Improving the Machine Accuracy Through Machine Tool Metrology and Error Correction

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Improving both the positioning accuracy and contouring accuracy of a vertical machining centre has been studied by using a machine tool metrology and in-house error correction techniques. Contouring errors caused by the servo lag and friction of servomechanisms were measured by the circular test and then reduced by off-line parameter tuning of the CNC and servo-driver. The quasistatic thermal errors were predicted on-line using a neural network based model which was calibrated in advance via a quick set-up and multiple-error measurement system consisting of a spindle-mounted probe and artifacts. Positioning errors caused by both the static geometric errors and thermal effects were eliminated in real-time by a PC based software error compensation scheme integrated with the CNC controller through digital communication. An error reduction of 70% was achieved after error compensation and CNC tuning.

Keywords: Accuracy; Error correction; Machine tool

1. Introduction

When machine accuracy is required down to the level of a micrometre or better, a machine must have good mechanical design, manufacturing, numerical control and servo-drive control if optimum machine performance is to be achieved. The machine should have a high stiffness-to-weight ratio with good thermal and damping characteristics. The machine should also have accurate geometry and proper preloading after fabrication and installation. The NC controller should provide functions to correct for mechanical inaccuracies, such as backlash, and to execute automatic acceleration/deceleration control in sudden start/stop or corner cutting conditions. The feed axes should be of advanced design to eliminate the effects due to external load and friction force on servomechanism which are generated at high feedrates.

Machine accuracy, however, also depends on the additional factors of environmental effects and operating methods which are not usually under the designer's control. A study of the Hewlett-Packard Co. [1] has found that 88% of 57 purchased production machines were out of specification upon installation where the foundation, mounting, alignment and temperature condition in shop floor are all critical to the machine accuracy. Therefore, a high accuracy machine also required in-house CNC tuning and software error compensation to correct for these influences. Machine tool metrology plays a critical role in the efficient utilisation of in-house error correction where a complete and quantitative understanding of how these influences and their interactions on the finished workpieces is required.

The calibration of a machine should include, at least, measurement of static geometric errors, quasi-static thermal effects, and dynamic contouring accuracy. Geometric errors and thermal effects of a machine are important for the positioning accuracy and long-term repeatability in point-to-point cutting. For a multi-axis machine, the calibration should include both the displacement accuracy of the slide along each axis and the geometric framework of three axes, i.e. the straightness, angular errors and squareness/parallelism. A contouring test in which a cutter moves along a specific profile at specific feedrates by the simultaneous movements of two or more axes should be carried out to reveal problems in the numerical control and servomechanism at high-speed contouring.

Positioning errors caused by geometric errors such as the backlash and displacement errors in a linear axis can be corrected by software error compensation where the CNC controller of a machine injects additional positioning signals into the servo control loops of feed axes. Compensation of the positioning errors due to the angular errors and dynamic thermal errors, however, is difficult, because the positioning errors at the cutting edge depend on the machine's kinematic configuration and temperature condition which can vary in time during machining. By the aid of an external PC, researchers have achieved real-time error compensation by
Improving the Machine Accuracy 199

2. Calibration and Compensation of Thermal Errors

2.1 Thermal Error Calibration System

For the vertical machining centre studied, the thermally induced positioning error at the cutting edge is a combination of:

1. The expansion of the spindle.
2. The distortion of the cantilever arm.
3. The expansion of three leadscrew.
4. The distortion of the machine column (see Fig. 1).

These thermal error sources have different thermal response characteristics to the variation of the cutting conditions. Most previous works related to thermal error calibration measure the distortion of individual machine elements separately, for example by using a laser interferometer to measure the linear axes and by using non-contact displacement sensors to measure the rotating spindle. Measuring thermal errors individually is not only time-consuming but may also neglect the thermal interactions among error sources.

In this research, a quick set-up and multiple-error measurement system consisting of an on-machine probe and artifacts was developed to speed up and simplify the thermal error calibration. The layout of artifacts within the working envelop is shown in Fig. 2. Seven measurement points are purposely