

Artifact Based Assessment of CNC Machine Thermal Growth and Compensation

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ABSTRACT

Thermal growth of spindle and other components is common in CNC machines, especially with MQL machining, and directly impacts positioning accuracy and thereby quality. A common method to address this is by measuring the thermal growth using gage bore probing and then compensating for it. Application of this method in 5-axis CNC machines is relatively new and effectiveness is often not tested. Error sources due to various orientations of the part could arise. A new artifact based method is presented for assessment of thermal compensation used by the CNC OEM. The method involves an artifact, test cycle and automated data logging. A precision granite artifact with gage bores on different faces is fabricated and can be presented for probing in different orientations. The machine is warmed up using repeated dry-cycling, thereby creating thermal growth. Compensation error is evaluated as the difference of actual thermal growth and compensation offset. Various metrics for overall compensation accuracy of the machine can then be evaluated. The artifact test is carried out on a 5-axis CNC machining center and compensation accuracy metrics evaluated.

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1. INTRODUCTION

Recently in automotive manufacturing there has been an increase in Minimum Quantity Lubrication (MQL) machining and has been implemented on Computer Numeric Control (CNC) Machines [1]. In MQL machining, flood coolant is replaced by small quantities of MQL fluid and air mixture through spindle-tool and target at cutting zone. However, a challenge that MQL machining faces is the thermal growth of machine components (spindle, fixture, column etc) resulting from heat accumulation and temperature increase. Besides machining activity, CNC thermal growth is also impacted by ambient temperature changes such as winter to summer seasonal change, vicinity to a heat source or sink. The thermal growth errors are large enough to impact CNC positioning accuracy and thereby part quality. CNC Original Equipment Manufacturers (OEMs) have attempted to address this in various ways - better machine design, better heat dissipation, thermal compensation etc [2, 3]. In this paper, we focus on thermal compensation strategy where the idea is to measure or estimate the thermal growth and then compensate (offset) for it.

1.1 CNC Machine Thermal Growth Assessment

There have been various methods to assess positioning accuracy and geometric tests, repeatability, thermal effects etc. ISO and ASME standards [4, 5] outline methods for thermal growth measurement, test conditions, assessment and related aspects. A sensor housing with 5 displacement sensors is installed on machine fixture or table, a mandrel installed in spindle, and other data acquisition instrumentation. Various spindle rotation, linear axes movement and ambient temperature variation tests can be done. Linear and tilt errors

are obtained by this method. However due to such logistics, this method is limited to offline assessments and is not easily applicable to production machines. Thermal compensation in MQL machining is an online requirement and is sought with characteristics such as small size and logistics, contamination free and low cycle time. There is significant research in analytical estimation of thermal growth errors and associated compensation [3, 6]. This can produce good results in offline controlled test conditions. However, in a production scenario where there are many uncontrolled factors, it is realized that a mixed approach (measurement and analytical) can be more beneficial. Various measurement methods have been developed for this purpose such as gage bore probing, gage ball probing, laser based measurement etc [6]. A drawback is extra cycle time taken for measurement and is not always favorable in high volume production scenario. Therefore only limited measurements are performed (that account for gross thermal error) and analytical estimation (for appropriate adjustments) is used.

Gage bore probing is a commonly used method by CNC OEMs for machine compensation and different OEMs use different strategies for this purpose. Besides probing, compensation also involves various algorithmic evaluations [7, 8]. In production environment, overall compensation accuracy is affected by various factors such as distance between gage bore location and machining feature location, various orientations of part in 5-axis CNC, time lag between gage bore probing and machining etc. Generally, it is assumed that the gage bore measurement is correctly applied for compensation of machining various features. As mentioned before, there are various methods to assess machine thermal growth, but, to authors'

knowledge, there have not been any effective methods to assess overall thermal compensation. In this paper, we discuss a newly developed artifact based test method for assessment of CNC thermal growth and effectiveness of the employed thermal compensation algorithms. We present our approach with reference to a 5-axis CNC Machining Center (x, y, z for linear movement and A, B rotary axes for part orientation), but is equally applicable to 3-axis and 4-axis CNCs. Also, various aspects are presented with respect to x -axis, but are equally applied to y and z axes.

1.2 Machine Compensation Using Gage Bore Probing

In this method, a precision gage bore is installed at a suitable location on or near part fixture. A touch probe is loaded in the spindle and the gage bore is probed (Fig 1). The gage bore-probe position coordinates (x_0, y_0, z_0) with respect to glass scales are used as the reference point (origin) against which various positioning during machining is done. However, as mentioned before, this reference point can shift due to thermal growth and needs correction in order to meet part quality specification. This is generally done by means of creating offsets (or machine offsets).

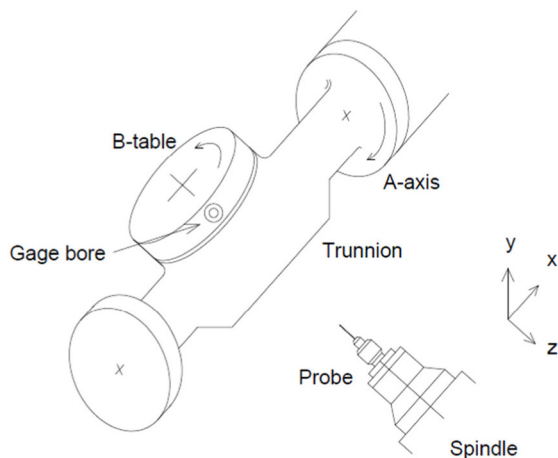


Figure 1. Schematic of Gage Bore Probing in a 5-axis CNC

$$x\text{-offset, } \Delta x = x_{cur} - x_{in} = x_{cur} - x_0$$

(1)

where x_{cur} is the current x position and x_{in} is the initial or previous x position. Similarly, y and z offsets are also obtained.

It should be noted that the gage bore probing is done in one A - B combination (e.g. A_0B_0 [$A = 0^\circ, B = 0^\circ$]), but offsets are evaluated for various different A - B combinations in which a part can be presented for machining. As mentioned before, this is generally not assessed for accuracy and could have algorithmic or mechanical errors. Also, different OEMs use different strategies for compensation in terms of gage bore location, temperature sensor location, algorithms, probing frequency etc. In a production environment, machine thermal compensation using gage bore probing is affected by various reasons such as given below -

- Growth between gage bore location and machining feature location
- Time lag between gage bore probing and machining feature time
- One orientation of A - B axes for gage bore probing vs multiple orientations of A - B axes for part machining.
- Various algorithmic evaluations for compensation
- Various machine starts and stops during production (part shortage, load / unload time, shift change etc) affect machine warm-ups and cool-downs. Gage bore probing in a production environment is done only certain times and not every machining cycle because of additional cycle time.
- Tilt errors are not measured by gage bore probing, only linear errors

There have been various methods for thermal growth assessment, but thermal compensation itself is not much assessed. However, this is important from production engineering viewpoint where quality and machine capability are important metrics. With increasing emphasis on quality and decreasing tolerances, various error sources need identified and addressed. Towards that end, "compensation error" is identified as a potential error source and methodology is presented for its evaluation.

2. ARTIFACT BASED THERMAL COMPENSATION ASSESSMENT

In this section, we present a newly developed method for assessment of CNC thermal growth and effectiveness of the employed thermal compensation scheme.

2.1 Artifact

A precision granite artifact with gage bores on various faces is fabricated (Fig 2). The artifact would serve as the part to be mounted on machine fixture / table using a through bolt. Gage bores on different faces allow presentation and probing in different A - B configurations. Granite is selected for its very low coefficient of thermal expansion and would not introduce thermal growth effects of its own.

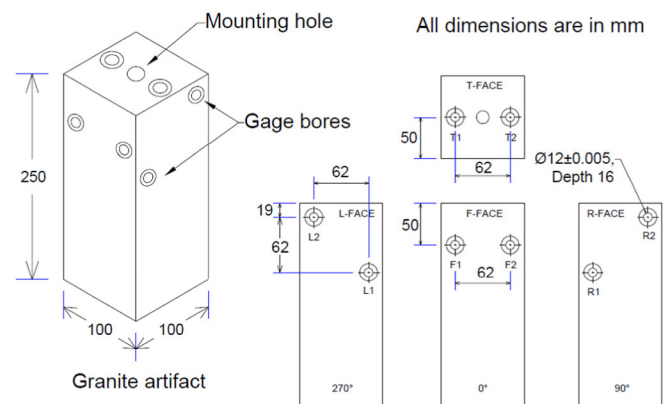


Figure 2. Granite Artifact with Gage Bores