the machine.

Standard test pieces are defined in machine-specific International Standards. In some machine-specific International Standards, recent machining applications are not be fully covered. For example, five-axis machining centres can perform turning operations by using a rotary table. The machine-specific International Standard for a machining centre, ISO 10791-7, describes no machining test for turning operation. Turning tests are included in ISO 13041-5. This document describes a family of machining tests that covers potential applications of various types of machine tools.

In general, machining tests described in machine-specific international standards, influenced by multiple causes, are not intended to identify individual error sources contributing to the measured errors of the machined test pieces. In contrast, tests for identifying quasi-static error motions described in ISO 230-1 are designed to identify individual error sources for each motion axis. This document provides test pieces for machining tests to isolate certain error sources and allow manufacturers/users to pick those corresponding to their intended machining applications.

The tests described in this document can be used either for testing different types of machine tools (type testing) or testing individual machine tools for acceptance purposes.

Test code for machine tools —

Part 12:
Accuracy of finished test pieces

1 Scope

This document specifies methods for defining machining tests for manufacturing accurate test pieces, and for evaluating the influence of quasi-static geometric errors of linear axes and rotary axes, and the influence of the synchronization error of simultaneously controlled multiple axes. Although quasi-static geometric errors are often major contributors for geometric errors of finished test pieces, other factors, e.g. the dynamic contouring error, can also have significant influence.

This document describes examples of test piece geometry applicable to individual machine tools, possible contributors to machining error, deviations to be measured and measuring instruments. By clarifying possible contributors to machining error in each machining test, this document gives a guidance to machine tool manufacturers or users such that proper machining tests can be chosen to evaluate a machine tool's machining performance in specified machining applications.

Machining tests to evaluate the geometric accuracy of a single surface are described in Clause 5, and those to evaluate geometric relationship of multiple machining features are described in Clause 6. Clause 7 presents machining tests for other objectives: machining tests for evaluation of short-term capability (7.2), and machining tests for evaluation of thermal influence (7.3).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 230-1:2012, *Test code for machine tools — Part 1: Geometric accuracy of machines operating under no-load or quasi-static conditions*

ISO 1101:2017, *Geometrical product specifications (GPS) — Geometrical tolerancing — Tolerances of form, orientation, location and run-out*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 230-1:2012 and ISO 1101:2017 apply.

ISO and IEC maintain terminology 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/

4 Preliminary remarks

4.1 Measuring units

In this document, all linear dimensions and deviations are expressed in millimetres. All angular dimensions are expressed in degrees. Angular deviations are, in principle, expressed in ratios but in some cases, micro-radians or arc-seconds can be used for clarification purposes. Formula (1) should always be considered:

$$0{,}010/1\,000 = 10\ \mu\text{rad} \approx 2'' \tag{1}$$

Temperatures are expressed in degrees Celsius (°C).

4.2 Reference to ISO 230-1

Reference should be made to ISO 230-1, especially for the installation of the machine before testing and for the recommended accuracy of the testing equipment.

4.3 Machining conditions

In principle, the machining tests described in this document shall be machined under conditions that are typical for the use of the machine tool under test. If no typical use is defined, and to recognize significant errors of the machine tool under test from the geometric accuracy of the finished test piece, the tests should be performed under the following conditions:

a) machine tool axes shall be moved slowly to minimize dynamic effects and behave in a quasi-static manner, i.e. with no dynamic influences and servo [control] limitations. However, this provision is not applicable to some machine tool-specific test pieces execution (e.g. five-axes contouring test pieces) where the aim is to test machine performances at specified tool path feed speed;

b) the machine tool and the cutting tool should not be influenced by any significant machining forces, which is the case for most finishing cuts;

c) the cutting tool and the cutting parameters, i.e. feed, speed, tool geometry, etc., should be suitable for the material machined;

d) the material machined should be uniform, i.e. the change in its parameters like hardness and strength over the machined surface should be within the prescribed tolerance;

e) the cutting tool used should not be worn and should not wear significantly during the machining of the test pieces;

f) for the tests described in Clauses 5 and 6, the machine tool should not be influenced by any thermal load, i.e. the machine tool should be in a thermally stable condition. The influence of the environmental thermal change, the spindle rotation, rotating axes, and the linear motion of components, can be checked by the tests described in ISO 230-3:2020. 7.3 describes machining tests to check the thermal influence on the geometric accuracy of the finished test piece.

Although quasi-static geometric errors of a machine tool are major contributors, it is always possible that other factors, e.g. the dynamic contouring error, can impose significant influence on the finished test piece's geometry.

4.4 Tests to be performed

When testing a machine, it is by no means necessary or possible to carry out all the tests described in this document. When the tests are required for acceptance purposes, it is up to the user to choose, in agreement with the manufacturer/supplier, those tests relating to the components and/or the properties of the machine which are of interest. These tests are to be clearly stated when ordering a machine. Mere reference to this document for the acceptance tests, without specifying the tests to be carried out, and without agreement on the relevant expenses, cannot be considered as binding for any contracting party.

In principle, no more than one piece of each type should be machined for acceptance purposes. In case of special requirements, such as statistical assessment of the machine tool performance (see 7.2), the machining of more test pieces is required.

4.5 Measuring instruments

Measuring instruments indicated in the tests described in the following sections are examples only. Other instruments capable of measuring the same quantities and having the same, or a smaller, measurement uncertainty can be used. Reference shall be made to ISO 230-1:2012, Clause 5, which indicates the relationship between measurement uncertainties and the tolerances.

When a “linear displacement sensor” is referred to, it can mean not only dial test indicators (DTI), but any type of linear displacement sensor such as analogue or digital dial gauges, linear variable differential transformers (LVDTs), linear scale displacement gauges, or non-contact sensors, when applicable to the test concerned (see ISO 230-1:2012, Clause 4).

In the same way, when a “squareness reference artefact” is mentioned, it can mean e.g. a granite or ceramic or steel or cast-iron square, a cylinder square, a reference cube, or, again, a special, dedicated artefact.

4.6 Location of test pieces

Test pieces shall be machined in the general location where production parts are machined. If no general location is specified for the machine tool under test, the test piece should be placed approximately at mid-travel of the X-axis, and in positions along Y- and Z-axes suitable for the location of the test piece and/or fixture, and for the tool lengths if not specified otherwise in the test procedure.

4.7 Fixing of test pieces

The test piece shall be conveniently mounted on a proper fixture, such that maximum stability of cutting tools and fixture is achieved. The mounting surfaces of the fixture and of the test piece shall be flat. A suitable means of fixturing should be used to allow for tool breakthrough and full-length machining of a centre hole, for example. The test piece should also be mounted on the fixture with countersink/counterbored screws, such that subsequent machining does not interfere with the screws. Other methods are possible and may be selected. The overall height of the test piece depends on the selected method of fixing. Fixtures used for machining are preferably used also for measurements.

4.8 Material of test pieces, tooling and cutting parameters

The test piece material, tooling and the subsequent cutting parameters are subject to agreement between manufacturer/supplier and user and shall be recorded. The test piece material shall be specified with proper material designations.

Machine-specific International Standards specify the size of test pieces. If not, it is subject to agreement between manufacturer/supplier and user.

4.9 Rough cuts

This document does not specify roughing operations. Preliminary cuts should be taken in order to make the depth of cut as constant as possible.

4.10 Diagrams

Diagrams in this document illustrate only an example test setup. The coordinate system, and the name of axes, depicted in diagrams are also only examples.

4.11 Information to be recorded

For tests made according to the requirements of this document, the following information shall be compiled as completely as possible and included in the test report. Additional information to be reported is described in each test.

a) material and designation of the test piece;

b) material, dimensions, and number of teeth of the tool;

c) cutting speed(s);

d) feed speed(s);

e) depth(s) of cut;

f) other cutting parameters, e.g. cutting fluid;

g) position and orientation of the test piece in the work space;

h) direction of cuts (where applicable);

i) measuring instrument and method;

j) measurement uncertainty with coverage factor $k = 2$.

4.12 Software compensation

When software facilities are available for compensating geometric, thermal or dynamic errors based on an agreement between the manufacturer/supplier and user, the relevant test can be carried out with these compensations. Some numerical thermal error compensations are based on temperature measurements on the machine structure, and others are based on operating conditions, e.g. the spindle rotation speed. Such a thermal compensation can be used, based on an agreement between the manufacturer/supplier and user. When any software compensation is used, this shall be stated in the test report.

5 Machining tests to evaluate the geometric accuracy of a single surface

5.1 General

Clause 5 specifies a set of machining tests, whose objective is to finish a single surface and to evaluate its geometric accuracy. The main objective of the tests is to observe the influence of quasi-static error motions, as well as position and orientation errors of axis average lines, of linear axes, rotary axes, or a spindle.

This clause does not specify drilling tests. The position accuracy of a drilled hole is often influenced by many factors other than the machine's geometric errors.

5.2 Machining of a cylindrical surface

5.2.1 Machining of rotating disc

5.2.1.1 Object

A cylindrical surface of a rotating test piece is machined. It is typically a turning operation with a non-rotating tool. It may be the cylindrical grinding with a rotating wheel. The circularity of the machined cylindrical surface is evaluated (see Table 1).

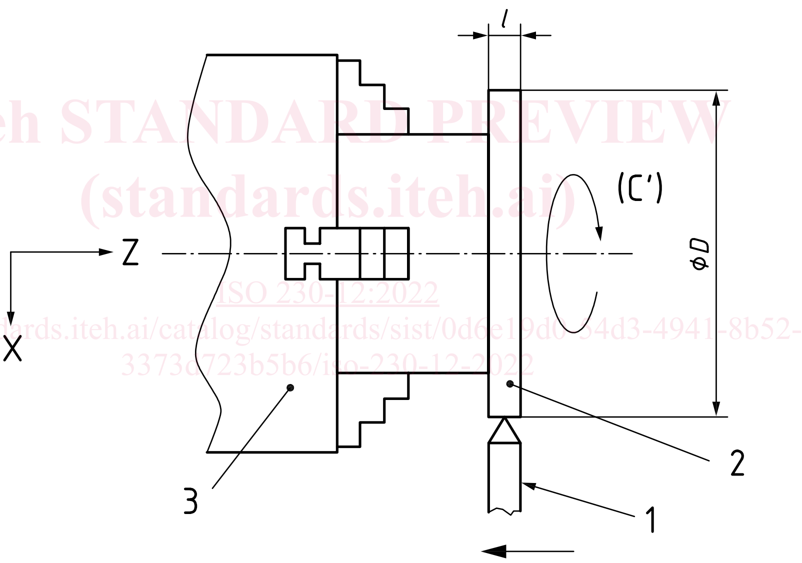
Table 1 — Machining of a rotating disc

Inputs			**Outputs**	**Major error contributors for machining in Figure 1**
No. of simultaneous linear motions during machining	No. of simultaneous rotary motions during machining	Type of interpolation	Geometric features to be measured	Radial error motion of (C')-axis, $E_{X(C')}$ Tilt error motion of (C')-axis, $E_{B(C')}$ Radial and tilt error motion of tool-holding spindle axis, if a rotating tool is used.
1 (Z)	1 (C') or 2, if a rotating tool is used.	—	Roundness	

The geometric errors observed in this test can be also observed in the test in 5.2.2. When the machine tool under test is used for the machining of not only thin ring parts but also cylindrical parts, the test in 5.2.2 should be carried out.

5.2.1.2 Test procedure

A cylindrical surface of a rotating test piece is machined by feeding a non-rotating tool (or a rotating wheel) to the axial direction of spindle (Z) (see Figure 1).



Key

1 cutting tool
2 test piece
3 machine chuck
l width of the cylindrical surface
D diameter of the cylindrical surface

Figure 1 — Machining of a rotating disc

The width of the cylindrical surface, *l*, should be chosen to suit the measuring instrument. The roundness shall be measured at middle of the width of the cylindrical surface.

5.2.1.3 Geometric features to be measured

The roundness of the finished cylindrical surface.

5.2.1.4 Measuring instrument

A roundness measuring machine.

5.2.1.5 Possible contributors to machining error

The radial error motion of a workholding spindle (C′) is the main contributor to the roundness of the finished surface. Its tilt error motion can contribute as well, and its influence is typically proportional to the distance from the chuck face to the machining position.

The contribution of the straightness error motion of the linear axis (Z) is negligibly small.

On machine tools with rotating tool spindle, radial and tilt error motions of tool spindle influence the test result.

5.2.1.6 Machines to be tested

— Machine tools that finish a rotating test piece by turning operations, e.g. turning machines and turning centres, and a machining centre with a rotary table with turning capability;

— cylindrical grinding machines.

5.2.1.7 Information to be reported

— The nominal diameter of the finished cylindrical surface, *D*;

— the width of the cylindrical surface, *l*;

— the distance from the chuck jaw face to the machining position;

— spindle speed and feed speed.

NOTE Details for machining parameters are shown in ISO 13041-6, ISO 1708 and ISO 2433.

5.2.2 Machining of rotating cylinder with a feed in the axial direction

5.2.2.1 Object

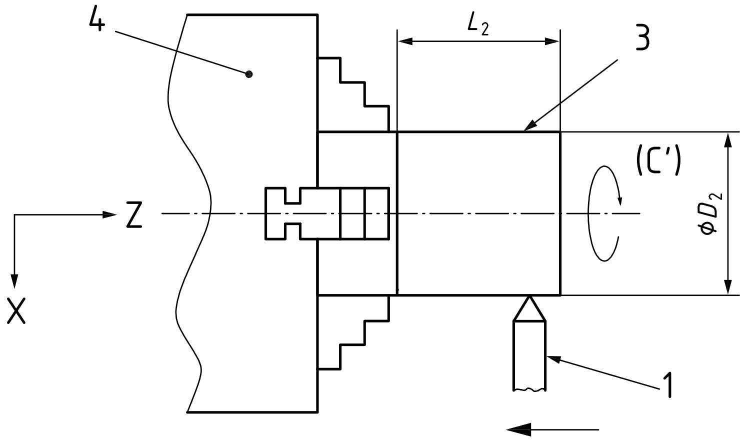
A cylindrical surface of a rotating test piece is machined by feeding a non-rotating tool in a turning operation, or a rotating wheel in a cylindrical grinding operation, to the axial direction of the spindle (Z). Unlike the test in 5.2.1, three-dimensional geometry of the finished test piece is evaluated (see Table 2).

Table 2 — Machining of a cylindrical surface with a feed in the axial direction

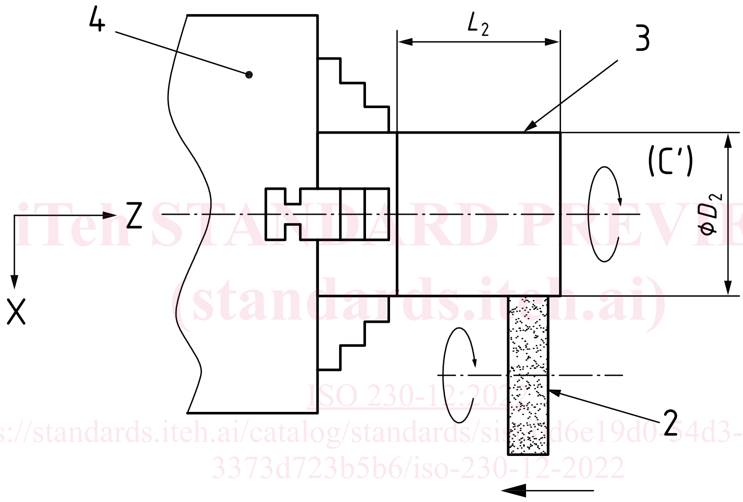
Inputs			Outputs	Major error contributors for machining in Figure 2
No. of simultaneous linear motions during machining	No. of simultaneous rotary motions during machining	Type of interpolation	Geometric features to be measured	Tilt error motions of (C')-axis, $E_{B(C')}$, Radial error motion of (C')-axis, $E_{X(C')}$ Parallelism error of (C')- to Z-axis, $E_{B(0Z)(C')}$. Straightness error motion of Z-axis, E_{XZ}. For a rotating tool: Radial and tilt error motion of tool spindle Tool spindle axis of rotation not parallel to Z Conical grinding wheel
1 (Z)	1 (C') or 2, if a rotating tool is used.	—	Cylindricity. The cylindricity may be estimated by the roundness and the consistency of diameters. Roundness at different Z positions	

5.2.2.2 Test procedure

A cylindrical surface of a rotating test piece is turned by feeding a non-rotating tool to the axial direction of the spindle (Z) [see Figure 2 a)]. The length of the finished cylinder, L, is typically the diameter of the finished test piece multiplied by 0,8 to 2,5, depending on the chucking of the test piece or the orientation of the spindle axis (vertical or horizontal). Figure 2 b) shows the setup on a cylindrical grinding machine.



a) Turning by a non-rotating cutting tool



b) Grinding by a grinding wheel

Key

1 cutting tool
2 grinding wheel
3 test piece
4 machine chuck
D_2 diameter of the finished cylinder
L_2 length of the finished cylinder

Figure 2 — Machining of a cylindrical surface with a feed in the axial direction

5.2.2.3 Geometric features to be measured

— The roundness of the finished cylindrical surface at two different axial (Z) positions;

— the cylindricity of the finished test piece (see ISO 12180-1). The cylindricity may be estimated by the roundness and the consistency of diameters machined at different Z positions.

5.2.2.4 Measuring instruments

— Roundness measuring machine;

— coordinate measuring machine (CMM);

— outside/inside micrometer to measure the consistency of diameters.

5.2.2.5 Possible contributors to machining error

See 5.2.1.5 for contributors to the roundness at each axial position (Z).

The difference in the roundness at two axial positions (Z) shows the influence of the tilt error motion of the spindle (C'). Its influence is proportional to the distance between two measured positions.

The parallelism error of the linear axis (Z) and the spindle axis (C') makes the finished test piece conical. It causes the inconsistency of the diameter at different axial (Z) positions, which increases the cylindricity error of the finished test piece. Another contributor to the cylindricity error of the finished test piece is the straightness error motion of the Z-axis in the radial (X) direction.

When a rotating tool is used, radial and tilt error motions of tool spindle, a conical grinding wheel, and a spindle of rotating tool not parallel to the Z-axis of machine tool, can contribute.

5.2.2.6 Analogous tests

An internal cylindrical surface of a rotating test piece is turned by feeding a non-rotating boring tool to the axial direction of the spindle (Z) (see Figure 3). Contributors to the machining error are analogous to those in the test above. In a boring operation, angular error motions of the linear axis, e.g. E_{BZ}, can have larger influence on the cylindricity of the finished test piece due to the larger offset in Z.

