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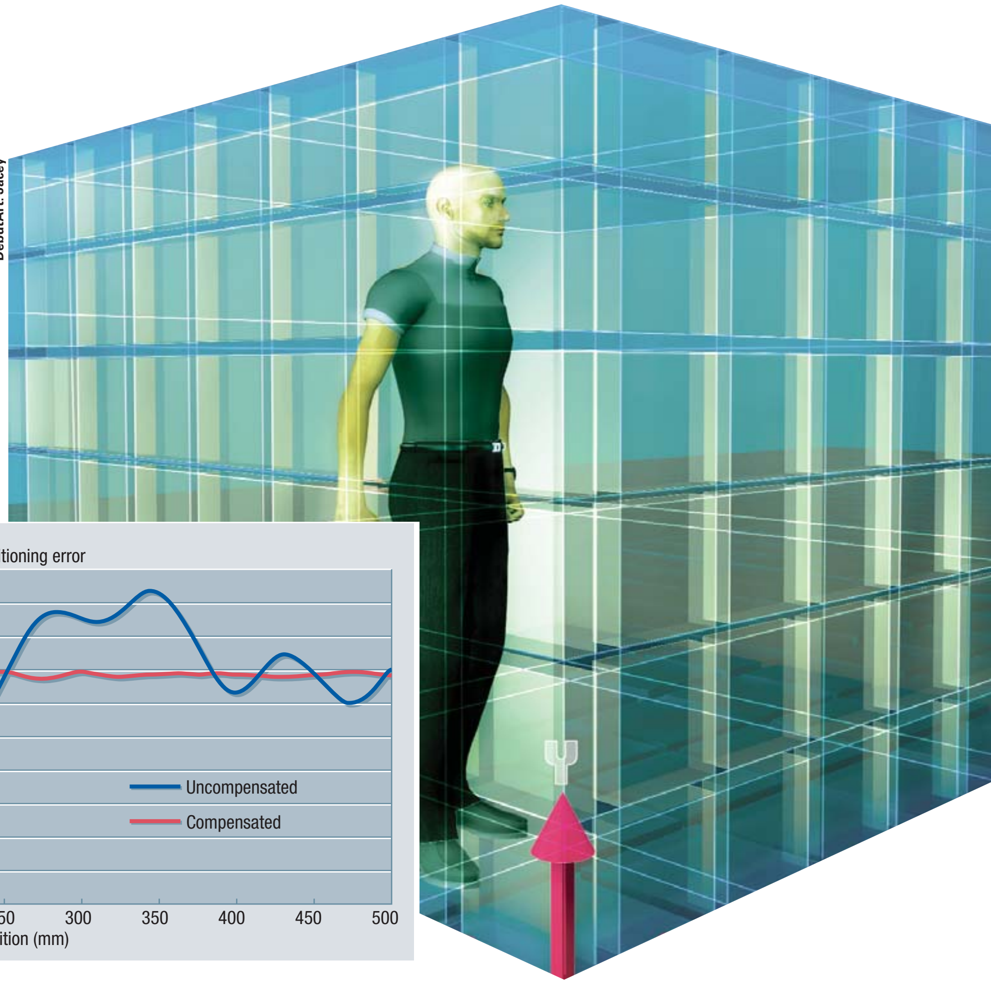
Better accuracy speaks volumes: lost in space

Lost in space

Using existing machinery with in-built volumetric accuracy compensation software can deliver huge improvements in achievable accuracy. Huddersfield University* has been developing the technology

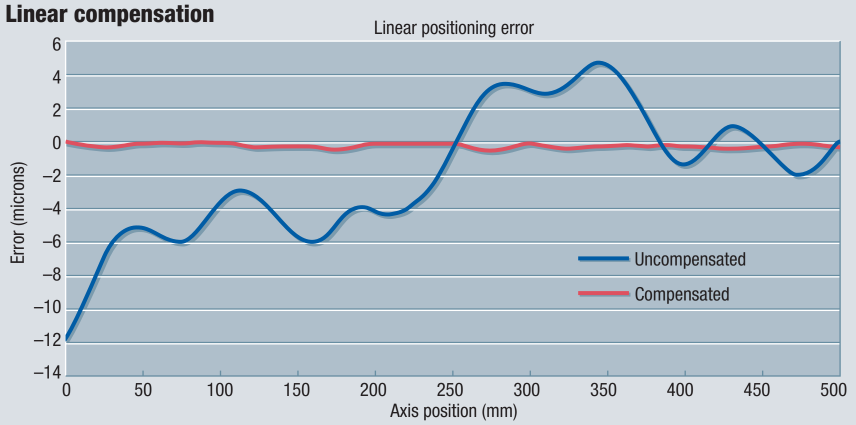


DebutArt: Jacey

One of the most difficult problems when buying new hardware is arriving at the specification. The problem is knowing what questions to ask.

Machine tools have historically been specified in terms of axis linear positioning accuracy and repeatability. "If I ask the x axis to move from A to B what will be the error? [positional error] And if I do it 20 times, how much will that error change? [repeatability]" But machining is seldom performed by moving only one axis. So the question needs to be supplemented by asking: "Will that error be the same if I move the z axis from the bottom to mid-stroke? What if I move the y axis as well?" We are no longer talking about axis accuracy, but the *volumetric* accuracy of the machine.

Linear compensation

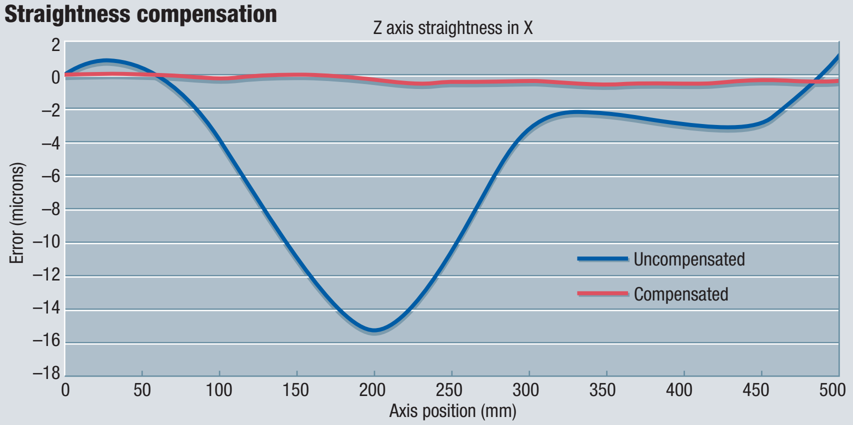


Volumetric accuracy is a measure of the ability of a machine to position accurately within a defined working envelope. It is a combination of the individual geometric errors inherent in any machine axis. For a 3-axis machine the errors are a combination of linear positioning, axis straightness, and pitch, roll and yaw of each of the three axes. When combined with the out-of-squareness of the axes, this gives a potential 21 sources. For a 5-axis machine, other sources exist, such as non-concentricity of the head.

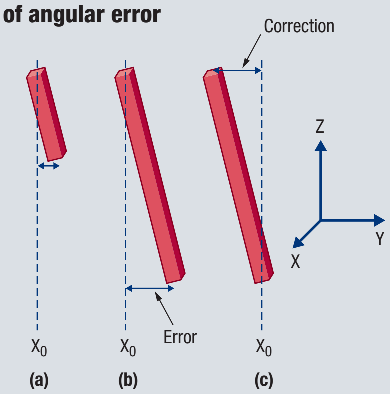
A key difference between axis accuracy and volumetric accuracy is the inclusion of angular errors. These only have an effect on axis positioning when another axis acts as an amplifier. In these circumstances, the effect of the error is proportional to the motion of the amplifier axis. Angular errors will have a bigger effect on machines with longer axes. It is probably for this reason that the aerospace industry has been most active in this field.

Simulation software (ESP) written at the University of Huddersfield can be used to predict the machining performance of

Straightness compensation



Linear correction for effect of angular error



any 3-axis machine based upon calibration data. The software not only outputs a single-value figure for the volumetric accuracy, but also indicates the most significant error sources.

An assessment of a machine using this technology allows a machine tool builder or maintenance engineer to improve the accuracy of a machine by mechanical adjustment. If, for example, the major contributor to the volumetric error were the column-to-bed squareness, then re-levelling the machine could help to improve the machine.

However, even with the best mechanical adjustment, there comes a point where it is uneconomic to improve the machine further by mechanical means. At this stage, electronic error compensation becomes attractive.

Compensation is applied by adjusting the position of a machine's axes by an amount equal to the error at that position. For linear compensation – available in all CNC units – this means a compensation table that tells the axis to move slightly further, or slightly less for a given target position. For volumetric compensation, a machine model combines values from a number of tables with the current axis position to calculate the error in the cardinal axis direction. It then applies compensation as a single value for each axis at that point in space.

Volumetric compensation differs from axis compensation because it requires knowledge of the combined linear effect of all the errors. For angular error, electronic compensation does not mechanically remove it, but applies a linear compensation offset for its effect.

So in the diagram above, right, (a) and (b) show that, because of the rotation of the y axis about the x axis (y-axis pitch), for different positions of the z axis, the end of the ram is offset from the nominal position in the y direction. This is the linear effect of the geometric error. Example (c) shows how this error can be reduced by moving the y axis by an amount equal and opposite to this error.

TIGHTER INTEGRATION

Such technology has been available for some years in the form of the Volumetric Compensation System (VCS) which was written at the University of Huddersfield. This runs under DOS on a PC and intercepts encoder feedback, adjusts the signals by the required amount then passes them on to the CNC. This mature technology has proved effective in industrial applications for over a decade.

Further advances were made when the system was incorporated in an OSAI Series 10 controller via a DOS partition.

Recent research at the University of Huddersfield has taken the concepts behind VCS and introduced them into the Siemens 840D controller. This application also has the benefits of requiring no additional hardware and takes advantage of running within the NC kernel itself.

The software, called SinVCS because it runs in the Sinumerik control, was created in collaboration with Siemens which created a software interface to the position signals which allows compensation to be applied at the same speed as the controller operates.

Furthermore, the system works in 'internal increments' which means that the resolution of the system can be much better than previously achievable. On the vertical milling machine used for research and validation, the resolution of the compensation could be as small as 0.001 microns, although 0.1 microns was sufficient for testing.

Using laser interferometry, the performance of SinVCS was tested over the full volume of 500 by 500 by 500 mm. Linear position (the old measure of a machine's accuracy) was significantly improved on all the axes – see diagram, page 14. The compensation values are excellent, but similar performance should be achievable through the normal CNC compensation tables.

SinVCS, however, reduces the errors from all the geometric error sources. For example, the z-axis straightness in the x-axis direction has also been reduced from over 17 microns to less than one micron – see diagram, this page, top left.

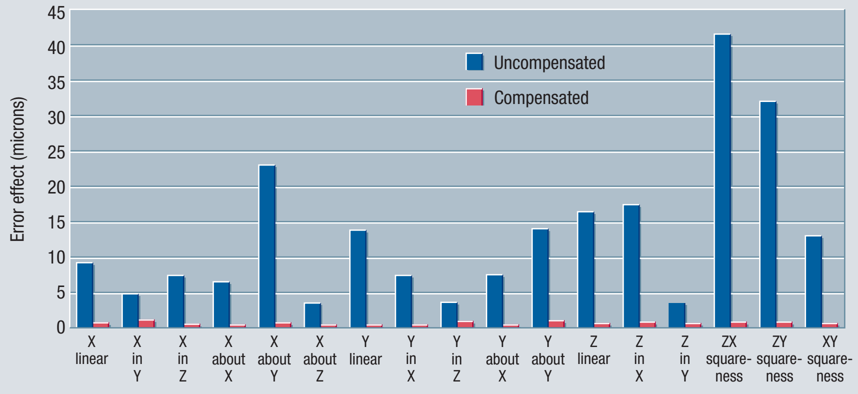
Similar performance was achieved for all the error components with most of the effects being reduced to a sub-micron level – see diagram, page16, top. The combined effect of the compensated errors provide an overall improvement in the volumetric accuracy from 65 microns to 2 microns – a 97 per cent improvement.

Of course, laser measurements are only an indication of expected performance benefits. The final proof of the system was to conduct machining tests. For this, several test pieces similar to the NAS-979 piece were machined. Dimensional results were then obtained for the size of the square, diamond and circle using a CMM.

The aluminium parts were manufactured in high temperatures so the dimensional measurements are adjusted for the thermal effects. Because the test piece is only 200 mm square, the errors are relatively small, being around 20 microns. However, post compensation the errors were reduced to less than 5 microns – the average improvement being 82 per cent. These results are excellent when considering that the test process suffers from uncertainty due to tool measurement, CMM errors, etc.

These test results show what is achievable on a relatively small machine. A standard workshop machine can now be used to manufacture parts to a much tighter tolerance than previously if the machine is run in a temperature-controlled environment with no internal heat generation (an almost impossible ideal). A further benefit of SinVCS is the option for thermal compensation. With this, the 5 micron machining accuracy was achieved in a standard workshop with no mechanical compensation for heat sources, such as spindle cooling.

Compensating for all error components



The historic measure of the accuracy of a machine, namely axis accuracy, is being replaced by volumetric accuracy as the understanding of machining errors increases. This understanding is driven mainly by manufacturers – particularly the aerospace industry – undertaking 5-axis work on large machines.

The improvement on such machines can be massive, allowing greater consistency in manufactured parts. However, such technology is quickly finding a market on smaller machines as it provides an inexpensive method of improving positional performance.

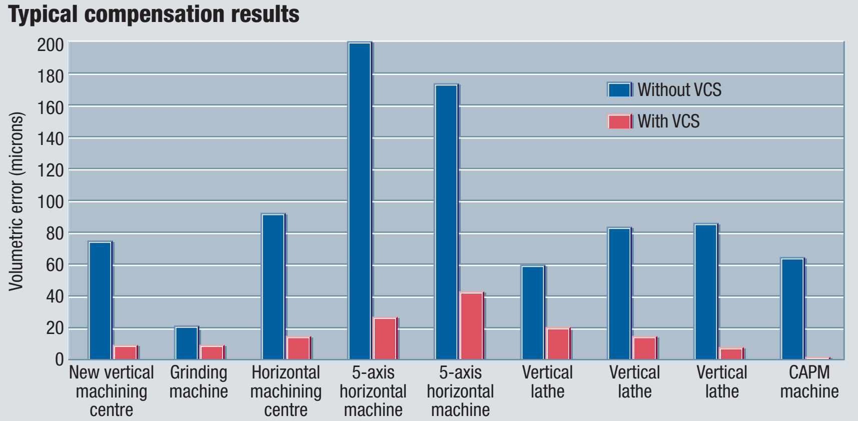
Using a machine capable of producing accurate components results in a reduction in both reworking of components and scrapped parts. This has obvious economic and throughput advantages, as does the potential for more efficient use of capital resources by roughing and finishing on the same machine. Indeed, if a machine can be proven to perform with sufficient accuracy and repeatability, some dimensional checking of components by probing could also be performed on the manufacturing machine. Such component checking, termed 'in-process probing' or 'on-machine inspection', is becoming more widely used but can only be as good as the machine which is being used.

The work on the university machine has shown that a good one can be made better by implementing compensation. This means that a new market becomes available for an existing machine since it can produce more accurate components. But this is only possible because the machine tool is both mechanically sound and has good axis control.

Volumetric compensation is used to achieve the optimum performance from a *good* machine, it is not designed to rectify the failings of poorly designed or badly constructed machinery, and typical results are shown – diagram, left.

Huddersfield and Siemens are together working on a commercial package, which will be available in some six months' time. It requires further work in the area of diagnostics and machine safety features, but a customer trial is expected to be validated this month. M

Typical compensation results



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