Measurement and compensation of displacement errors by non-stop synchronized data collection

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Abstract

Conventional technique for the calibration and compensation of displacement errors of a CNC machine is static. That is, the machine is stopped at every increment and dwell for a few seconds for the machine to settle then collect the positioning data. The measured static positioning error, usually caused by the machine geometry, guide way and structure rigidity, etc., may not be the same as the actual dynamic positioning errors. In addition to the static positioning errors, the dynamic errors are caused by the servo parameters, resonance frequency, acceleration/deceleration, etc.

Using the dynamic displacement error table instead of the static displacement error table for displacement error compensation, better contouring accuracy may be achieved. Furthermore, using the non-stop synchronized data collection technique to measure the displacement errors of a long lead screw with small increment, significant time saving can be achieved.

Reported here is the basic theory of non-stop synchronized data collection method, its features and requirements, its advantages, limitations, and applications. The laser system used is a MCV-500 laser calibration system with a high data rate interface and external trigger. Measurements were performed on A CNC vertical milling machine with static data collection and non-stop data collection. Measurement results and a comparison of the displacement errors at static condition and dynamic conditions are discussed.

I. Introduction

Conventional technique for the calibration and compensation of displacement errors of a CNC machine is time consuming. The machine has to stop at every increment and dwell for a few seconds for the machine to settle then collect the positioning data. For a small increment or a large machine, this may take a long time. For example, at an increment of 25 mm, dwell time 6 sec., axis length of 1250 mm, and 5 bidirectional runs, the total data collection time is more than 50 minutes. With non-stop synchronized data collection, it only takes a few minutes, a significant time saving.

The measured static positioning error, usually caused by the machine geometry, guide way and structure rigidity, etc., may not be the same as the actual dynamic positioning errors [1, 2]. In addition to the static positioning errors, the dynamic errors are caused by the servo parameters, resonance frequency, acceleration/deceleration, etc.

II. Basic theory

For lead screw calibration, as shown in Fig. 1, the lead screw is motor driven with a blade to trigger the position sensors (IHS) mounted on the lead screw. 4 position sensors can be used to collect 4 data per revolution [3]. The position sensor sends a TTL pulse to the PCMCIA card to trigger the data collection.

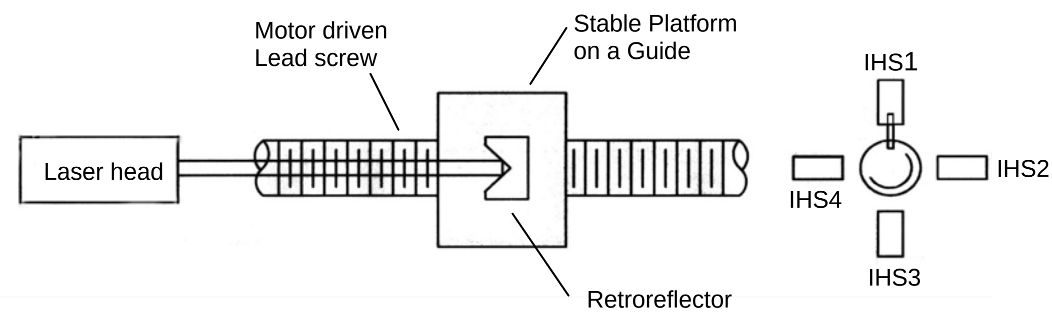

Figure 1: Schematics of automatic lead screw calibration setup with 4 trigger pulses per revolution.

Hence the displacement readings can be collected synchronized with the TTL trigger pulses. Typical measured pitch errors with 4 position sensors are plotted in Fig. 2. The lead screw pitch is 0.2” (5mm) per revolution. Hence there are 20 data points per inch over 20 inches (500mm). Here the thermal expansion error is much smaller than the pitch error.

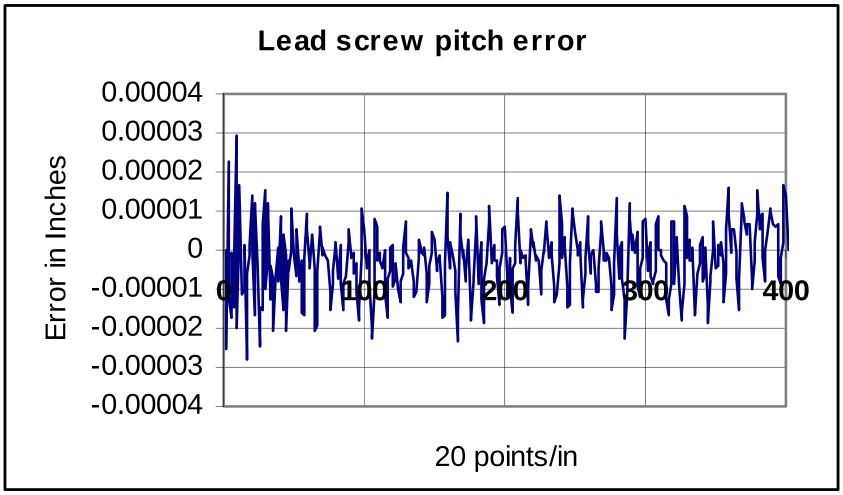

Figure 2: Measured lead screw pitch errors at an increment of 0.05” (1.27mm) over 19” (482mm) travel.

The key to the non-stop data collection is the external trigger and synchronized data collection. For the calibration of an axis of a CNC machine, mount the laser head on the machine bed and the retroreflector target on the spindle. Align the laser beam to be parallel to the axis similar to regular laser calibration. However, instead program the spindle to move from the starting

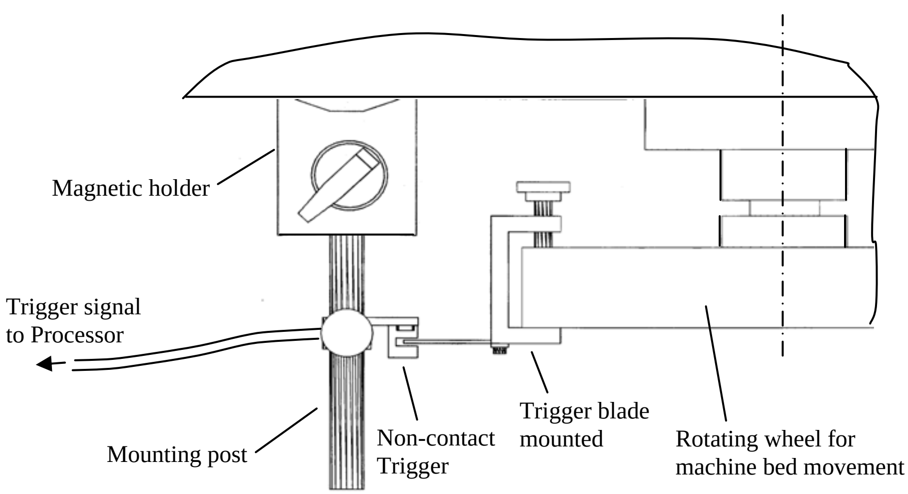

Figure 3: Schematics of the external trigger set up for non-stop synchronized data collection for a CNC machine tool.

position to the ending position, stop at every increment with a 5 seconds dwell time, and program the spindle to move from the starting position to the ending position continuously without stop. The position sensor can be mounted on the lead screw or the rotary wheel of the lead screw as shown in Fig. 3. The noncontact trigger is mounted on a magnetic holder with post. The trigger blade is mounted on the rotating wheel of the lead screw. For every revolution of the wheel, a trigger signal is send to the PCMCIA card to collect the data. For some machines, the trigger signal may come from the machine controller or encoder output.

III. Experimental setup

A CNC vertical milling machine is used for the test. Using a Laser Doppler displacement meter (LDDM) laser calibration system [4] with a high data rate PCMCIA interface card and an external trigger option, the data can be collected non-stop and synchronously up to 10,000 data/sec. The laser system comes with a barometric pressure sensor, an air temperature sensor and a material temperature sensor for automatic compensation the speed of light change and material thermal expansion.

The LDDM laser head was mounted on the bed and the retroreflector was mounted on the spindle. A non-contact trigger was mounted on the post of a magnetic holder and a trigger blade was mounted on the rotating wheel as shown in Fig. 3.

A notebook PC was used for the data collection. The high speed PCMCIA card was inserted in the notebook PC. A special cable was used to connect the LDDM Processor box output to the PCMCIA card and the trigger signal is connected to the LDDM Processor box. In the LDDM software main menu, click on the "2D time base" to data collection. Select the data rate, time duration and external trigger. The maximum speed is 5 m/sec, and the maximum data rate is 10,000 data/sec. The data age, time between the trigger pulse and latched displacement reading, is less than 100 nsec.

IV. Experimental results

In the test here, 2 LDDM laser heads were aligned in the y-axis direction separated by 4.25"(107.95mm). The displacement data were collected with conventional static data collection at an increment of 2" (50mm) over 18" (460mm). The measured positioning errors are shown in Fig. 4. The maximum error is 0.020" (0,51mm) and the back lash is 0.005" (0.13mm).

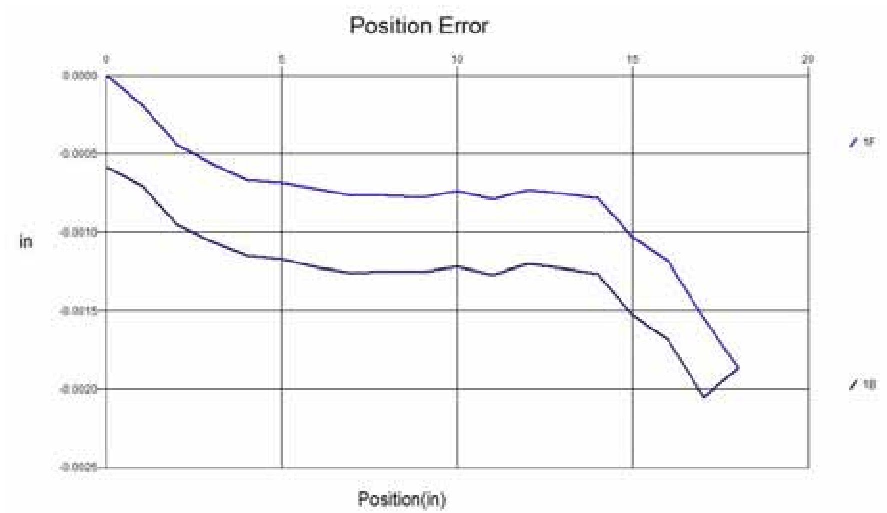

Figure 4: The displacement errors measured by conventional static data collection method.

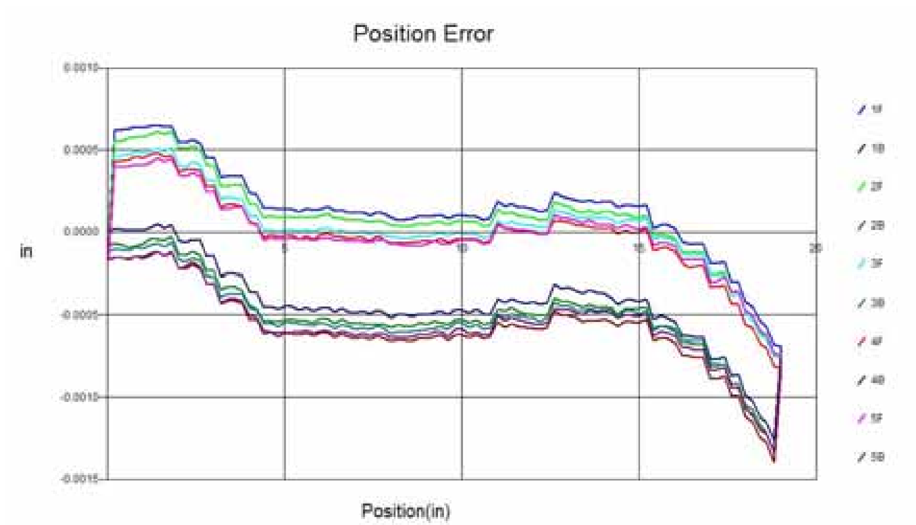

Figure 5: The same displacement errors measured by non-stop synchronized data collection method. There are 5 bi-direction runs with an increment of 0.2" (5mm) over 19" (480mm) were performed.

In the same setup, the displacement data were collected with non-stop synchronized external triggers. Data were collected over 5 bidirectional runs with an increment of 0.2" (5mm) over 19"(480mm) as shown in Fig. 5. The average of these 5 runs is plotted in Fig. 6. The shape of the error curve is very similar to Fig. 4 but with more points and more features instead of more smoothed error curve. The final parts accuracy seems to be better using the non-stop synchronized data than the conventional static data.

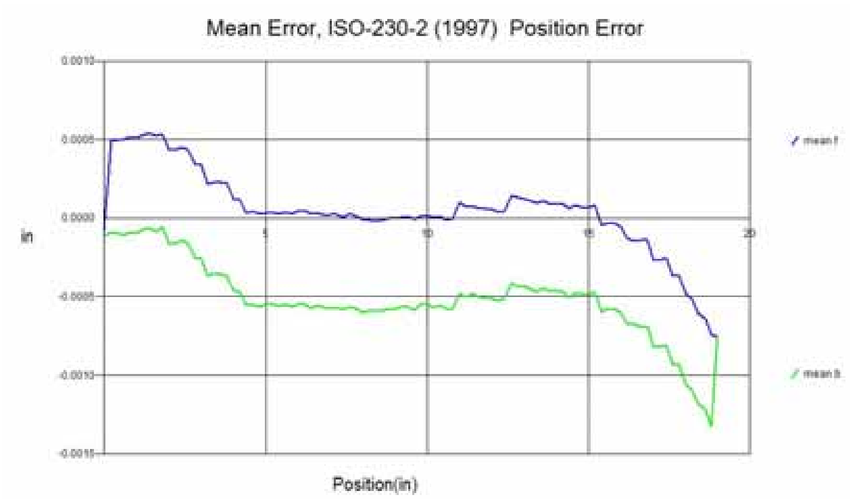

Figure 6: Averaged displacement errors based on the data in Fig. 5.

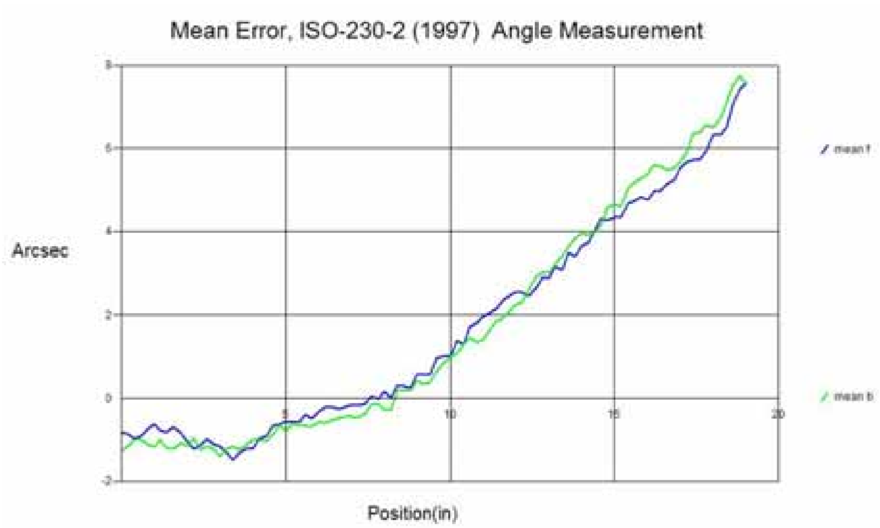

Figure 7: Angular errors calculated by 2 displacement errors separated by 4.25".

The 2 LDDM displacement data were collected non-stop synchronously and simultaneously. The angular errors can be calculated by the difference of the 2 displacement errors divided by the separation. The calculated angular errors are plotted in Fig. 7. The maximum angular error is 8.5 arcsec. Using the angular errors, the adjusted straightness can be calculated as shown in Fig. 8. The maximum straightness error is 0.00012" (0.003 mm).

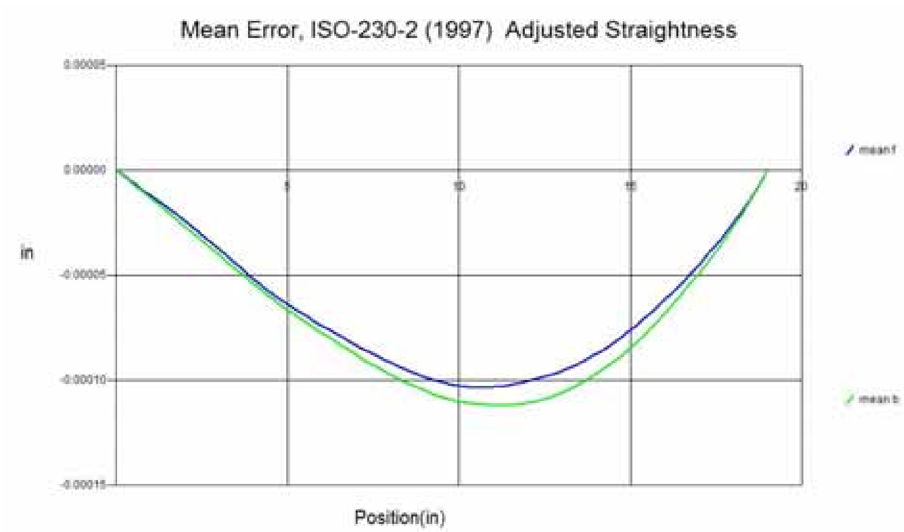

Figure 8: The straightness errors calculated by the angular errors.

V. Summary and conclusion

Measurements were performed on a CNC vertical milling machine with static data collection and non-stop data collection. As compared to statically collected data, result is similar but with more detailed features. Using the displacement data to compensate the machine errors, the final parts accuracy seems to be better using the non-stop synchronized data than the conventional static data. Furthermore, for large machines, using the non-stop synchronous data collection, the time saving is significant.

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