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Traceable Measurement and Characterization Methods of Nano Step-height Standards using Laser Focus Sensor

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Abstract
Nanopositioning and nanomeasuring machines are universal devices for solving various positioning and measuring problems in the macroscopic range with sub-nanometre resolution. This paper introduces a traceable measurement and characterization method of nano step-height standard based on the nano positioning and measuring machine. The laser focus sensor was utilized as a zero indicator. To realize traceable measurement, laser beat frequency experiments were conducted in all three axes. A 190.8 nm step-height standard was measured. To reduce noises in the evaluation process, the Savitzky-Golay filter and the fast Fourier transform filter were adopted as pre-processing methods. Results indicate the proposed methods can improve the evaluation accuracy. And the FFT filter shows a better noise reduction property.

Keywords: Traceable measurement; Nano step-height standard; Laser focus sensor; Nano positioning and measuring machine; Pre-processing method

1. Introduction

Rapid progress in several high-tech industry branches like semiconductor and optical industries as well as in the fields of micro-electromechanical system and micro-fabrication has significantly increased the need for dimensional micro- and nano-metrology. Nanoscale step-height or depth standards are widely utilized to calibrate the *z*-axis of microscopes and stylus profilometers [1-4].

Nano positioning and measuring machines are devices for solving various positioning and measuring problems in a range of several millimetres with sub-nanometre resolution. This paper presents a traceable measurement and characterization method of nano step-height standards by utilizing the laser focus sensor (LFS) based on the nano positioning and measuring machine (NPMM).

2. Measuring platform and probe

The measuring platform applied in this paper was designed at the Technical University of Ilmenau and produced by SIOS Messtechnik GmbH [5]. It has the ability to trace the measurement results to the meter definition.

The structure of the NPMM [6, 7] is shown schematically in Figure 1. The laser beams from the three interferometers are orthogonal to each other. The unique sensor arrangement provides Abbe error-free measurements on all three axes. The measurement range is 25 mm × 25 mm × 5 mm with a resolution of 0.1 nm. Different types of probing systems can be integrated to the platform.

The laser focus sensor was integrated into the NPMM as a zero indicator. It presents the advantages of noncontact and relatively high speed. The hologram laser unit based sensor has a resolution of 1 nm and scan speed of 500 µm/s [8].

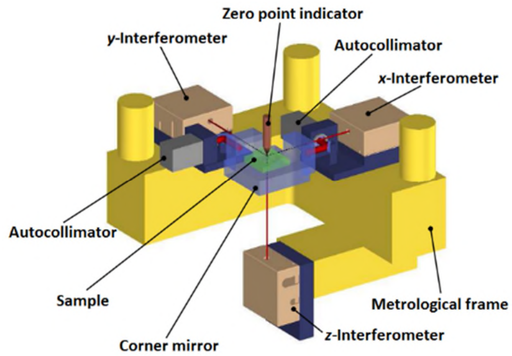

Figure 1. Structure of the NPMM.

3. Traceability research

The measurement results are recorded by the three axes laser interferometers embedded in the NPMM, which can be traced to the meter definition directly. A beat frequency experiment was conducted.

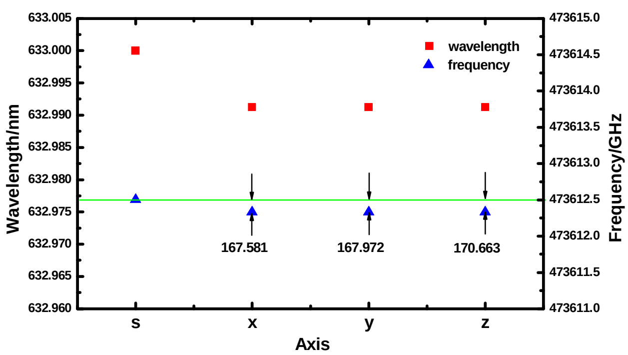

Figure 2. Results of beat frequency.

The calibration results can be seen in figure 2. The letter 's' in figure 2 means the 'standard laser interferometer'. The deviation of wavelength is less than 0.01 nm in all the three interferometers compared with the standard value of 633 nm. The horizontal line (green) in figure 2 represents the frequency of standard laser interferometer and has a frequency deviation of 167.581 MHz, 167.972 MHz and 170.663 MHz with *x*, *y* and *z* axes respectively.

3. Evaluation methods and results analysis

The step-height value was evaluated according to ISO 5436-1:2000. A, B and C are the effective evaluation regions (shown in figure 3). The evaluation is based on the method of least squares.

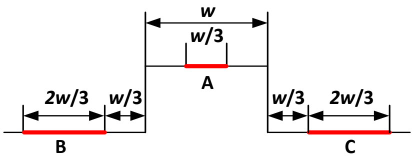

Figure 3. Evaluation regions of step-height

To standards of nanometre level, the measurement results could be easily affected by noises. Figure 4 is a typical case. It is the measurement result of a nano step-height with a calibrated value of 190.8 nm (U=3.0 nm, k=2). Plenty of spike pulses appeared in the curve. They were also existed in the evaluation regions and thus had an influence on the evaluation result. This is even more significant in a narrower step.

To reduce these effect, the Savitzky-Golay filter (S-G) and the fast Fourier transform (FFT) filter are introduced as the pre-processing methods. Ten times of repeated measurements were taken to evaluate the step-height, the mean value of the original data is 189.8 nm, with a standard deviation of 1.4 nm.

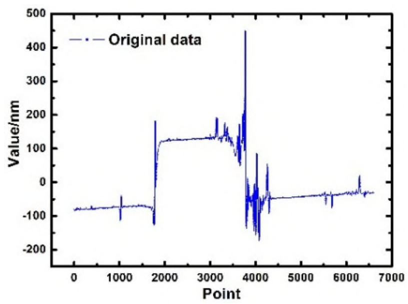

Figure 4. Original measure result

3.1. Savitzky-Golay filter

The S-G filter has peak preservation and low-pass properties and performs good noise reduction for stationary white noise [9, 10]. Figure 5 is an S-G filtered curve. The spike pulses were weakened but the peaks' shape had been reserved. The mean value after filtered is 190.0 nm, with a standard deviation of 1.2 nm. It has a 0.8 nm error compared to the calibrated value.

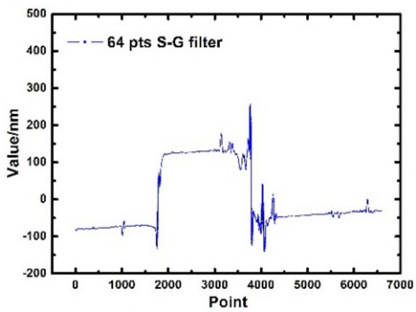

Figure 5. S-G filtered result

3.2. Fast Fourier transform filter

The FFT filter has the ability to separate high frequency noises and was used to pre-process the waveform. It has a low-pass property with a cut-off frequency of 0.008 Hz. One of the filtered curve is shown in figure 6. The mean value after filtered is 190.9 nm, with a standard deviation of 1.1 nm. It has only 0.1 nm error with the calibrated value.

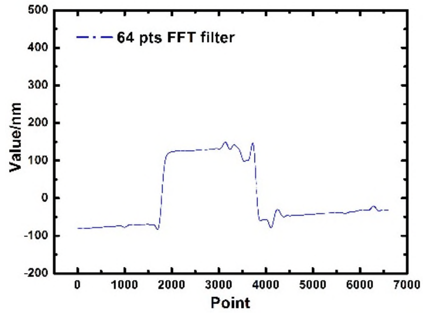

Figure 6. FFT filtered result

From figure 6, it can be seen that the filtered curve is much smoother than that in figure 4 and figure 5. And the evaluated value is closest to the calibrated value, compared to the original result and the S-G filtered result.

All the three results, including the original result, the S-G filtered result and FFT filtered result, are within an error of 1 nm, which indicates a good accuracy of the measuring system. From the evaluation values and curves, it can also be seen that when the pre-processing method is applied, results could be improved and FFT filter shows better noise reduction property.

4. Conclusions

In this paper, a traceable measurement and characterization method of nano step-height standards were demonstrated based on the nano positioning and measuring machine. The laser focus sensor was utilized as a zero indicator. Two pre-processing methods, the S-G filter and the FFT filter, were applied to evaluate the results.

Measurement results of a 190.8 nm step-height standard indicate that the proposed method has a high accuracy to measure nano step-height standards. By using the pre-processing methods, results can be improved and FFT filter shows a better noise reduction property. In the future research, the two pre-processing methods will also be tried in other measurement systems to evaluate nano step-height standards.

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