Calibration of an interferometric surface measurement system on an ultra-precision turning lathe

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Abstract

On-machine measurement avoids the time-consuming transposition operations between the measurement and machine coordinates. The present work integrates an interferometric probing system on an ultra-precision turning machine. Due to the relatively harsh environment in the machine tools, metrological characteristics of the surface measurement instrument would deviate from those tested under standard laboratory conditions. In order to improve the performance of on-machine measurement systems, it is necessary to calibrate the on-machine measurement (OMM) system and compensate for any systematic errors. Three key issues, including on-machine vibration, machine tool kinematics error, and linearity error are discussed in this study. Experimental investigation is conducted to prove the validity of proposed calibration methodology and the effectiveness of on-machine measurement.

1 Introduction

Ultra-precision manufacturing has developed over decades to provide highly demanding surfaces geometries with optical, electronic or mechanical functions [1]. In order to enhance availability of metrology for such applications there has been a shift in the approach of metrology from offline, lab based solutions towards the use of metrology within manufacturing platforms [2]. However, due the fact that measurement probe actuation is carried out using the machine tool axes, it is necessary to calibrate and compensate the systematic errors of the tool to facilitate the measurement process. In this work, an interferometric probe, termed Dispersed Reference Interferometry (DRI) [3] is integrated onto a 3 axis ultra-precision lathe (Nanoform 250 Ametek Precitech). The system configuration is illustrated in Figure 1.

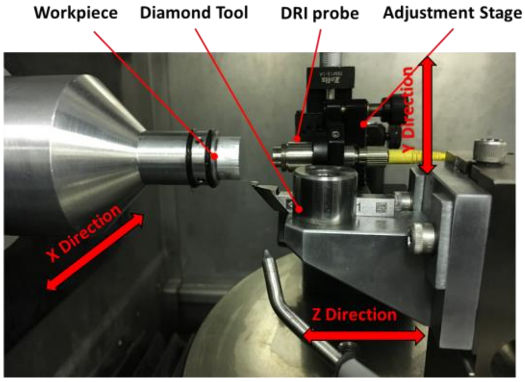


Figure 1: On-machine measurement system configuration

2 Structure of on-machine calibration

According to the configuration and measurement task of OMM system for diamond turning process, calibration is performed in the sensitive measurement direction (Z direction), including on-machine vibration test, kinematics error mapping and linearity error correction. The structure diagram for the on-machine measurement calibration process is illustrated in Figure 2.

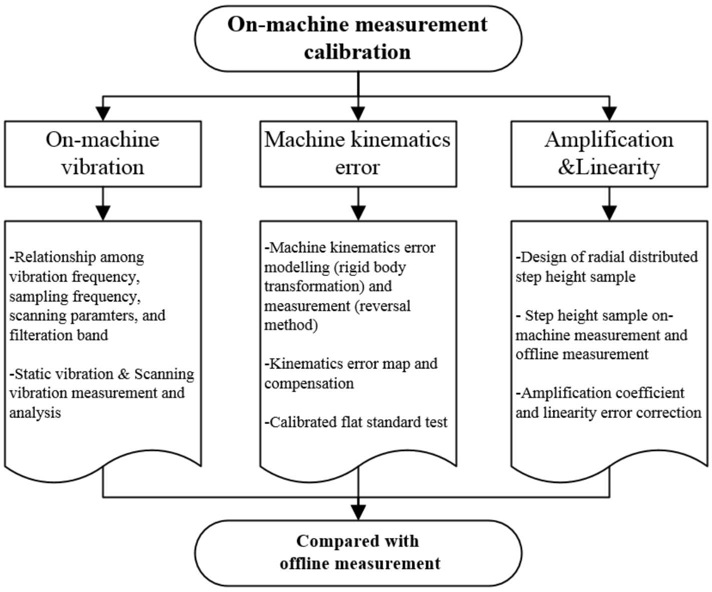


Figure 2: Structure diagram of on-machine measurement calibration

3 Experiment and discussions

3.1 On-machine vibration

Vibration from machine tool axes, such as the air bearing spindle and linear stages will be inevitably induced into the measurement results. According to Nyquist sampling theorem, the sampling frequency F_s is required to be at least 2 times $F_{vibration}$ in order to separate the vibration induced components from the actual surface topography. Both static and scanning tests were performed. The acquired signal indicated that primary vibration frequencies were less than 100 Hz. The sampling frequency is thus set to be 200 Hz.

3.2 Machine tool kinematics error

Due to mechanical imperfections, wear of machine tool elements, and stage misalignments, the deviation from the programmed scanning path will induce additional error to measurement results [4]. The machine tool kinematics error was modelled (Multi-body rigid kinematics), measured (Reversal method) and compensated for the OMM results. After scanning error mapping, a commercial optical flat (Edmund optics) was measured on-machine and offline on a calibrated Twyman–Green interferometer (Fisba FS10). The measurement results and scanning error map are respectively shown in Figure 4.

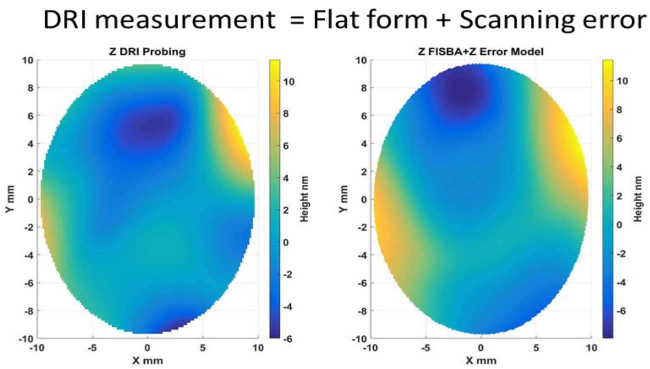
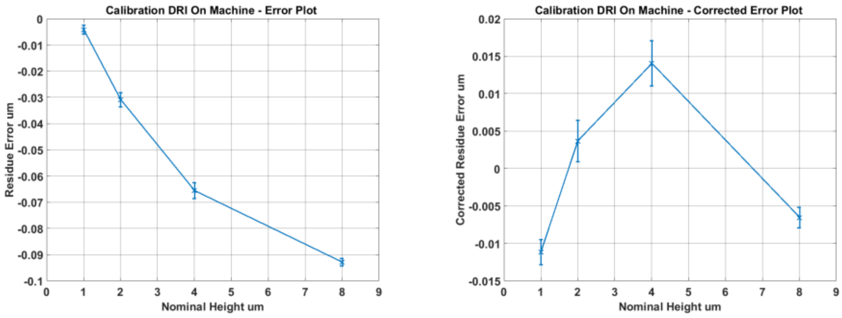


Figure 3: DRI OMM vs. combination of scanning error and Fisba measurement

Figure 3 indicates that DRI OMM comprises machine kinematics error and flat form error. With the aid of machine kinematics error mapping established above, the on-machine probing data was compensated. The characterized flatness error from OMM reduced from 17.3 nm to 11.4 nm, compared with results of calibrated offline measurement 8.7 nm. The remaining deviation resulted from the alignment issue in the offline measurement process.

3.3 Amplification coefficient and linearity error

Calibration of amplification coefficient and linearity error in Z direction includes measuring different step heights to study the relationship between the ideal response curve and the instrument response curve. An artefact with 4 step height (1 µm, 2 µm, 4 µm, and 8 µm respectively) is used for DRI on-machine calibration of amplification coefficient and linearity error. Figure 4 (a) and Figure 4 (b) respectively show the uncorrected and corrected error plot of the step height standards measurement. The error bars represent the measurement repeatability, calculated as the standard deviation of the mean value. After calibration, the slope correction coefficient was 1.0123 and the linearity error was reduced from 93 nm to 14 nm.



(a)Step height error plot (b) Corrected error plot

Figure 4: Step height measurement error plot

4 Conclusions

The paper presents calibration of an interferometric probing system on an ultra-precision turning machine. Three main aspects, including on-machine vibration, machine kinematics error and linearity error, have been discussed. Experimental work has been conducted to prove the validity of proposed calibration methodology.

References

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