Developments in BSI and ISO machine tool accuracy standards

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Abstract

The geometric accuracy of conventional machine tools is tested, in general, in accordance the principles proposed by Schlesinger [1], who established a system of test charts for a range of metal working machine tools. With the advent of NC and CNC machine tools, however, it has been found necessary to extend the basic Schlesinger tests which have now been incorporated in many National and International Standards.

Certainly, up to the 1980's most standards on test conditions for machine tools, which represented most of the production of the MTE/1 (British Standards Institution [BSI]) and TC39 (International Organisation for Standardisation [ISO]) technical committees, only dealt with geometric accuracy and, in order to provide some information on the cutting performance, with finishing cuts.

However, since that period, the emphasis has widened with the increased complexity of CNC and by demand from industry for different tests for assessing more thoroughly the machine performance. Also, ten years ago, over 90% of BSI's standards were purely national, today, the tables have turned with over 90% of BSI's standards being either dual numbered from European and International standards or renumbered as ISO standards.

This paper only describes the current status of the relevant BSI and ISO standards on machine tool testing and previews how this harmonisation will affect our national outlook on standards. It does not address safety related standards that are produced by CEN (Comite European de Normalisation - European Committee for Standardisation).

Background

At a meeting of the British Association for the Advancement of Science in August 1906, its Chairman, Sir John Wolfe Barry, stated that, "Standardisation is a rather barbarous word, but describes by a short cut and better than any paraphrase, an important departure which is of great interest to us all, the study

The British Engineering Standards Association, forerunner of BSI, was founded in 1901 to coordinate the development of national standards and represented, in that time, a major breakthrough in the history of technology and industrialisation. This foundation of BSI preceded by nearly 20 years that of other major national standards bodies.

In April 1926, those countries that had set up standards bodies met and formed the International Federation of the National Standardising Associations (ISA). The ISA lasted until 1939 when war broke out in Europe, it was eventually replaced by the International Organisation for Standardisation (ISO) that was formed on 23rd February 1947.

British Standards Institution (BSI)

BSI was incorporated by Royal Charter in 1929: a non-profit-distributing organisation, BSI remains independent of Government, industry or trade associations.

BSI plays a vital enabling role in the creation of standards. Interested parties representing the relevant industries, trade associations, consumer bodies, product testing organisations and local government are brought together by BSI to define the new British Standard.

One of the first British Standards, published in 1903, reduced the number of tramway rails manufactured from 75 to 5 - saving £1 million a year even then. Today, there are nearly 13,000 British Standards, with over 1,200 new standards produced each year. BSI's work is ensuring that, increasingly, they are being adopted worldwide. Equally, all important European automatically become British Standards and all important International Standards are adopted as British Standards.

International Organisation for Standardisation (ISO)

ISO is a worldwide federation of national standards bodies, comprising over 100 members. The object of ISO is to promote the development of standardisation and related activities in the world with a view to facilitating international exchange of goods and services, and to developing cooperation in the sphere of intelligent, scientific, technological and economic activity. The results of ISO technical work are published as International Standards.

An International Standard is the result of an agreement between the member bodies of ISO and may be used as such, or may be implemented through incorporation in national standards of different countries.

International standards are developed on the basis of a project approach through seven project stages. The first important step towards an International Standard is the committee draft (CD) - a document circulated for study with the technical committee or subcommittee. When agreement is reached within the

committee, the CD becomes a Draft International Standard (DIS) which is circulated as an enquiry draft to all member bodies for voting. If this draft meets the acceptance criteria, it is circulated as a Final Draft International Standard (FDIS) for a two-month unconditional vote and, if accepted, is published as an International Standard.

All BSI and ISO standards are reviewed at intervals not exceeding five years.

BSI MACHINE TOOL STANDARDS

BSI technical committee MTE/1 has the overall responsibility for the direction and coordination of work carried out on the national and international field of machine tool standardisation.

Although MTE/1 has the overall responsibility, virtually all the technical work is done at either subcommittee or committee panel level. Currently there are 3 subcommittees and 8 panels reporting directly to MTE/1.

When a new machine tool related work item is accepted by BSI, it is then forwarded to MTE/1 for implementation, who delegate the technical 'working draft' to either a subcommittee or panel. Once the 'working draft' has been prepared to the satisfaction of the subcommittee or panel it is forwarded to MTE/1 for approval. Once approved, it is circulated for public comment. Any comments are then examined by MTE/1 for implementation or rejection before the final draft is forwarded to BSI for publication.

There are nearly 30 published standards (not including standards that have many parts) dealing with such wide topics as symbols, glossary of terms for machine tool ball screws through to methods of test for specific types of machine tools.

Of the 30 standards published, there are probably 2 that are most widely known and these are the BS 3800 series (General Tests for Machine Tools) and the BS 4656 series (Accuracy of Machine Tools and Methods of Test). However, the harmonisation with ISO has brought a 'slight' complication to these series of standards. If the MTE/1 committee considers that a British Standard should be prepared/revised on the basis of an international text, it will forward the working draft or applicable BSI standard to the ISO TC 39 committee. If the eventual ISO standard is confirmed as acceptable to MTE/1 as it stands, the resulting BSI standard could take two possible routes:-

1. If the ISO standard is made up from a number of parts in a similar format to it's equivalent BSI standard (as in BS 3800 and ISO 230) any new parts / revisions to existing parts results in the BSI series being withdrawn and the replacement renumbered as the ISO series. An example of this is BS 3800: Part 1:1990 - "Code of practice for testing geometric accuracy of machines operating under no-load or finishing conditions" which has been withdrawn and is superseded by BS ISO 230-1:1996.

2. If the content of the new ISO standard is identical to the equivalent BSI standard, but not from a similar format (part of a series) then they are simply dual numbered. An example of this is BS 4656: Part 24 :1993 - "Gear Planing Machines" which is dual numbered as ISO 3875:1990.

MTE/1 also have the authority to disregard the eventual ISO standard if the content is totally different from an existing BSI standard. An example of this is BS 4656: Part 30:1992 - Specification for machining centres and computer controlled milling machines. A decision was taken by MTE/1 prior to work commencing on Part 30 that the standard would be a 'stand-alone' document, i.e. it would include the methods of tests for all configurations of machining centre and include all optional axes and features. The ISO equivalent is ISO 10791 - "Test code for machining centres" which is made up of 12 parts.

BS 3800 - General Tests for Machine Tools

This standard is the reference book for machine tool testing, it details all the methods and instruments that may be applied to a particular test but it does not include permissible deviations. Currently there are only 2 parts remaining in this series and these are:-

a) BS 3800: Part 2: 1991 - "Statistical methods for determination of accuracy and repeatability of machine tools".

b) BS 3800: Part 3: 1990 - "Method of testing performance of machines operating under loaded conditions in respect of thermal distortion".

To simplify matters, the new BSI/ISO parts that were previously occupied by the superseded BSI parts are mentioned.

BS ISO 230: Part 1: 1996 - "Geometric accuracy of machines operating under no-load or finishing conditions".

The aim of this part, which supersedes BS 3800: Part 1:1990 which in turn superseded BS 3800: Part 1:1964, is to standardise methods of testing the accuracy of all types of metalworking machine tools by means of geometrical and practical tests such as straightness, flatness, parallelism and squareness. It relates only to testing of geometrical accuracy and not with the checking of the running of the machine tool, e.g. vibrations, abnormal noises, nor with speeds and feeds etc.

This part also provides information on definitions, testing methods, and the use of checking instruments and tolerances. In addition to a description and precautions for use on the various checking instruments such as straightedges, precision levels and lasers.

It describes preliminary checking operations and geometrical checks as well as some special checks such as circularity, cylindricity and consistency of machined diameters.

BS 3800: Part 2: 1991 - "Statistical methods for determination of accuracy and repeatability of machine tools".

This part, which supersedes BS 4656: Part 16:1985, describes statistical methods of testing and evaluating the accuracy and repeatability of numerically controlled machine tools and related accessories by direct measurements on the machine. The methods described are for linear and rotary positioning errors as well as for straightness and angular positioning (pitch, yaw and roll) errors.

The methods for linear and rotary positioning errors involve repeat measurements at a series of random target positions along the length of the axis under test. The number of measurements and the nature of the errors does not allow the confidence level of the results to be estimated accurately. Nevertheless the methods chosen, which assumes a Gaussian distribution, have been shown in practice to have an adequate confidence level and, provided the procedure is followed, will give acceptable results. Definitive statements of the mean positioning error, and the ± 3 sigma (99.7% confidence) repeatability bands (unidirectional and bidirectional) are calculated to give a value of the Total Positioning Accuracy of the axis.

The methods for angular and straightness errors also involve repeat measurements at a series of target positions, but this time the target positions can either be randomly or uniformly spaced. For measurements of straightness, a regression line is fitted to the measured data values using the least squares analysis method.

For the first time, to my knowledge, a test for measurement uncertainty is required in a British machine tool related standard. If the straightness and angular tests are conducted using laser interferometers, then external factors such as air turbulence can affect the repeatability of the measured data. This 'Uncertainty of Measurement' value is determined by moving the machine axis to a target point and recording a number of measurements (equal to the number of measurement runs used in the straightness or angular tests) whilst the axis is stationary. If the uncertainty of measurement value is greater than one-third of the unidirectional repeatability recorded in the standard test then no repeatability figures should be quoted or plotted for that axis

BS 3800: Part 3: 1990 - "Method of testing performance of machines operating under loaded conditions in respect of thermal distortion".

This part gives methods for assessing the contribution to workpiece inaccuracy arising from thermal behaviour of the machine, due to internal heat sources, in respect of:

(a) distortion of the structure; and
(b) drift of the axis drives.

The tests for thermal distortion of the structure are applicable to any machine which incorporates a rotating spindle or spindles supporting the tool or workpiece. The tests are designed to establish the relative displacements occurring between the tool and workpiece sides of the structure as a result of thermal expansion or contraction of key structural elements.

The tests for thermal drift of the axis drives are applicable to numerically controlled machines only and are designed to quantify the effects on positioning accuracy and repeatability of thermal expansion and contraction of axis drives.

The standard specified that the test mandrel and fixture used for the test on the structure should be constructed from a low-expansion alloy material. It also indicated a presentation format for the resultant data.

BS ISO 230: Part 4: 1996 - "Circular Tests for Numerically Controlled Machine Tools"

A decision was taken by MTE/1, in the early 1990's, to prepare a specific standard dealing with circular tests produced on CNC machine tools. It was also decided that the standard would form part of the BS 3800 series and most importantly, that it would be prepared at ISO level. In 1996, ISO published ISO 230-4. This part reproduces verbatim ISO 230-4: 1996 and implements it as a BSI standard.

This part specifies methods of testing and evaluating the circular hysteresis and the circular and radial deviation of circular paths that are produced by the simultaneous movements of two linear axes. It includes definitions, test conditions, test parameters and procedures, as well as a presentation of the results.

BS 4656 'Accuracy of Machine Tools and Methods of Test'

This is probably the backbone of BSI's machine tool testing standards. There are currently 38 parts to this standard, with each part relating to a specific machine type, with the exception of a few parts. The exceptions are Part 12 - Dividing heads, Part 33 - Specification for Floor Plates and Part 38 - Specification for Surface Finish of Test Pieces.

The range of machine types covered include manual machines through to CNC machines and from copying lathes through to boring machines, grinders and power presses, to name but a few. The latest addition has been Part 38 - "Specification for Surface Finish of Test Pieces" which has added permissible deviations of surface quality to all previous machined test pieces from other parts of BS 4656.

This standard gives both methods of test and permissible deviations for each individual test with references made to the applicable BS 3800 (BS ISO 230) series. Which, as previously stated, is very much in the format of Schlesinger, BS 4656 is primarily intended for developing and verifying individual machine specifications.

ISO MACHINE TOOL STANDARDS

The work of preparing machine tool related standards for ISO is by Technical Committee ISO/TC39. This committee delegates the work involving Test Conditions and Methods to a subcommittee, namely SC2, which acts similar to its BSI equivalent (MTE/1). Subcommittee SC2 is currently assisted by 6 working groups in the preparation of specific standards. These are as follows:

WG 1	Revision of ISO 230-1
WG 2	Accuracy and repeatability of positioning (230-2)
WG 3	Test conditions for machining centres (10791)
WG 4	Test conditions for turning centres (13041)
WG 5	Circular tests for numerically controlled machines (230-4)
WG 6	Evaluation of thermal effects (230-3).

For the purpose of this paper, only those standards being worked on by a working group will be discussed here.

ISO 230 "Test Code for Machine Tools

As previously stated, this is similar to BS 3800 and currently there are 5 parts to this series

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 machine tools.
Part 3:	Determination of thermal distortion of machine tools.
Part 4:	Circular tests for numerically controlled machine tools.
Part 5:	Noise emissions.

ISO 230-1: 1996 - "Geometric accuracy of machines operating under no-load or finishing conditions"

As previously described in BS ISO 230: Part 1

ISO 230-2: 1996 - "Determination of accuracy and repeatability of positioning of numerically controlled machine tools"

This is currently under preparation by WG 2 and is at the FDIS stage, which means that, hopefully, it will be published either this year or early next. WG 2 is under a UK Chairman as the basis for this work was BS 3800: Part 2 (formally BS 4656: Part 16).

The latest draft is significantly different from the original BSI base document. At the very first working group meeting it was decided to limit the scope to testing and evaluating the accuracy and repeatability of positioning only, i.e. not to include straightness and angularity.

Since then it has been decided to follow the recommendations provided by the "Guide to the Expression of Uncertainty of Measurement"[2] which was published by ISO in 1993. This has resulted in numerous other modifications.

The first modification was related to the assumption of the type of distribution of the positional deviations. The modified definitions uses no assumptions for the shape of the distribution by referring to "standard uncertainties" rather than "standard deviations". The new definition of expanded uncertainty with a coverage factor of 2 (95% confidence) instead of 3 (99.7% confidence) was also used following the recommendations of the Guide.

Secondly, in order to highlight the systematic behaviour of machine tools, new definitions of E (corresponding to the term "Accuracy" in ANSI B5.54[3]) and M (corresponding to the term "Positional Deviation, P_a " in VDI 3441 [4]).

Once published, it will be the decision of MTE/1 whether to withdraw BS 4656: Part 2 and replace it with this new ISO 230-2.

ISO 230-3 "Determination of Thermal Effects".

This is currently under preparation by WG 6 and is at the DIS stage, which means that, hopefully, it will be published sometime in 1998. WG 6 is under a USA Chairman as the basis for this work was BS 3800: Part 3: 1990 with considerable reference, especially for the environmental tests, from ASME B5.54.1992.

The major change from BS 3800: Part 3 has been the addition of a third test, namely ETVE (Environmental Temperature Variation Error) together with user and supplier responsibilities. ETVE tests are designed to reveal the effects of environmental temperature changes on the machine to be tested and is determined by a drift test.

Basically the equipment is set up for the test to determine thermal distortion caused by the rotating spindle, but the drift test is performed before the spindle is rotated. The test mandrel should be manufactured from steel (rather than a low-expansion alloy material - BS 4656: Part 3). The argument was that the use of a steel mandrel will automatically compensate for any environmental changes and the resulting

measurements will indicate the effects of the internal machine heat sources.

The standard recommends that the supplier (of the machine) should offer clear guidelines regarding what kind of thermal environment should be acceptable for the machine to perform with the specified accuracy.

The user has the responsibility to provide an environment that meets these guidelines, if he does, then the responsibility for machine performance according to the specification belongs to the supplier.

ISO 230-4 : 1996 "Circular Test for Numerically Controlled Machine Tools".

As previously described in BS ISO 230: Part 4: 1996

ISO 10791 - Test Code for Machining Centres

This standard specifies with reference to the relevant parts of ISO 230, several families of tests for machining centres with horizontal or vertical spindle or universal heads of different types. The machines may be stand-alone or integrated into flexible manufacturing systems. It establishes the tolerances corresponding to general purpose and normal accuracy machines.

The standard is also applicable to numerically controlled milling or boring machines when their configurations, components and movements are compatible with the tests so described.

As previously stated, this standard is being prepared by WG 3 and is currently made up of 12 parts, although new parts covering such features as tests under load, checking performance and stiffness of the machine under specified loads are being proposed. Currently the title and status of each part is as follows:-

Part 1 "Geometric tests for machining centres with horizontal spindle and with accessory heads (Z axis - horizontal)"

Currently at FDIS stage, should be published within the next 12 months.

Part 2 "Geometric tests for machining centres with vertical spindle or universal heads with vertical primary rotary axis (Z axis - vertical)"

Currently at DIS stage

Part 3 "Geometric tests for machining centres with integral universal heads with horizontal primary rotary axis B (Z axis - vertical)"

Currently at FDIS stage, should be published within the next 12 months.

Part 4 "Accuracy and repeatability of positioning of linear and rotary axes"

Currently at DIS stage, 2nd vote terminated March 1997, awaiting result.

Part 5 "Accuracy and repeatability of work-holding pallets"
Currently at FDIS stage, should be published within the next 12 months.

Part 6 "Accuracy of speeds, feeds and interpolations"
Currently at DIS stage, 2nd vote terminates August 1997, awaiting result.

Part 7 "Accuracy of finished test piece"
Currently at FDIS stage, should be published within the next 12 months.

Part 8 "Global evaluation by means of circular tests"
Currently at CD stage, awaiting public comments.

Part 9 "Evaluation of the operating times of tool change and pallet change"
Currently at CD stage, a draft has been prepared and will be discussed at the next WG 3 meeting scheduled for October 1997 at London.

Part 10 "Evaluation of the thermal distortions"
Currently at CD stage, awaiting finalisation of ISO 230-3

Part 11 "Noise tests"
Currently at CD stage, a draft has been prepared and will be discussed at the next WG 3 meeting scheduled for October 1997 at London.

Part 12 "Evaluation of the vibration severity
Currently at CD stage, a draft has been prepared and is awaiting initial comments.

ISO 13041 - Test Code for Turning Centres

This standard is based on a UK proposal and was first discussed in Frankfurt (October 1996). At that meeting it was decided to allow the Japanese have the Chairmanship with additional assistance from the UK. It is proposed to present a revised draft at the May 1997 meeting in Turin with further discussion at the October 1997 meeting in London.

At the time of writing no final decision has yet been taken as to whether the standard will follow the BS 4656: Part 30 format (i.e. all in one document) or the ISO 10791 format (i.e. divided into many parts).

REFERENCES

1. G. SCHLESINGER, "Inspection Tests on Machine Tools", Machinery Publishing Co., 1932.

2. ISO Standard - GUM 1:1994 "Guide to the Expression of Uncertainty in Measurement"

3. American Standard ASME B5.54 - 1992 "Methods of Performance Evaluation of Computer Numerically Controlled Machining Centres

4. Germany Standard VDI/DGQ 3441- 1982 "Statistical Testing of the Operational and Positional Accuracy of Machine Tools"