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Virtual Sensing Technique For Thermal Error Compensation Of A CNC Machine Tool

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Abstract

Thermal errors in any machine tool are most incredible and major contributors affecting the positioning accuracy of the cutting tool. Researchers from different fields have exposed various factors and possibilities of reducing them in which the main two methods are prevention and compensation. Prevention is done by thermo symmetric design of a machine tool and compensation involves the long study of a particular machine tool behaviour in various conditions, modeling the behaviour and feeding it to the controller. This paper present a low-cost study of the vertical machining centre undergoing thermal deformation, modeling the behaviour of the tool taking few effective parameters into consideration, implementing virtual sensing technique and compensating the errors using the inbuilt platform of FANUC PMC and MACRO programming.

1. Introduction

Thermal errors occur in any machine tool because of the different type of metal with which it is built i.e., ball screws, bearings, cartridges, axis-drive motors and changes in cutting forces, flow of coolants etc., So the heat generation will vary significantly as the machine is used in different environmental conditions, as a result the complexity increases in quantifying and reducing the thermal deformations. In the past years machine tools were operated by skilled labour who would take care of these errors by manually operating the machine for produced parts degree of conformance and now in the recent years with trend of CNC for fast and automated production, operator is less or not involved. Extensive research has been conducted to reduce these errors. A reduction of thermal errors more than 60% was possible by using various modeling techniques, but these do not meet industrial requirements in terms of cost and simplicity. The major considerations of this research work are the effectiveness and applicability through low-cost, simple model-generation and error compensation within a very short time. A most widely used 3-axis vertical machining centre is chosen and a measurement system for spindle thermal error and feed axis thermal error is developed. Any curve fitting tool can be used for algorithm development after studying the behaviour of machine tool relating to different parameters of machine. Developed algorithms are evaluated at different conditions and after a several iterations the optimal models were selected for feeding the controller. Software for compensation is developed on the FANUC platform based on the developed algorithms. The idea behind doing this is very straightforward, as we know the nominal cutting path is given in the form of NC code, the software fed to controller will identify the coordinates of cutting trajectory to use them as inputs for error predictions and then automatically modify trajectory according to predicted position errors of tool.

2. Low-cost measurement system

2.1 Virtual sensor

A thermometer used for sensing the ambient temperature near the machine and observations are plotted with respect to absolute time shown on the machine continuously for three days and randomly on some days to understand the variation of ambient in a whole day. This kind of measurement is generally done using RTD sensors, thermocouples on machine structures for reliable values of temperature but the limitation exists in placing and bonding of the sensor.

2.2 Measurement of Thermal Displacement

The spindle thermal drift is measured using a simple setup of two dial gauges fixed as shown in the Figure 1 For different loading conditions and execution times for which the spindle is running, the spindle displacements are observed in the z and y directions. Important observations made here are that z-axis grows in the downward direction and deflects towards the operator as the spindle is free at the end to grow and z-axis ball screw growth is constrained at the boundaries.

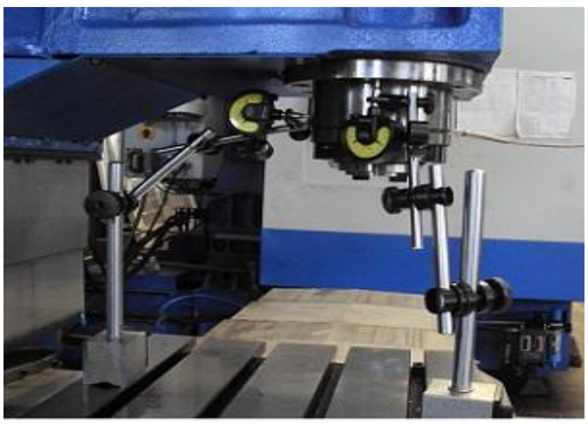


Figure 1: Spindle displacement measurement setup

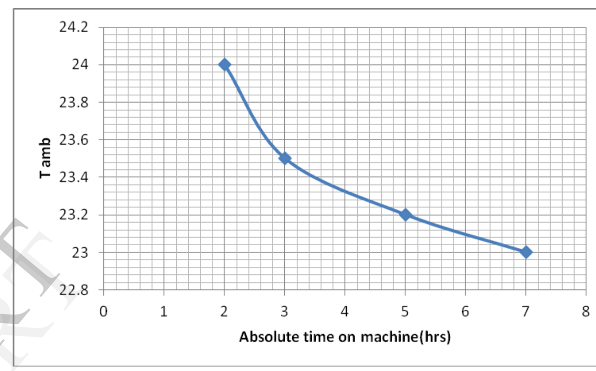
For y-axis and x-axis growth measurement the laser interferometry setup by Renishaw which is available in all the machine tool industries is used as shown in Figure 2. Different programs are fed to the controller for axis movement and the distance moved by the axis and the servomotor temperature are continuously monitored and recorded with respect to the growth observed in each axis independently.

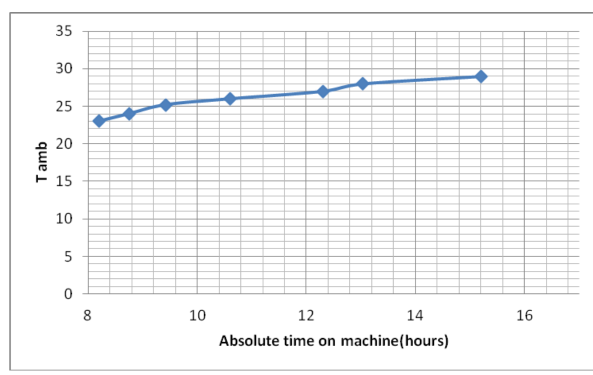
Figure 2: Laser interferometry setup

An important observation made after performing these experiments is that the y-axis growth is very less compared to the other two axis and x-axis growth is considerably greater than the y-axis this is because of the metal involved in ball screw is more in case of x-axis.

3. Data Modeling and Evaluation

A linear equation with least variables is the best model for error compensation in all respects. Based on this observation a virtual sensor model developed for predicting the ambient temperature(T amb) with respect to the absolute time involves three models as shown in Figure 3, as the ambient temperature from morning till the end of afternoon is rising and then decreasing and the limitation with absolute time on the machine is a sudden and vast change in the time shown for every 24 hours which spoils the curve.





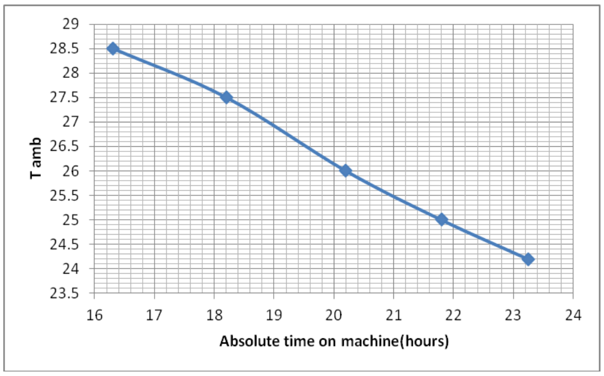


Figure 3: Ambient temperature Vs Absolute time.

3.1 Spindle displacement modelling

From the data collected it is observed that there is a considerable growth in the z-direction of spindle. The growth of the spindle mainly depends on the load application, cutting forces acting, the time for which the load is applied and the environmental conditions like ambient temperature and human intervention. Based on this fact a number of experiments are done and observations recorded each day as shown in Figure 4, for different loading conditions starting from 1% load which can be observed on the machine for the execution time till 3 hours.

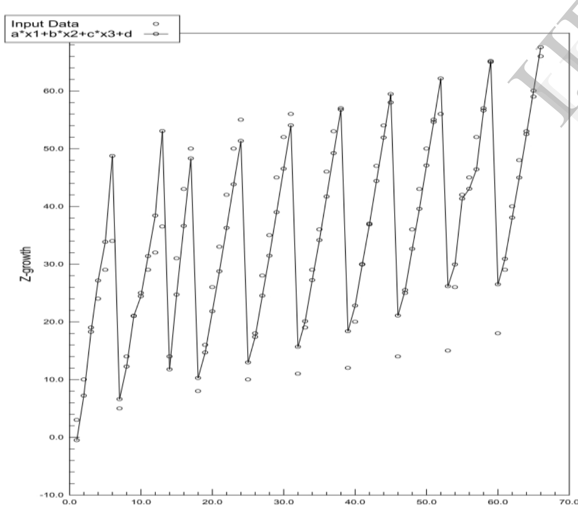


Figure 4: Model for spindle growth in z-direction.

3.3 Feed drive displacement modeling

As observed y-axis growth is less and also that the cutting tool tip is moving towards the operator, the error prediction in this axis seems to be complex. But from the fact that the relative motion between the tool and work piece is less even when heat is induced in the axis, y-axis growth is not modeled.

X-axis growth is modeled considering the parameters distance travelled by the axis, servo motor temperature range 20c and ambient temperature as shown in Figure 5.

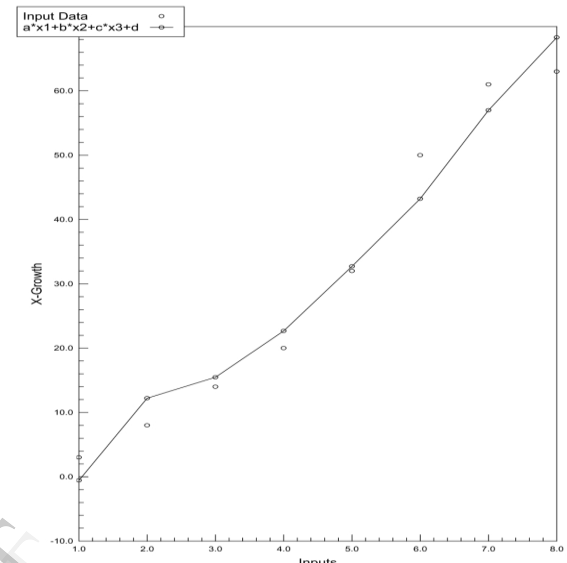


Figure 5: Model for x-axis growth.

The models obtained are continuously evaluated for all types of conditions with proper data fitting so that an optimal model with %error less than 15 is obtained.

4. Error compensation

The values for most of the parameters used in the evaluated models are obtained from the CNC machine itself except ambient temperature which is our virtual sensor. FANUC PMC is used for the logic controlling and MACRO programming is done for the models to be fed on to the controller for compensation in regular intervals.

A failsafe compensation logic is included through programming using conditional statements for making sure that the models will not misbehave on the machine at any point of time.

A model with only 10% load for execution time of 3 hours is also obtained as shown in Figure 7, for applying the model prediction values using multiplication factors to a wide range of loads.

As the loading is dynamic on a machine a PMC logic for sampling and averaging the loads in regular intervals is used.

For the cooling breaks like tea, lunch and sessions, different models work. After a number of experiments it was seen that a contraction at the least of 4micron per hour any time happens in spindle or axis. On applying the kinematic principle to find out the rate of linear velocity where velocity is a function of displacement, making the initial velocity to be zero and using the cooling time which can be obtained from the logic included in PMC we will be able to compensate a bit for the cooling as well.

Switching these heating and cooling models through proper programming will give a decent error compensation any time.

5. Results

For the load values and execution time of 3 hours on any day the growth in the spindle before compensation and after compensation is shown in Figure 6.

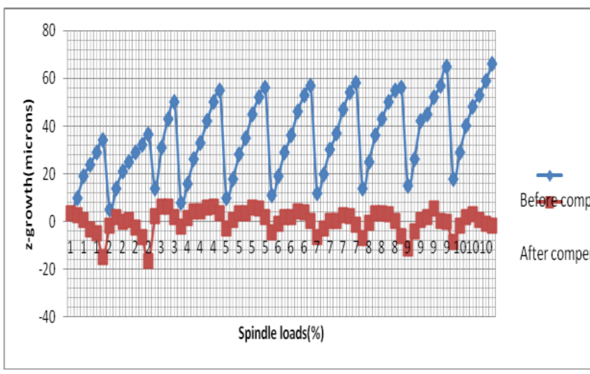


Figure 6: Spindle growth in z-direction before and after compensation.

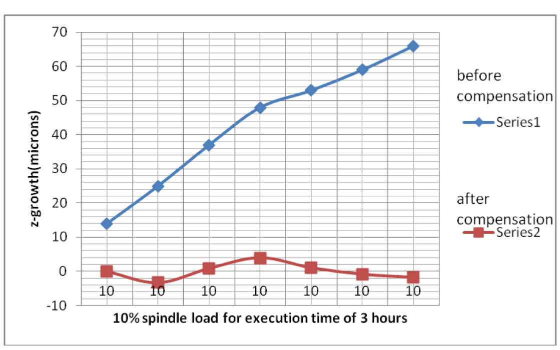


Figure 7: Spindle growth in z-direction before and after compensation for a 10% load applied for 3 hours on a day.

Growth in the x-axis before and after compensation for the distance travelled, motor temperature range of 20c and ambient range in a day is shown in Figure 8.

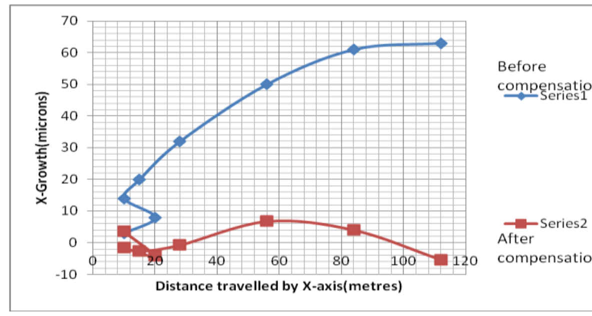


Figure 8: X-axis growth before and after compensation

These results are also observed on the CNC console while performing a number of cutting tests on the machine tool.

The values of all the parameters are continuously getting monitored in the assigned variables of CNC as shown in Figure 9.

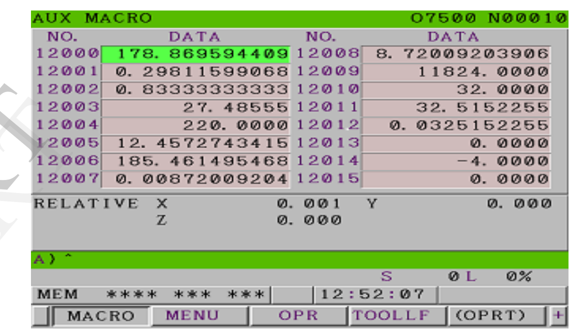


Figure 9: CNC screen showing transferred values of parameters.

Compensation values at regular intervals are getting transferred as shown in Figure 10.

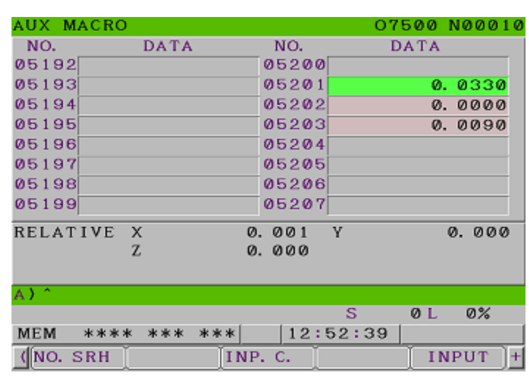


Figure 10: X-axis offset- 33microns, z-axis-9micron.

6. Conclusions

A very systematic, effective and low-cost method for thermal error measurement and compensation of CNC machine tool is presented in this paper. This work has been verified its applicability in industrial environment. The important features of this system include:

1.The implementation of virtual sensing to identify ambient temperature using the absolute time in a day.

2.The parameters chosen for modeling are less and key factors affecting the model whose values can be directly obtained from the CNC.

3.Growth measurement setup just includes a dialguage setup and very much available laser interferometry setup.

4.The compensation model can be generalised for wide range of load applications by programming with a multiplication factor.

5.Cooling compensation is solved in a simplest way to reduce it to a decent level.

6.This failsafe system will work anytime in any conditions for 3 hours.

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