Lean Manufacturing: High Accuracy Part Production by Low Accuracy Machines with Volumetric Calibration and Compensation

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I. Introduction

The competition in global manufacturing today requires better quality, higher productivity and lean manufacturing. Manufacturing process control has long been recognized as an important and necessary milestone on the road to reduce cost, improve throughput and superior quality product. Calibrate and compensate the positioning errors can be used to improve quality without excessive capital investment. It yields time, quality and productivity improvement. However, the major objection for this approach is that only calibrate and compensate the pitch error is not enough and calibrate and compensate the volumetric positioning errors are very time consuming, need expansive and balky instrument and more advanced CNC controller.

To solve this problem, Optodyne has developed a new laser vector measurement technique for the determination of volumetric positioning errors. The setup and operation is simple. It can be operated by a machine operator and measure the volumetric errors in 2 to 4 hours for a working volume of 1 cubic meter. Using the measured volumetric positioning errors, a lookup correction table can be generated for the controller to compensate the machine positioning errors volumetrically. Therefore, improve the accuracy. However, many CNC machines today do not have the capability to compensate the volumetric positioning errors.

For lean manufacturing, instead of replacing the CNC by a more capable ones, which cost capital investment and downtimes, it may be more economical to compensate the part program to achieve higher accuracy part production with low accuracy but repeatable machine tools. For the new manufacturing process to improve part accuracy without major capital investment, the key factors are 1, how to measure the volumetric positioning errors of a machine tool accurately and quickly, without the need of expansive and complicated instrument, and 2, how to compensate the part program to achieve higher part accuracy. The basic theory, experimental setup and test results, are reported, and an improvement of the parts accuracy of 700% has been demonstrated.

II. Repeatable low accuracy CNC machine tools

To produce high quality or accurate parts, the volumetric positioning accuracy of the CNC machine tool, including the linear displacement errors and straightness errors of all three axes, are very important. Measuring all these errors and then compensating these errors can improve the machine accuracy, provided that the machine is repeatable [1, 2 and 3]. The key is how to measure these errors accurately and with minimum downtime.

There are many methods to measure these errors [4 and 5]. However, all of these methods are very complex and time consuming. Recently, Optodyne has developed a new laser vector measurement technique [6,7] for the determination of volumetric positioning errors. The volumetric errors can be measured in a short time significantly less than that using the conventional laser measurement technique. The measured volumetric errors can be used to compensate the machine errors and achieve higher volumetric accuracy.

III. Linear displacement and body diagonal displacement measurement

A laser interferometer can be used to measure the displacement accuracy of a linear axis. The laser beam is aligned to be parallel to the motion of the linear axis and the positioning errors are measured at each increment. Usually, measure the linear displacement errors of all 3 axes is not enough. The straightness errors and the squareness errors may cause large volumetric positioning errors.

It is noted that for a quick check of volumetric accuracy, linear displacement measurement along 4 body diagonals is recommended by the B5.57 standard [8]. This is because the body diagonal displacement measurements are sensitive to all the errors such as the displacement errors, straightness errors, squareness errors and angular errors. Hence it is a good check of volumetric accuracy. However, if the measured errors are large, there is not enough data to identify the error sources.

IV. Laser vector measurement of volumetric positioning errors

The basic concept of the laser **vector** method is described in Ref [6]. Briefly, pointing the laser beam not parallel to the motion of the linear axis. Hence, the measured displacement errors are sensitive to errors both parallel and perpendicular to the direction of the linear axis. More precisely, the measured linear errors are the **vector** sum of errors, namely, the displacement errors (parallel to the linear axis), the vertical straightness errors (perpendicular to the linear axis), and horizontal straightness errors (perpendicular to the linear axis and the vertical straightness error direction), projected to the direction of the laser beam.

For the body diagonal displacement measurement, all 3 axes move simultaneously, the displacement is a straight line along the body diagonal; hence a laser interferometer can be used to do the measurement. However, for the laser **vector** measurement, the laser beam is pointed in the body diagonal direction but the movements are along the x-axis, then along the y-axis and then along the z-axis. The trajectory of the target or the retroreflector is not parallel to the diagonal direction and the deviations from the body diagonal are large. Hence, a conventional laser interferometer will be way out of alignment. To tolerate such large lateral deviation, a Laser Doppler Displacement Meter [9] using a single aperture laser head and a flat-mirror as target can be used.

This is because any lateral movement or movement perpendicular to the normal direction of the flat-mirror will not displace the laser beam. Hence the alignment is maintained. After 3 movements, the flat-mirror target will move back to the center of the diagonal again, hence the size of the flat-mirror has only to be larger than the largest increment. Furthermore, in the vector measurement all 3 axes move in sequence along a body diagonal and collect data after each axis is moved. Hence, not only 3 times more data are collected, the error due to the movement of each axis can also be separated. After all four body diagonals have been measured, all 9 errors (3 linear and 6 straightness) and 3 squareness errors can all be determined.

V. Measurement setup and results

The measurement was performed on an AWEA vertical machining center model FV-1000 in Hsinchu, Taiwan, Republic of China. The FV-1000 is designed for high-speed mold making. It has thick steel structure with reinforcement ribs to give the machine unsurpassed rigidity and prevent any bending or twist that may affect machining accuracy.

The machine working volume is 1050 mm by 600 mm by 540 mm. Without any compensation, the volumetric errors were measured by the laser vector method or sequential diagonal measurement. The measured volumetric errors are shown in Fig. 1. Based on the measured volumetric errors, new compensated body diagonal parts programs were generated [10,11]. The body diagonal displacement errors were measured again with the compensated parts program. The measured body diagonal displacement errors without and with volumetric compensation are shown in Fig. 2a and 2b. The measured maximum diagonal displacement error without compensation is 110 μm. Similarly, the body diagonal displacement errors of the machine with volumetric error compensation is 12.5 μm, an improvement of 900%.

VI. Summary and Conclusions

To achieve higher position accuracy of a machine tool, it is important to measure the volumetric errors and to compensate the volumetric errors provided that the machine tool using conventional measurement, making it easier to achieve lean manufacturing.

Figure Caption

1. Measured volumetric positioning errors, a. x-axis, b. y-axis and c. z-axis.
2. The body diagonal displacement errors, a. without compensation, and b. with volumetric compensation.

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Keywords
Manufacturing, CNC, Laser calibration, positioning errors, compensation, part program

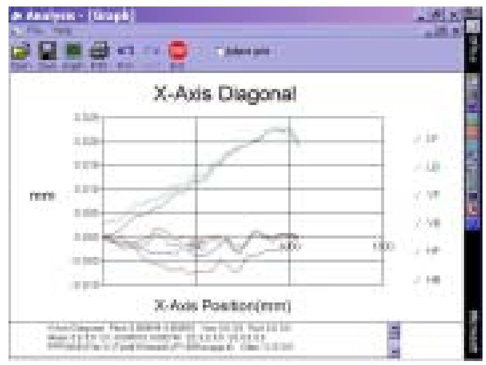

Fig. 1a Measured x-axis volumetric positioning errors

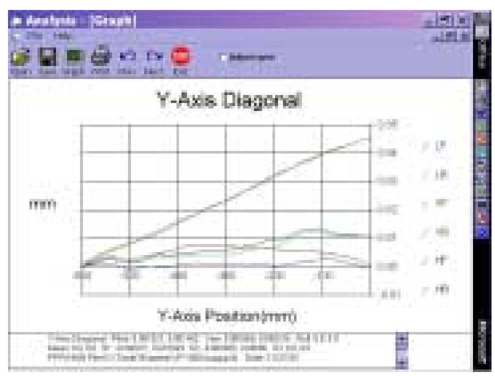

Fig. 1b Measured y-axis volumetric positioning errors

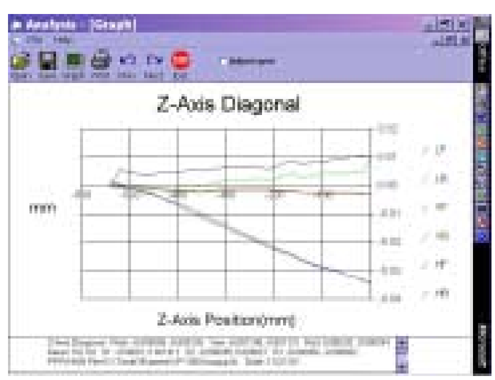

Fig. 1c Measured z-axis volumetric positioning errors

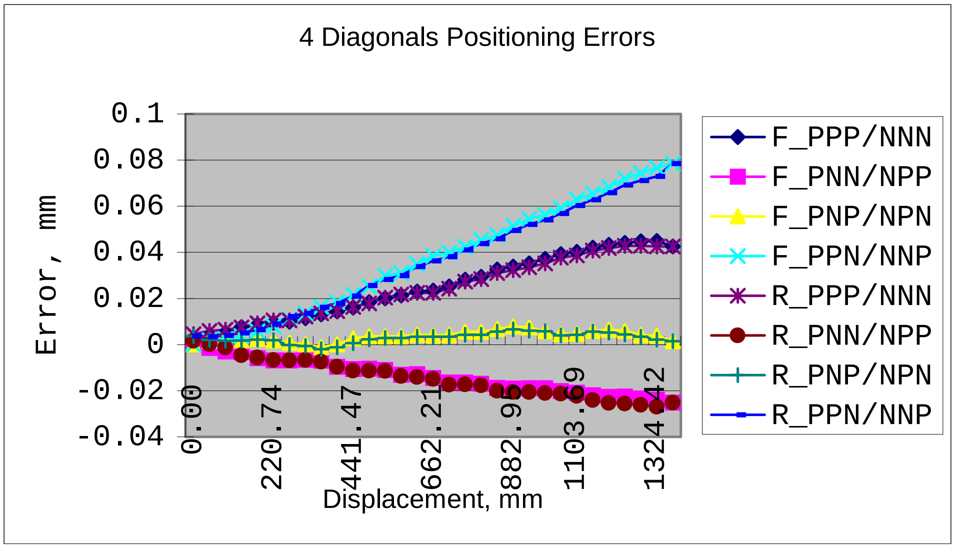

Fig. 2a The body diagonal displacement errors without compensation

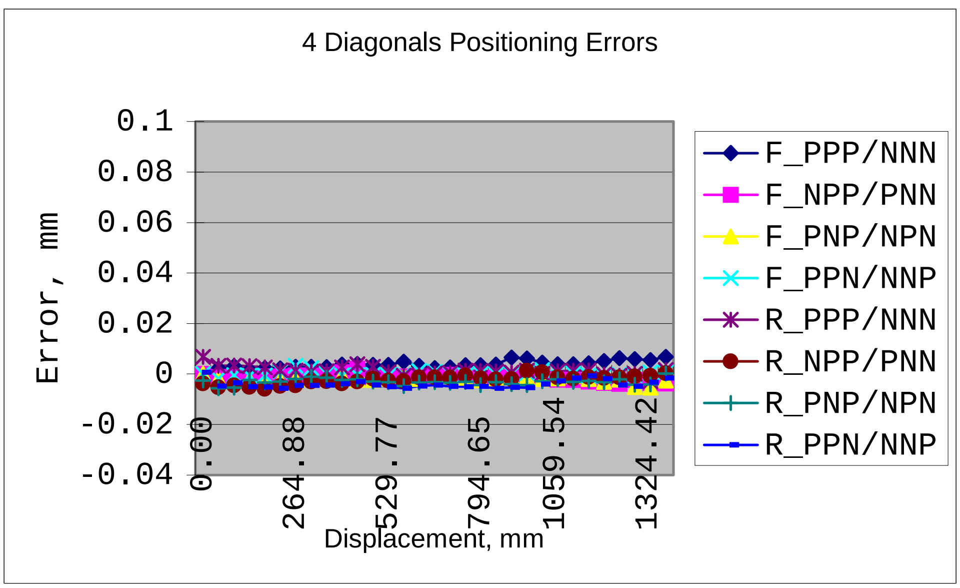

Fig. 2b The body diagonal displacement errors with compensation