Study of Thermal Growth Measurement for Intergraded Spindles

Ching-Feng Chang, Kuen-Cheng Wang, Te-Chau Chen, Jin-Jia Chen and Tsair-Rong Chen, *Member, IEEE*

***Abstract*—A second Displacement Measurement Meter is used as a compensatory device, it's greatly increases the accuracy which matches a laser inspection report. However, the non-flat surface of motion and fluctuating measurement distance create a certain percentage of error, when the Displacement Measurement Meter is applied, despite of being much more accurate than the traditional thermal coupler design. Moreover, a differential amplifier greatly enhances the linear output voltage being fed back to the CPU, which providing a highly sensitive level of compensation. The application reduces the compensated error of 6% down to 2%, which is based on a single displacement measurement meter applications. The quality of machines can be upgraded and its overall cutting performance is improved.**

***Index Terms*—Displacement Measurement Meter, Compensation Error.**

I. Introduction

A. Background

Spindle is the heart of machine tools. Especially, in the field of high speed machining (HSM) technology, which has been used in a broad range of application[1]-[3]. Rigid designs combined with spindles capable of delivering high torque value at high spindle speeds are allowing occur on the same machine in one setup [4]-[8]. Also, repair time and cost are certainly important issues to be considered. To achieve all these targets, a compact intergraded spindle is the best choice.

As the high spindle speed and torque are within a compact design, remaining within a limited temperature increase can be accepted [9]-[11], how to develop one more effective spindle at low heat increase is one of the biggest challenges. The thermal growth reaction is one of the most important factors to be considered of HSM technology.

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B. Thermo coupler

PT100 has been used traditionally and it gives good feedback [12]. Fig. 1 shows a thermo response of PT100 with a linear output; therefore it gives the best output to set compensation value in relatively to PLC parameters. Normally the thermo coupler is placed very close to the front bearing of spindle, as shown in Fig. 2, which allow the temperature measured within less tolerance.

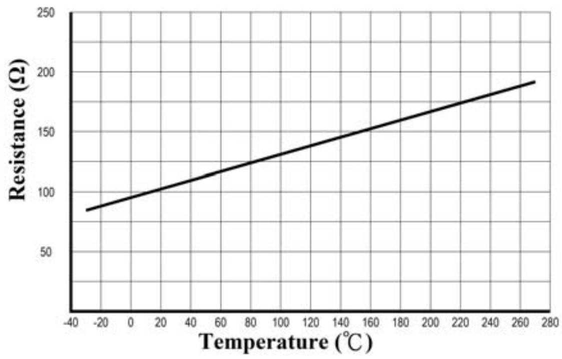

Fig. 1. PT-100 Thermo nature

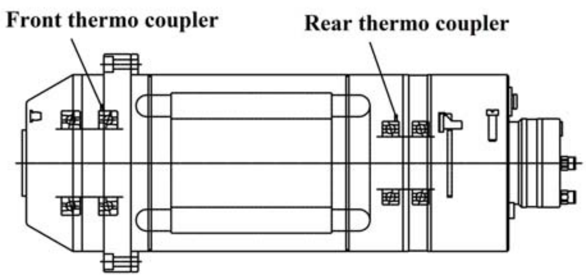

Fig. 2. Spindle with thermo coupler

But the problem is that distance between thermo coupler and bearings, where the heat comes from mainly, and the timing delay of feedback due to thermo coupler's characteristic. Also, the compensation value is normally set under no loaded condition, and it will never be an equivalent to the temperature raise in comparing with when spindle is running under loading condition [12]. Thus, the performance will never be a perfect one. Fig. 3 shows the difference between the spindle growth, which is proved by laser unit, and the measured value of thermo coupler.

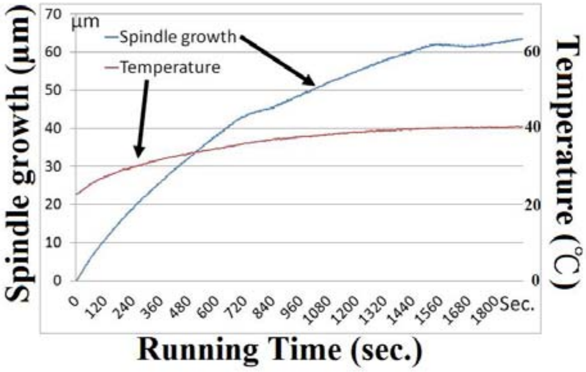

Fig. 3. Spindle growth v.s. PT-100 thermo measured value.

C. *Displacement measurement meter*

Based on the law of Foucault current (Eddy Current) and faraday current, a displacement measurement meter is found, see Fig. 4. It gives a much precise result of spindle thermal growth, without any timing delay and the output is a perfect linear as well [13]-[16]. It's much better than PT100 to set the compensation value of PLC parameter. Problem is that the displacement measurement meter is very hard to be placed upright to the spindle surface. The feedback will be hard to be an exactly linear output; in fact, it's a rms value. Fig. 5 shows a report from a laser test and its displacement measuring meter. Only when spindle warm up, both curves become closer.

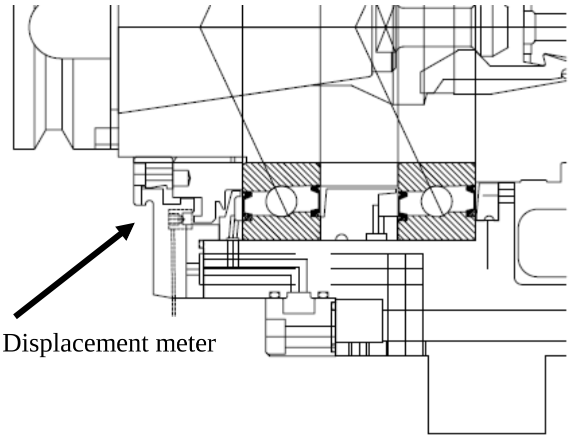

Fig. 4. Spindle with a displacement meter.

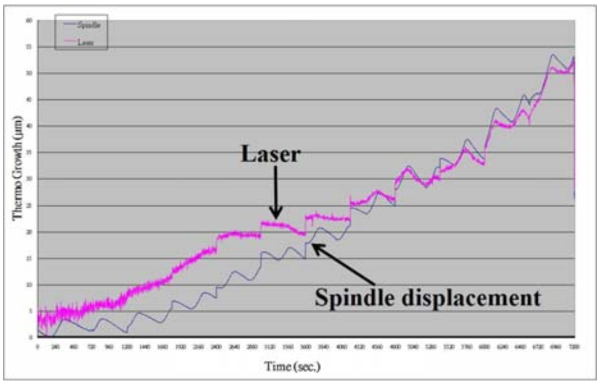

Fig. 5. Spindle growth comparison of PT-100 v.s. Laser report.

II. An Advanced Measurement Model Development

A. *Mechanical design*

This new model consists two pieces of measurement meters, which is placed in front of the spindle[17]-[18]; one used as a reference and the other one used to measure from 3-5mm away, depending on the room and its rigidity of the spindle end cover. Both meters should be fitted under very closed position and exactly same geometrical condition, upright to the spindle end, and all geometrical condition should be as close as they can. And a differential amplifier is applied. Fig. 6 shows the sensors which been placed on bottom cover.

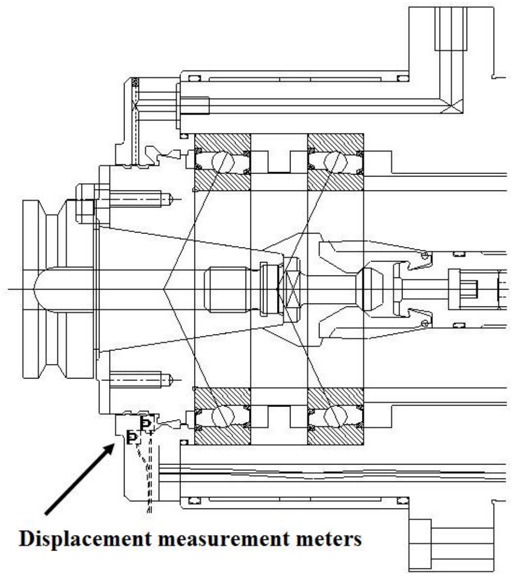

Fig. 6. Double displacement measurement sensor.

B. *Logic concept*

To get a perfect performance of cutting result, the compensation logic has been set, which is to allow the spindle axis compensation of every 1μm when the output voltage changes per +/-0.02V, and the logic chart is shown in Fig. 7.

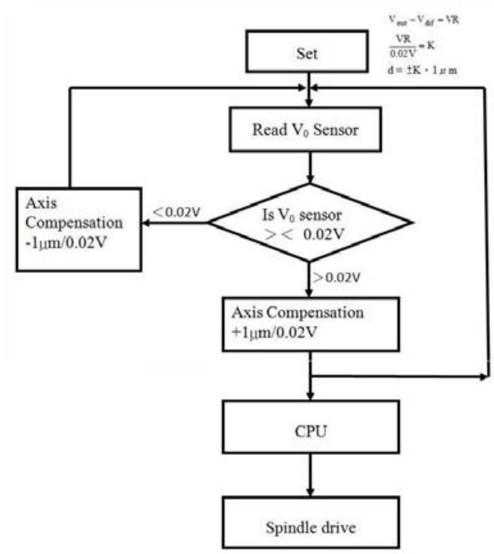

Fig. 7. Logic chart

A differential amplifier is shown as Fig. 8 [19]-[21], which meet the requirement of the above logic concept.

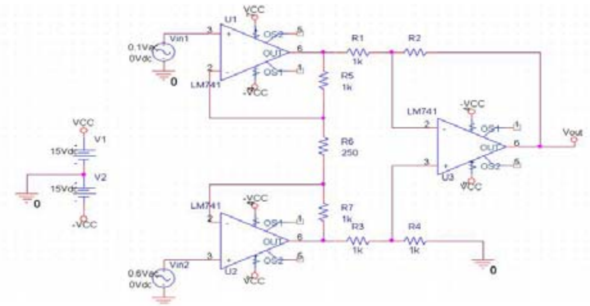

Fig. 8. Differential amplifier diagram.

where:

Vin1	is the compensation (reference) displacement meter.
Vin2	is the measuring displacement meter
R6	is a ratio resistor
R1, R3	are input circuit insulation resistors
R2	is the time control resistor.

And the equation is given as following:

$$i = \frac{Vin2 - Vin1}{R1} = \frac{Vdif}{R \cdot Sin\omega t} \quad \text{.......................(1)}$$

Where:

ωt is the phase at time t.

The output of this measurement meter is shown in Fig. 9, which meet the requirement of compensation parameter, as it's linear.

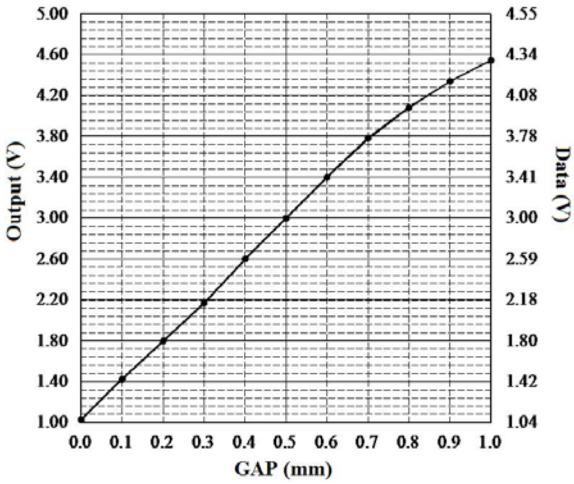

Fig.9. Output of displacement sensor.

Fig. 10 shows the output responses, both the current and voltage, the output response is stable, also highly precise and sensitive when it is fed back to the CPU for axis compensation.

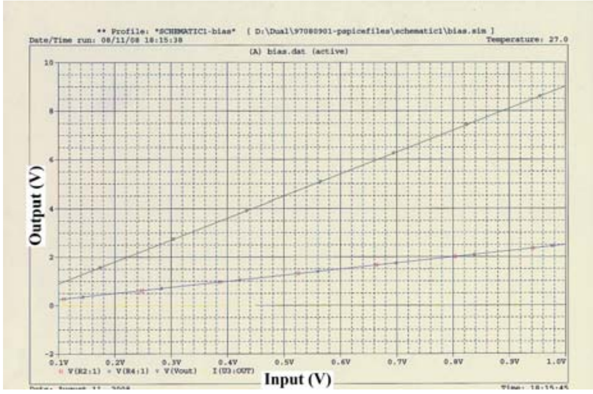

Fig. 10. Simulation.

Fig. 11 shows the output responses of both current and voltage. The output response is stable. The amplifier meet the requirement.

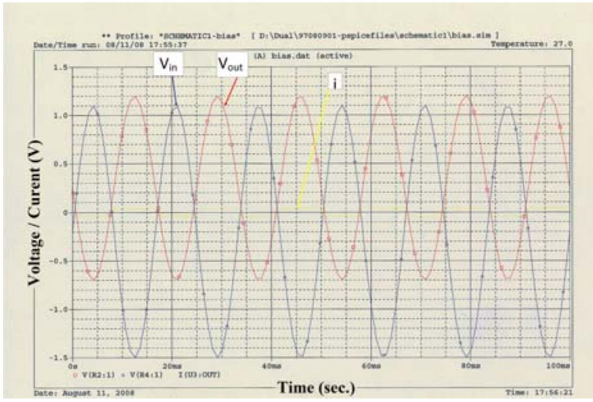

Fig. 11. Voltage and current response.

III. EXPERIMENTAL RESULT

The testing is done on a Challenger high speed vertical machining center, which is equipped with a 24000-rpm high speed electronics intergraded spindle. A laser checking unit is placed on the surface of the working table, as shown in Fig. 12.

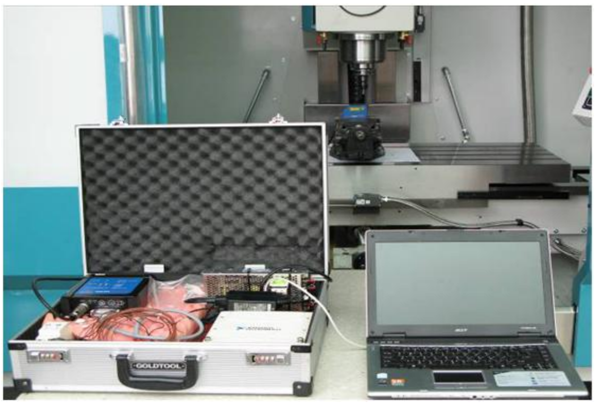

Fig. 12. Laser measurement setup.

A comparison of new design to the spindle equipped with only one displacement meter with the proposed new model is shown in Fig. 13. A report is also provided to approve the test results. This figure shows that there exists some discrepancy between the measure 1, only single displacement meter used, and the laser curve, while the measure 2 with this new model is nearly matching the laser curve.

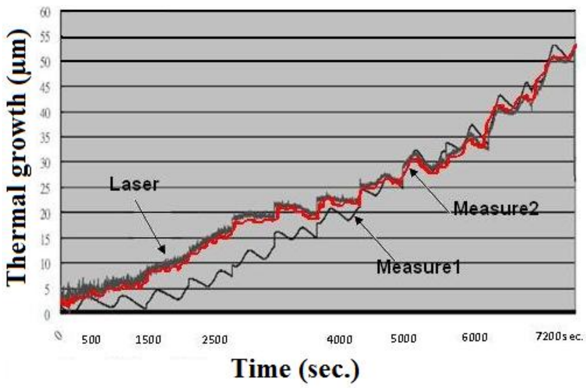

Fig. 13 Comparison curve of lasers and two models.

As a result of fact, in comparing the difference of its thermal growth error between two different models, it's clear to from Fig. 14 that the new model gives temperature error only max 2% and the simple displacement meter will give error up to 6%. Consequently, the new model gets great improvement.

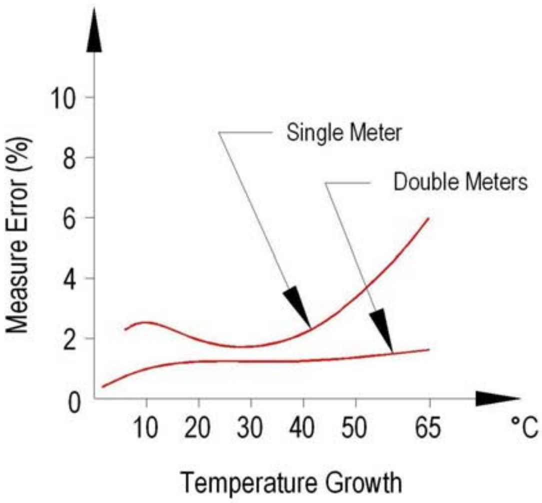

Fig. 14. Measurement error comparison.

IV. Conclusion

The proposed new model approved that the thermal error is 3 times better than that of the old design. It's going to be big quality improvement of the accuracy performance for machine cutting. This will greatly help to improve machine quality level and meet the requirement of HSM technology.

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