Development of CNC machine performance standards

D.M.S. Blackshaw, V. Chiles, D. Jenkinson
School of Engineering, University of Northumbria,
Newcastle upon Tyne, NE1 8ST
vic.chiles@unn.ac.uk

Abstract

This paper summarises our approach to a new EU project to investigate current and proposed ISO machine tool standards by conducting tests on a range of CNC machine tools to investigate and report on the feasibility of improvements to existing test procedures. A partnership of six EU companies has been established to review the limitations of current test procedures, and to investigate possible enhancements that may be required. This paper summarises some of the preliminary work which has led to the establishment of this new project. It is submitted as part of an ongoing discussion procedure to gather suggestions for enhancements that can be examined during the two years of the project. Some preliminary results are shown to assist these discussions.

Current ISO machine tool standards position

We have briefly listed the current standards that are used, and shown when they are due for revision. Revisions always take several years of consultation to be considered and issued as a proposed standard, then issued as Drafts for Public comment **(DC)**. After comments are received from the engineering community at large they are then reconsidered and issued as - Draft ISO standards **(DIS)**, and again circulated for further comment After that stage a standard is issued as a Final Draft Standard **(FDIS)**, for final acceptance after a final round of comments.[1]

ISO 230-2 Accuracy & Repeatability Current standards are well defined for 'normal' sized machining centres (i.e. axis lengths up to 2 metres), but do not give acceptable procedures for large machines. It is now apparent that

Transactions on Engineering Sciences vol 23, © 1999 WIT Press, www.witpress.com, ISSN 1743-3533

warm up procedures need clear definition because we are much more aware of the extent of thermal errors in machine structures [2] and particularly in lead screws [3] and this means that error compensation must be performed at a 'typical' operating state of the machine.

(1) ISO 230-2:1997 (Accuracy/Repeatability)

⇩

International Standard

Next Revision - Include Dynamic Measurement

230-3 Thermal Effects- The current draft standard was issued in 1998 but involves tests over many hours, one proposal is to investigate a shorter test which can be used to confirm that a machine complies with the current extended test procedures.

(2) ISO 230-3 (Thermal Effects)

⇩

Final Draft International Standard now due ⇨ (June 1999)
(FDIS)

⇩

Next: - Comments /FDIS/Publish ⇨ (2000)

230-4 Circularity, current procedures are well established, and are due for revision in three years. One major limitation is that the test procedures do not define exactly where circularity tests should be done on a machine table . It is well known that tests conducted at the end of a machine table will give worse results than when they are conducted in the centre of a table, and customers may want to know about the extent of these effects on the particular configuration of machine which they are using.. Also current feedrates for tests do not cover 'high speed' machining feedrates that are now coming into common use.

(3) ISO 230-4:1996 (Circularity)

⇩

Published 1996

⇩

Next:- Revision due in 2001, comments required

230- 6 Diagonal tests- We have been conducting some tests to investigate the use of this test to give a general perspective of the quality of a machine. We plan to relate this to detailed volumetric error analysis of machines to confirm the usefulness of this test procedure. [4,5]

Transactions on Engineering Sciences vol 23, © 1999 WIT Press, www.witpress.com, ISSN 1743-3533

(4) ISO 230-6 (Diagonals) (Laser)

⇩

1st working draft- Dec '97

⇩

Next: comments /DC/DIS/FDIS/publish ⇨ *2002*

Dynamic Diagonals / Volumetric

Geometric Errors There were comprehensive test procedures defined in BS 4656, but these have not been adopted yet at ISO level, so we plan to conduct further tests and to submit possible test procedures to the ISO committee.

(5) Geometric Errors

(no General Method of Test established as ISO standard yet- New Investigation Area)

Definitions contained in ISO230-1:96

Angular /Straightness/Parallelism/Squareness

ISO 230-6- some initial test results

We have conducted some preliminary 3D body diagonal tests on some of the machine tools in our laboratory in preparation for this project, with some interesting results, and we are presenting these results as a way of stimulating further discussion of developments in test procedures. At this stage we have focused on ISO 230-6 - Diagonal tests, and spent some time examining three different CNC machines, a 15 year old knee type vertical CNC mill, a ten year old horizontal machining centre, and a one year old vertical machining centre..

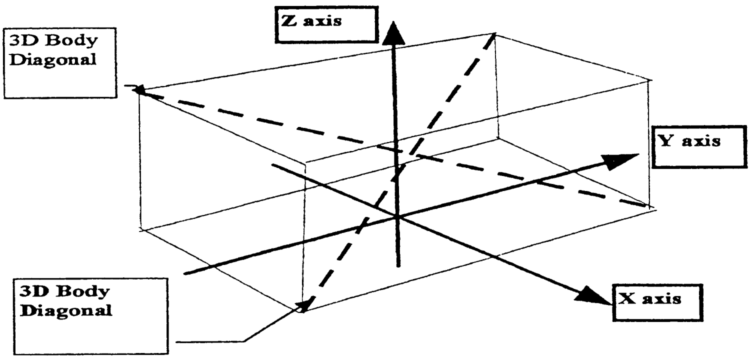


Fig 1- 3D diagonal measurements

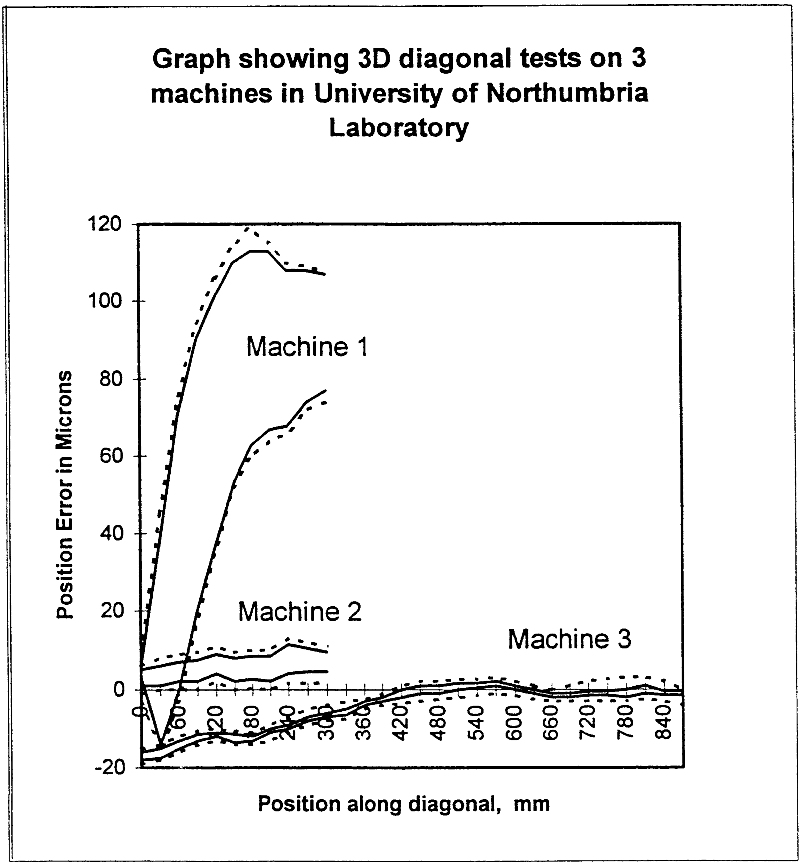
Problems encountered:- On two of the machines the relative motions of the axes meant that it was necessary to mount the retro-reflector on the spindle nose to measure motion in the Z axis, and to have the laser placed on the machine table to capture the X and Y motions. A turning mirror was used to align the beam across the 3D body diagonal. Normal laser alignment

Transactions on Engineering Sciences vol 23, © 1999 WIT Press, www.witpress.com, ISSN 1743-3533

procedures do not apply in this situation, since you cannot jog the machine along a 3D line. It was found much more convenient to position the mirrors to get a good signal at the extreme end of the diagonal, and then to move the mirror as close to the origin of the diagonal as possible, and to 'search' for a good signal with the jog button giving small moves in X, Y & Z. In this way it was possible to obtain the 3D coordinates of the start and end points of the diagonal, and to then generate a series of ten measuring positions along this line. The two end points were used as the turnaround points for the machine motion. It is not easy to position the mirrors to follow the exact line of the maximum length diagonal, but what is required is a repeatable set up to allow checking of the machine at regular intervals.
This test was first performed on Machine 1 (a 15 year old vertical mill), which has dovetail slideways, and is known to have significant errors in the X axis (up to 120 microns position error at full X travel) , although the Y and Z axis motions have very small errors. The resulting plot shows the same order of X axis error, i.e. around 120 microns maximum error. This shows a maximum volumetric error of 135 microns. What was surprising was the amount of backlash shown on the 3D plot, up to 60 microns. This is far in excess of the X axis error (18.8 microns).. You must be aware though that this graph now represents the result of errors arising from all 21 degrees of freedom on the accuracy of the target positions along this line. Subsequent analysis showed that there is some slideway clearance in this machine which would appear as backlash on the graph.

The second test was performed on machine 2 (a horizontal machining centre) which has all the axis motions applied to the spindle, the table being stationary. This means that the laser can be mounted on a tripod as usual, with the retro-reflector mounted on the spindle nose. This is a ten year old machine fitted with resolvers on each axis, and the resulting graph clearly shows the machine to be in excellent condition, with a maximum volumetric error of 16 microns, about ten times better than the first machine.

The third test was on Machine 3 (a vertical machining centre), which is one year old, and which has a larger working volume than the above two machines. It has Heidenhain glass scales fitted to all three axes.. On this machine the retro-reflector was attached to the spindle nose, and the laser placed on the machine table, the turning mirror was used to turn the beam back across the 3D diagonal. The graph shows that the machine is, as expected, in very good condition, with an overall volumetric error of 20 microns, and zero backlash. These are extremely good results considering that the machine has a working volume of 750 x 500 x 500 mm.



Note:- All the graphs in this paper show conventional laser plots with +/- 3 sigma limits shown dotted.)

The resulting graph comparing the condition of the three machines clearly shows the value of this test as a visual confirmation of the overall accuracy of a machine, with two of the machines being clearly in excellent condition, and the older knee type mill showing serious volumetric errors.

Further tests

Machine 3 was tested several times , and large variations were found in the results, so a systematic test was conducted over one day to determine the cause of these variations in the results. Figure 3 shows the resulting graph. The workshop environment is having a large effect upon the volumetric accuracy of the machine.

Time	Volumetric error
9.50 am	20 microns
12.40 am	35 microns
2.20 pm	45 microns
4.20 pm	50 microns

Chart 1- Changes in volumetric error during the day- note increase in machine temperature = 2° C over the day, Spindle NOT running [6]

(See Figure Two for the graph of the growth in the 3D body diagonal over the day.)
It is obvious that this test is a very good measurement of the effect of the environment upon the machine accuracy. It is worth stating that these tests were completed in our Teaching laboratory, which is holds 20 machine tools, but typically 4 or 5 are running at any one time, the laboratory is quite extensive with no windows which allow sunlight onto this machine.
There is one loading bay 30M from the machine which is not in regular use, thus our environment is probably more stable than most companies' premises. These results thus probably understate the likely volumetric errors in most workshop environments.
These results made us interested in the volumetric errors that would arise when the machine is running and thus generating its own internal heat sources, and thus we expected to find considerably larger volumetric errors when these machine thermal errors are added to the environmental errors shown above. The tests were thus repeated with a set up which allowed us to run the machine spindle at 6000rpm (75% of max. speed) The below results were obtained.

Time	Volumetric error
11.00am	36 microns
12.30pm	34 microns
13.50 pm	20 microns
15.45 pm	10 microns

Chart 2- Volumetric Errors measured with spindle running at 6000 rpm [6]
(Figure Three shows the complete results of these tests.)

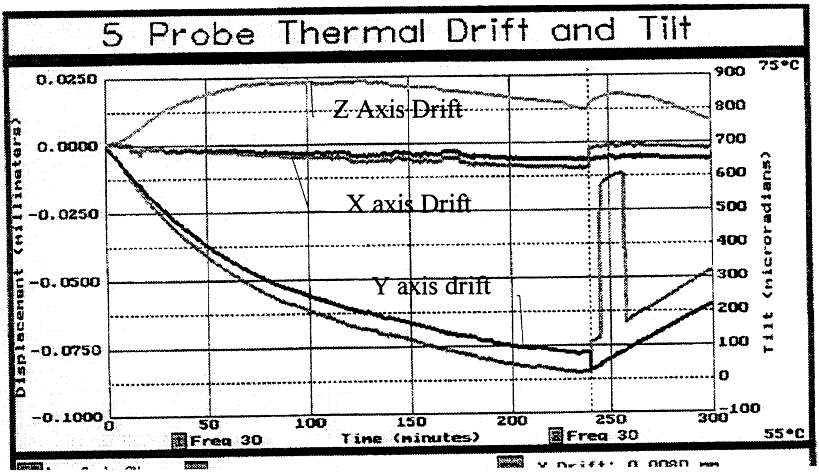
These results clearly are very different to our expectations- the machine's volumetric error and repeatability IMPROVED as it warmed up. The machine held a volumetric accuracy of 10 microns, including the plus and minus 3σ limits, which is extremely good. This is clearly a case of the manufacturer having a deep knowledge of their machines characteristics and thus designing the machine structure to accommodate the thermal errors.

Work is ongoing to relate these results to volumetric errors calculated from a full analysis of each of the 21 separate axis errors, but this 3D diagonal test

Transactions on Engineering Sciences vol 23, © 1999 WIT Press, www.witpress.com, ISSN 1743-3533

procedure clearly provides a convenient 'quick check' on volumetric accuracy. It also opens the door to a simple procedure to assess the magnitude of thermal errors on the volumetric stability of a machine tool.

Thermal stability tests using a spindle analyser have also been conducted on this machine, and it must be remembered that the 3D diagonal test does not detect the drift in the position of the spindle nose revealed by the spindle analyser. this machine grows by 25 microns in the Z axis over the first hour of a test, and grows by 85 microns in the Y axis over the four hour test period [7].. These motions are NOT detected by the laser, since the laser readings are taken over a ten minute period only. The volumetric errors shown in the above charts thus represent snapshots in time of the machine errors. They are a good indication of the overall state of the machine slideways, squareness of the axes, and the overall accumulation of the various possible errors on the machine.



Graph 3- spindle analyser tests on Machine 3
(machine running at 6000 rpm)

Conclusions

We have presented some initial test results at the start of this major project in the development of machine tool standards to provoke some discussion. As usual new tests raise new questions- we will be examining many of these issues over the two years of the project- and we would be very pleased to get comments on these results and to get suggestions for improved test procedures from the various delegates at this conference.

Transactions on Engineering Sciences vol 23, © 1999 WIT Press, www.witpress.com, ISSN 1743-3533

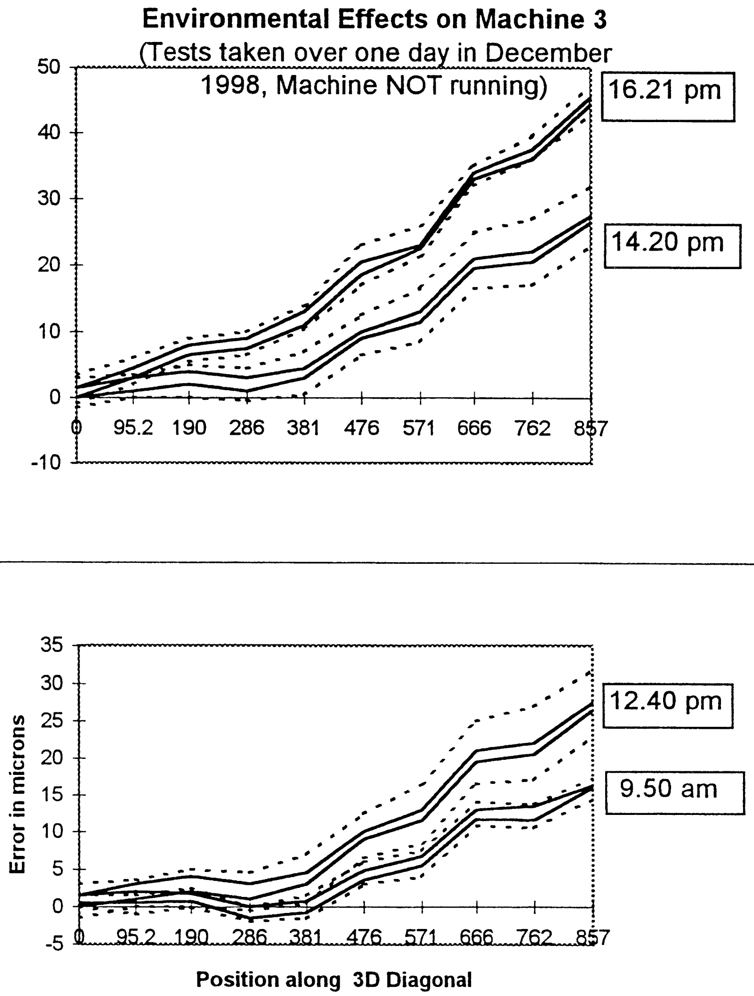


Figure Two - plot of changes in length of 3D body diagonal, measured at intervals during the day, spindle stationary

Transactions on Engineering Sciences vol 23, © 1999 WIT Press, www.witpress.com, ISSN 1743-3533

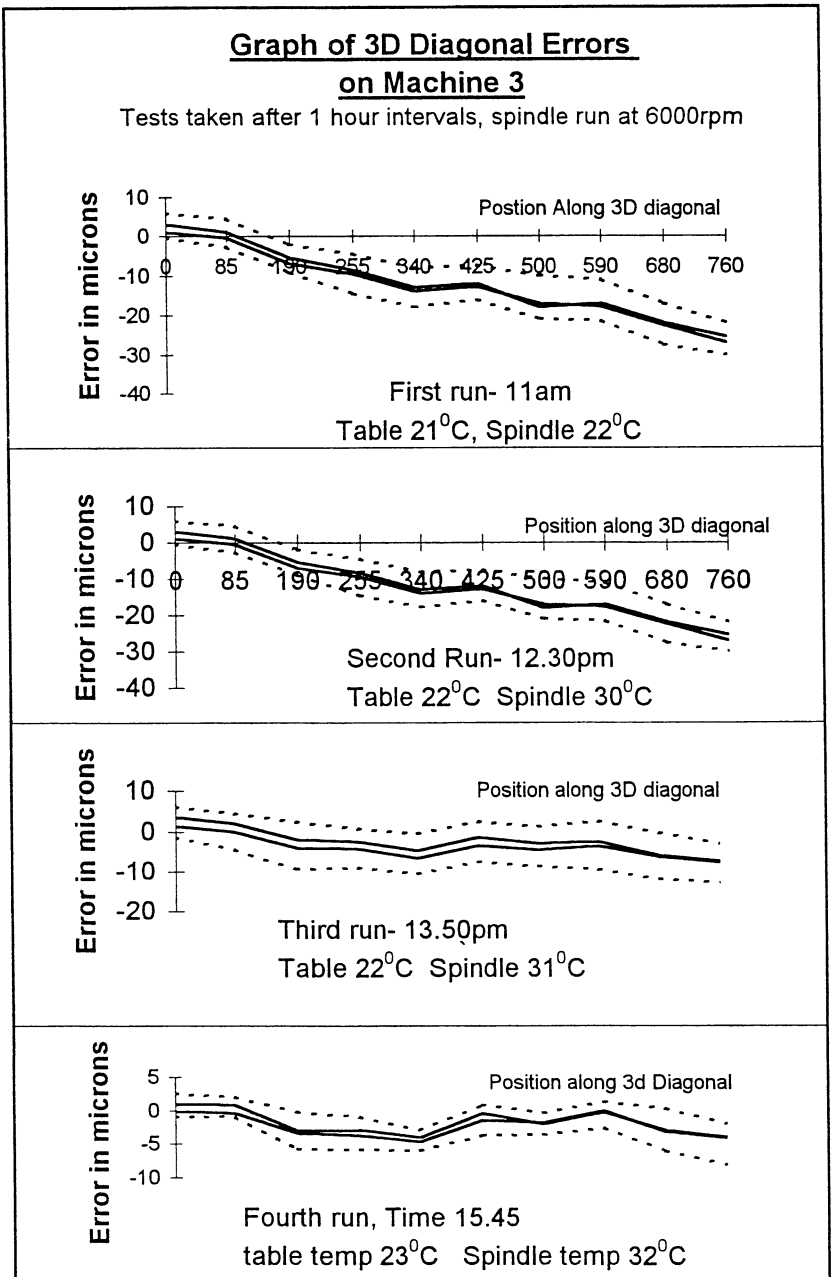


Figure three- plot o f changes in length of 3D body diagonal, measured at intervals during the day, spindle run at 6000rpm for 1 hour between tests

Transactions on Engineering Sciences vol 23, © 1999 WIT Press, www.witpress.com, ISSN 1743-3533

References

[1] *Developments in BSI and ISO machine tool accuracy standards*, p79-90, M. Gull, Lamdamap 97

[2] *Practical application of thermal error correction - 4 case studies*, pp359-370 Allen, Postlethwaite & Ford, Lamdamap 97

[3] *Thermal errors in CNC machine tools- ballscrew expansion*, A. Frank F. Ruech, Technical University of Graz, MTTA Seminar (ISBN 0-907348-04-1) November 1998, at UMIST.

[4] *Interim checks for machine tools*, W. Knapp, Lamdamap 97 p161-168

[5] ISO 230-2, 3, 4.6

[6] *3D Diagonal Measurements on CNC machines,* student project, University of Northumbria, Tee Tai Lian, Jan 1999

[7] *Assessing thermal distortion of machining centre using draft standard ISO/DIS 230-3* Statham, Martin & Blackshaw, p101-112, Lamdamap 97