EVALUATION OF PERIODIC ERROR COMPENSATION USING A TIME DOMAIN REGRESSION ALGORITHM

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ABSTRACT

Heterodyne interferometry offers high accuracy, resolution, and range for noncontact displacement measurement. Periodic error due to frequency mixing can reduce the achievable measurement accuracy. Recent trends in semiconductor manufacturing have increased interest in real-time compensation of periodic errors. The Agilent N1225A four-axis laser card offers hardware implementation of periodic error compensation based upon the time domain regression (TDR) algorithm. In this paper, performance of the compensation algorithm is evaluated experimentally.

INTRODUCTION

Periodic error is well-described in the literature [e.g., 1-3]. In heterodyne interferometry, misalignment of the optical system or defects in the optical components can result in periodic error due to frequency mixing of the nominally orthogonal beams. As described in [4], periodic error for any motion profile can be characterized as first and second order errors which are non-cumulative and repeat with each unit wavelength change in optical path length. First order errors have a spatial wavelength Λ_1, which is equal to the laser wavelength divided by the interferometer's fold factor (two for a single pass setup). Second order errors have spatial wavelength of Λ_2, which is half of Λ_1.

The time domain regression (TDR) algorithm [5] is an extension of a scheme first proposed by Chu and Ray [6]. In [5], a software implementation of the algorithm and considerations for FPGA implementation are discussed.

EXPERIMENTAL SETUP

The heterodyne interferometer setup used for experimental evaluation [4-5] is shown in Fig. 1. By appropriate displacement of the rotating LP and HWP [7], desired levels of misalignment can be introduced into the system, resulting in controllable first and second order periodic error amplitudes. The reference and measurement signals are connected to the N1225A axis card.

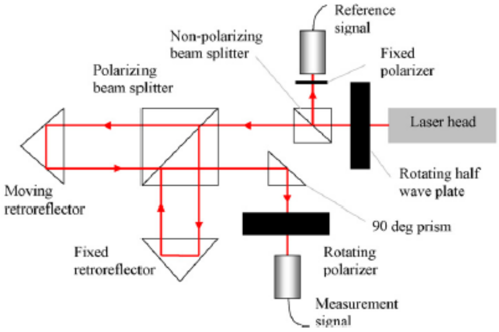

FIGURE 1. Schematic diagram of the heterodyne DMI [4-5].

EVALUATION OF ALGORITHM

To evaluate the performance of the compensation algorithm, the Agilent axis card was configured to record two channels of data: raw position and compensated position (with periodic error removed). Following data collection, Fourier transform (FT) techniques were used to determine periodic error magnitudes following the approach in [4].

An air bearing stage, carrying the moving retroreflector, was commanded to perform sinusoidal (non-constant velocity) motion with 1 mm peak to peak amplitude at 0.25 Hz. Because the presence of second order error does not notably affect measurement and compensation of first order error, the HWP and LP were configured to give significant first order (5.0 nm) and second order (4.5 nm) error. To capture large portions of the motion cycle, 300,000 data samples were collected for each channel at 62.5 kHz.

The collected position data was resampled in equal increments of 2 nm displacement. The spatial FT was applied to determine periodic error magnitudes on intervals of 25 cycles of first order error. At velocities below 10 mm/min, low frequency errors due to the imperfect displacement of the stage dominate the FT results, so data intervals with corresponding velocities were omitted from the analysis.

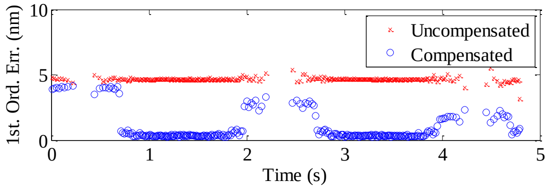

FIGURE 2. Uncompensated and compensated first order error magnitudes.

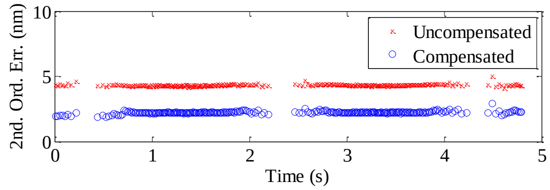

FIGURE 3. Uncompensated and compensated second order error magnitudes

Figures 2-3 illustrate uncompensated and compensated error magnitudes throughout the sinusoidal profile for first and second order periodic errors. Inspection of these figures shows that less error compensation is achieved in regions of low velocity (i.e., the compensated error approaches the magnitude of the compensated error). The mean CR as a function of velocity is shown in Figs. 4-5.

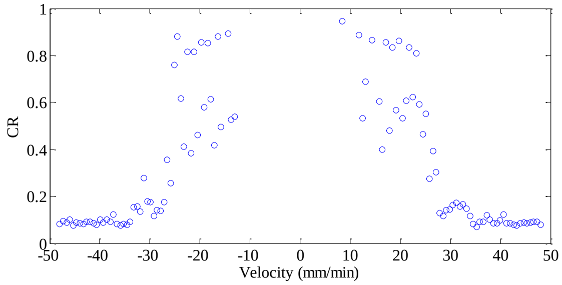

FIGURE 4. First order CR variation with velocity.

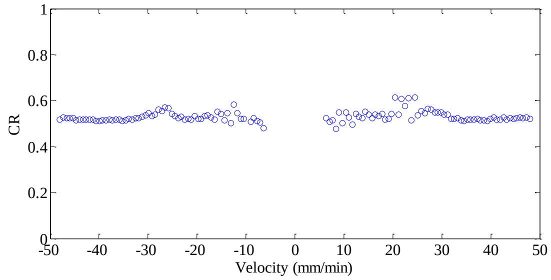

FIGURE 5. Second order CR variation with velocity.

CONCLUSIONS

The time domain regression (TDR) algorithm enables first and second order error compensation using iterative matrix methods. The Agilent N1225A laser axis card, which offers a hardware implementation of this algorithm, was experimentally evaluated during sinusoidal motions with varying velocities. It was observed that the error compensation was successful overall with up to 90% reduction in first order periodic error. However, performance of the algorithm was shown to degrade below speeds of approximately 20 mm/min for both constant and non-constant velocity motions.

ACKNOWLEDGEMENT

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