Trends and future possibilities of ISO standards for machine tools

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Abstract

The paper focuses on accuracy tests, capability tests and environmental assessment for NC machine tools.
For accuracy tests the range of ISO standards is presented in a short overview. Main developments of the last years are presented, as well as gaps that are being closed by actual research activities. Advantages of accuracy standards are discussed, as well as future developments.
A capability test for machine tools is defined in an ISO project; the standard under development is just about to be finished. Differences in the approach of the ISO committee on statistics and the ISO committee for machine tools are presented and discussed.
Environmental assessment of machine tools is a new topic that caused the launch of new projects within the ISO committee for machine tools. The statuses of the projects are explained and future developments are discussed. Goals and benefits of this group of standards are given and discussed.
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1 Introduction

The introduction gives a short overview of ISO technical committees responsible for machine tools, for accuracy testing of machine tools, and for environmental issues for machine tools.
Relevant standards for accuracy tests, capability tests, and environmental issues of machine tools are summarized to allow the reader selecting standards relevant to him easily.

1.1 ISO Technical Committee ISO/TC 39, machine tools

The relevant ISO committee for machine tools is ISO/TC 39 that is responsible of a total of 161 ISO standards. 22 countries participate in the work of ISO/TC 39, machine tools, the participating countries being Austria, Belgium, Brazil, China, Czech Republic, Finland, France, Germany, India, Italy, Japan, Korea (Democratic People's Republic), Korea (Republic of), Poland, Portugal, Russian Federation, Spain, Sweden, Switzerland (holding the secretariat and chairmanship), Thailand, USA, and United Kingdom. Another 20 countries are observers that do not have the obligation of voting on projects and documents, but may attend any meetings and comment documents.
ISO/TC 39, machine tools, is subdivided into 5 subcommittees (SC) with the topics test conditions (SC 2), woodworking machines (SC 4), noise (SC 6), work holding spindles and chucks (SC 8), and safety (SC 10).
Standards related to machine tool accuracy and to capability are written and maintained by ISO/TC 39/SC 2, test conditions for metal cutting machine tools. 16 participating and 11 observing countries deal with 66 standards and are led by US that holds the secretariat and chairmanship.
Standards related to environmental issues are developed within one of the working groups (WG) of ISO/TC 39, machine tools, i.e. within ISO/TC 39/WG 12, environmental evaluation of machine tools

1.2 Subcommittee ISO/TC 39/SC 2, test conditions for metal cutting machine tools

The standards of ISO/TC 39/SC 2, test conditions for metal cutting machine tools, can be divided into two groups: basic standards and machine specific standards. Basic standards are applicable to all types of machine tools; machine specific standards are applications of the basic standards to a specific type of a machine tool. Basic standards offer basic definitions, e.g. definition of straightness, and methods of testing; machine specific standards provide a selection of methods assessed as best suitable for the specific machine tool including tolerances for most of the tests.

Basic standards
ISO 230-1:2012, Test code for machine tools -- Part 1: Geometric accuracy of machines operating under no-load or quasi-static conditions
ISO 230-2:2006, Test code for machine tools -- Part 2: Determination of accuracy and repeatability of positioning numerically controlled axes
ISO 230-3:2007, Test code for machine tools -- Part 3: Determination of thermal effects
ISO 230-4:2005, Test code for machine tools -- Part 4: Circular tests for numerically controlled machine tools
ISO 230-5:2000, Test code for machine tools -- Part 5: Determination of the noise emission (under the responsibility of ISO/TC 39/SC 6, noise of machine tools)

ISO 230-6:2002, Test code for machine tools -- Part 6: Determination of positioning accuracy on body and face diagonals (Diagonal displacement tests)
ISO 230-7:2006, Test code for machine tools -- Part 7: Geometric accuracy of axes of rotation
ISO/TR 230-8:2010, Test code for machine tools -- Part 8: Vibrations, a technical report (TR)
ISO/TR 230-9:2005, Test code for machine tools -- Part 9: Estimation of measurement uncertainty for machine tool tests according to series ISO 230, basic equations, a technical report (TR)
ISO 230-10:2010, Test code for machine tools -- Part 10: Determination of the measuring performance of probing systems of numerically controlled machine tools
ISO 26303:2012, Machine tools -- Short-term capability evaluation of machining processes on metal-cutting machine tools

Machine specific standards

Machine specific standards can be sub-divided for milling, drilling and boring machines and machining centres, for turning machines, grinding machines, electro-discharge machines (EDM), broaching machines, hobbing machines and machining heads. All are related to accuracy tests.
Machine specific standards for milling, drilling and boring machines and machining centres address

- milling machines with table of variable height (ISO 1701-1:2001, ISO 1701-2:2004), milling machines with table of fixed height (ISO1984-1;2001, ISO 1984-2:2001), bridge-type milling machines (ISO 8636-1:2000, ISO 8636-2:2007), machining centres (ISO 10791 series),
- radial drilling machines (ISO 2423:1982), vertical drilling machines (ISO 2772-1:1973, ISO 2772-2:1974, ISO 2773-1:1973, ISO 2773-2:1973), coordinate drilling machines (ISO 3190:1975), coordinate drilling and boring machines (ISO 3686-1:2000, ISO 3686-2:2000)
- boring and milling machines with horizontal spindle (ISO 3070-1:2007, ISO 3070-2:2007, ISO 3070-3:2007)

The most advanced standards in this group are the standards of series ISO 10791, test conditions for machining centres, which comprise the following parts:
ISO 10791-1:1998, Test conditions for machining centres -- Part 1: Geometric tests for machines with horizontal spindle and with accessory heads (horizontal Z-axis)
ISO 10791-2:2001, Test conditions for machining centres -- Part 2: Geometric tests for machines with vertical spindle or universal heads with vertical primary rotary axis (vertical Z-axis)
ISO 10791-3:1998, Test conditions for machining centres -- Part 3: Geometric tests for machines with integral indexable or continuous universal heads (vertical Z –axis)

ISO 10791-4:1998, Test conditions for machining centres -- Part 4: Accuracy and repeatability of positioning of linear and rotary axes
ISO 10791-5:1998, Test conditions for machining centres -- Part 5: Accuracy and repeatability of positioning of work-holding pallets
ISO 10791-6:1998, Test conditions for machining centres -- Part 6: Accuracy of feeds, speeds and interpolations
ISO 10791-7:1998, Test conditions for machining centres -- Part 7: Accuracy of a finished test piece
ISO 10791-8:2001, Test conditions for machining centres -- Part 8: Evaluation of contouring performance in the three coordinate planes
ISO 10791-9:2001, Test conditions for machining centres -- Part 9: Evaluation of the operating times of tool change and pallet change
ISO 10791-10:2007, Test conditions for machining centres -- Part 10: Evaluation of thermal distortions
Machine specific standards for turning machines include standards for general purpose parallel lathes (ISO 1708:1989), vertical turning and boring lathes (ISO 3655:1986), turret and single spindle automatic lathes (ISO 6155:1998), copying attachments for lathes (ISO 8956:1986) and NC turning machines and turning centres (ISO 13041 series).
The most detailed standard for turning machines is series ISO 13041 consisting of the following parts:
ISO 13041-1:2004, Test conditions for numerically controlled turning machines and turning centres -- Part 1: Geometric tests for machines with a horizontal workholding spindle
ISO 13041-2:2008, Test conditions for numerically controlled turning machines and turning centres -- Part 2: Geometric tests for machines with a vertical workholding spindle
ISO 13041-3:2009, Test conditions for numerically controlled turning machines and turning centres -- Part 3: Geometric tests for machines with inverted vertical workholding spindles
ISO 13041-4:2004, Test conditions for numerically controlled turning machines and turning centres -- Part 4: Accuracy and repeatability of positioning of linear and rotary axes
ISO 13041-5:2006, Test conditions for numerically controlled turning machines and turning centres -- Part 5: Accuracy of feeds, speeds and interpolations
ISO 13041-6:2009, Test conditions for numerically controlled turning machines and turning centres -- Part 6: Accuracy of a finished test piece
ISO 13041-7:2004, Test conditions for numerically controlled turning machines and turning centres -- Part 7: Evaluation of contouring performance in the coordinate planes
ISO 13041-8:2004, Test conditions for numerically controlled turning machines and turning centres -- Part 8: Evaluation of thermal distortions
6 machine specific standards deal with testing grinding machines, in detail with surface grinding machines (ISO 1985:1998, ISO 1986-1:2001, ISO 4703:2001), internal cylindrical grinding machines (ISO 2407:1997), external cylindrical and

universal grinding machines (ISO 2433:1999), and centreless grinding machines (ISO 3875:2004).
EDM are covered by three machine specific standards, two for die sinking EDM (ISO 11090-1:1998, ISO 11090-2:1998), one for wire EDM (ISO 14137:2000).
Test conditions for broaching machines are covered by three standards, i.e. for internal broaching machines (ISO 6480:1983, ISO 6779:1981) and for surface type broaching machines (ISO 6481:1981).
Acceptance conditions for gear hobbing machines are covered by ISO 6545:1992.
ISO 5734:1986 deals with acceptance conditions for dividing heads for machine tools.

1.3 Working group (WG) ISO/TC 39/WG 12, environmental evaluation of machine tools

This new working group deals with environmental issues by developing
ISO 14955-1, Machine tools -- Environmental evaluation of machine tools -- Part 1: Design methodology for energy-efficient machine tools, and
ISO 14955-2, Machine tools -- Environmental evaluation of machine tools -- Part 2: Methods for measuring energy supplied to machine tools and machine tool components.
Both standards are not published yet as they are still under development.

2 Trends and gaps in ISO standards for machine tools

2.1 Trends and gaps in ISO standards for accuracy testing of machine tools

Current ISO standards cover mainly 3-axis machine tools, 5-axis machine tools are covered only partly. Participating countries and their industries stressed the importance to deal fully with 5-axis machine tools and started projects to cover 5-axis machining centres, a first trend for accuracy testing of machine tools.
ISO 10791-1:1998, Test conditions for machining centres -- Part 1: Geometric tests for machines with horizontal spindle and with accessory heads (horizontal Z-axis) is under revision to include annexes to deal with classical geometric tests of 5-axis machine tools with horizontal and vertical swivelling rotary tables. In consequence also ISO 10791-6:1998, Test conditions for machining centres -- Part 6: Accuracy of feeds, speeds and interpolations, is under revision. Kinematic tests for machine tools with two rotary axes in the spindle head, with two rotary axes in the workpiece side, and with a swivel head and/or a rotary table are covered. The kinematic tests comprehend testing of 5-axis machine tools with ball bars, linear probes and radial tests, a method using three linear displacement sensors and a spherical artefact.
The development of this standard was in close cooperation with research institutes that have been engaged in calibration of 5-axis machine tools.

Representatives of such research institutes are active members of the relevant working group.
Furthermore, ISO 10791-7:1998, Test conditions for machining centres -- Part 7: Accuracy of a finished test piece, is under revision in order to include test pieces for 5-axis machining. Also this development was in close cooperation with relevant research institutes.
Thermal influences on machine tools are an important issue. ISO 230-3:2007, Test code for machine tools -- Part 3: Determination of thermal effects, deals with thermal influences from the environment, from rotating spindles, and from moving linear axes. Recent research activities showed that rotary axes and swivelling axes can induce significant thermal errors, which showed a gap in the current standards and started another trend in machine tool accuracy tests related to thermal influences, i.e. having more thermal effects tested.
In industry we can see a trend to measurements on machine tools, e.g. to align workpieces, to define tool offsets, to measure the actual position of a rotary table axis, to measure machined parts. Accordingly we have the trend in machine tool standards to include testing of probing on machine tools. Basic standard ISO 230-10:2010, Test code for machine tools -- Part 10: Determination of the measuring performance of probing systems of numerically controlled machine tools, defines repeatability checks for mechanical probing on machine tools, as well as size (1D), 2D and 3D probing performance.
Gaps in this area are scanning probes and non-contacting probes, like optical and laser systems, inductive and capacitive systems. Furthermore the basis standard ISO 230-10, measuring performance, is based on probing on machining centres, and not specifically on probing on turning centres or grinding machines or EDM. Currently ISO/TC 39/SC 2, testing of machine tools, is working on an amendment to ISO 230-10 to include testing of scanning probes on machine tools.

2.2 Trends and gaps in ISO standards for capability tests for machine tools

Basic standard ISO 26303:2012, Machine tools -- Short-term capability evaluation of machining processes on metal-cutting machine tools, has just been published. In principle this is an updated version of VDMA recommendation 8669.
During the development of ISO 26303:2012, capability, ISO technical committee ISO/TC 69, applications of statistical methods, had some objections, because this standard differs from capability standards of ISO/TC 69, statistics, which might be seen as a gap in this standard.
One point is related to the term “process performance” specified in ISO 22514-3 that corresponds to the term “short-term capability” in ISO 26303:2012, capability. The term “short-term capability” has been widely used in the machine tool industry for many years; therefore, ISO/TC 39/SC 2, testing of machine tools, decided to maintain this term, but explains the relation to ISO 22514-3 in the document.

Another point of concern from ISO/TC 69, statistics, is the use of range values in ISO 26303:2012, capability. Range values are especially proposed and recommended for features machined under in-process measurement control and for roughness values, as both items in general do not offer Gaussian distribution. Furthermore, range values are common practice in the machine tool industry; therefore range values are kept in the standard.
A further point of concern from ISO/TC 69, statistics, was the strict rule on the performance of the measurement equipment in ISO 26303:2012, capability: 50 repeated measurements on one workpiece shall have a standard deviation of less than 2.5% of the tolerance to qualify the measurement equipment as fit for the purpose. Theoretical calculations and practical experience proved the need for such a strict rule; therefore ISO/TC 39/SC 2, testing of machine tools, kept this requirement.

2.3 Trends and gaps in ISO standards for environmental issues of machine tools

ISO 14955-1, Machine tools -- Environmental evaluation of machine tools -- Part 1: Design methodology for energy-efficient machine tools, is currently under vote as a draft international standard (DIS).

This standard is not for the evaluation of machine tools, but for setting up a process for integrating environmental aspects into product design and development and evaluating the integration of design procedures for energy efficiency. The standard restricts itself to the energy supplied to the machine tool during the use stage of the machine tool, because this is the most relevant phase for environmental impact of machine tools in an industrial manufacturing environment. With this methodology components relevant for energy supplied to the machine tool shall be known for the manufacturer and user of the machine tool.
Lists of environmentally relevant improvements and machine components, control of machine components and combinations of machine components are given in two informative annexes, one for metal cutting machine tools and one for metal forming machine tools. These annexes allow a comparison of machine tools under evaluation to the state of the art.
ISO 14955-2, Machine tools -- Environmental evaluation of machine tools -- Part 2: Methods for measuring energy supplied to machine tools and machine tool components, is currently under discussion within ISO/TC 39/WG 12, environmental evaluation of machine tools. This standard defines system boundaries, modes of operation, shift regimes, measurement procedures and measurement uncertainties, reporting and monitoring of results. With this standard, repeatable measurements during machine tool operations will be definable, without defining the operations.

3 Future possibilities

3.1 Future possibilities for accuracy testing of machine tools

ISO series 10791, test conditions for machining centres, and ISO series 13041, test conditions for numerically controlled turning machines and turning centres, have been well received by industry. These two series contain the most up-to-date test procedures for numerically controlled machine tools.

As a future possibility I see an ISO series for numerically controlled grinding machines or grinding centres that focus on up-to-date test procedures for all or for the most important NC grinding machines. Currently six ISO standards cover test conditions for grinding machines (see 1.2). These standards are dated between 1998 and 2004 and certainly would need some revision, especially in the light of new features on NC grinding machines and of new test equipment applied in industry.

As another future possibility I see an ISO series for numerically controlled drilling machines. Currently eight ISO standards cover test conditions for drilling machines, but those standards are dated between 1973 and 2000. As another option up-to-date testing of NC drilling machines might be also included in ISO series 10791, test conditions for machining centres, as this series already includes NC milling and boring machines.

A further future possibility are ISO documents dealing with compensation of NC machine tools. Today a lot of compensations are offered, but often it is not clear, what exactly is covered by the offered compensation, as different expressions are used or the same expressions are used for different items. ISO/TC 39/SC 2, test conditions for metal cutting machine tools, has already started a project in this area and discussed a first document, ISO preparatory draft technical report ISO/PDTR 16907.2: 2012-02-21, Numerical compensation of geometric errors of machine tools.

This ISO technical report will contain terms and definitions, kinematic representation of machine tool structures, geometric errors of machine tool, determination of geometric errors, representation of geometric errors, compensation of geometric errors, application of numerical compensation of geometric errors, and validation of numerical compensation of geometric errors.

Many parts will summarize and reference basic standards of ISO series 230, test code for machine tools, like the parts on kinematic representation of machine tools, geometric errors and their determination. In addition to the basic standards this report shall give definitions for types of compensation, like a definition for volumetric compensation, point to interrelations between e.g. angular and linear error motions. Testing compensated machine tools is another point of concern as not all test procedures can be applied on geometrically compensated or partly compensated machine tools.

This technical report shall facilitate comparability between geometrically compensated machine tools and shall help to understand potentials and limits of compensation, based on a common language.

3.2 Future possibilities for capability tests of machine tools

For the future I see ISO 26303:2012, Machine tools -- Short-term capability evaluation of machining processes on metal-cutting machine tools, to be applied in industry and perhaps compared with standards of ISO/TC 69, statistics. Practical experience with the standard might lead to a revision that will strengthen ISO 26303 as it is or align ISO 26303 to existing standards of ISO/TC 69, statistics.
In the relevant working group for capability of machine tools, ISO/TC 39/SC 2/WG 7, reliability, availability and capability, topics on reliability and availability have been discussed, but no participating country formulated a new work item proposal. I see one reason for discontinuing these topics in the fact, that duty cycles for machine tools are predictable in a few cases only; therefore calculations on reliability and availability are rather vague and often lack reliable data from the application field. Here I do not see any activity in the near future.

3.3 Future possibilities for environmental issues of machine tools

Project ISO 14955-1, design methodology for energy-efficient machine tools, will allow comparing machine tools to the state of the art, when energy supplied to the machine tool is concerned. Furthermore machine tool components relevant for energy supplied to the machine tool will be identified.
Project ISO 14955-2, methods for measuring energy supplied to machine tools and machine tool components, will define reliable and repeatable measurements including statements of measurement uncertainty for energy measurements on machine tools.
Both parts of ISO series 14955, environmental evaluation of machine tools, will allow producing reliable data on energy supplied to machine tools. This is a necessary basis for reliable selection of machining processes if environmental issues are concerned.
For a fair and relevant comparison of similar machine tools and a fair and relevant comparison for machine tools with different features further parts of series ISO 14955 will be necessary, which is a future possibility and need. Today it is not clear if we need definitions of test pieces for different types of machines tools.
First discussions showed that the variety of test pieces might become very large, especially if we include different quality of the test pieces (or different tolerances), different machining times, or different workpiece and/or tool materials.
Another option might be a general description of machine tool operations necessary for environmental evaluation of machine tools. This approach might be seen similar to ISO 26303, capability, where the procedure for evaluation is described, but not the specific feature to be machined. For environmental evaluation test pieces or test procedures have to be defined clearly to achieve relevant and comparable results.

4 Benefits of standards and of participating in standardizing process

A significant benefits for participating countries is a simplified standardisation process, as standards are produced just once, meaning just internationally. Most participating countries of ISO/TC 39, machine tools, are not producing own national standards for machine tools since many years, but just use ISO standards.
International standards form a uniform testing and understanding for interested parties, i.e. machine tool manufacturers and users, as well as academia. This starts with clear definitions and ends with comprehensive descriptions of complex procedures and lists of relevant parameters to be stated with test reports. Standards help to keep market access open, as criteria are defined and accepted internationally.
International standards are a kind of protection from unrealistic expectations by assigning tolerances to test procedures, as well as limits of applications and warnings.
ISO standards also point to practical problems, e.g. an uncertainty statement for positioning tests of linear axes. Such uncertainty statements have been neglected for many years. With ISO 230-2, positioning tests, such statements are presented in an annex, including the evaluation of uncertainties. With this a critical item in positioning tests is addressed.
Participating in the standardization process is also using a platform for learning: representatives from different companies, national metrology institutes and universities present their arguments and findings in the meetings, discuss impacts on future standards and search for common grounds. Participation gives early access to information that might shape the market in the future.
Participating in the standardization process is also being a partner in taking decisions on standards, on topics, and on timing of standardisation projects. And it gives your company or your organisation a voice in the development of standards.

5 Summary

ISO/TC 39, machine tools, and its 22 participating countries maintain some 160 standards related to machine tools, including eleven basic standards and numerous machine specific standards for machine tool testing.
Identified trends are the extension of the standards to cover 5-axis machine tools including thermal influences on those machine tools, to cover measuring on machine tools with contacting or non-contacting probes, to cover evaluation of short-term capability values, and environmental assessments of machine tools.
Future possibilities are standard series for groups of machine tools, like NC grinding centres, standards for issues related to compensation of machine tools, and standards to define test procedures and machine operations for environmental assessment of machine tools.

Major benefits for participating in machine tool standards development are being member in a platform for learning about latest developments, sharing a common view on actual problems and their solutions, and influencing contents of standards that might shape future markets.