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Measurement noise evaluation, noise bandwidth specification and temperature effects in 3D point autofocusing microscopy

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Abstract
In this work, we evaluate the measurement noise of a commercial point autofocus surface topography measuring instrument. This metrological characteristic was determined using a calibrated optical flat following methodologies described in good practice guidelines and draft ISO specification standards, using the averaging and subtraction methods. The static noise of the instrument was investigated by examining the repeatability of the vertical *Z*-axis. The autofocus sensor repeatability was assessed by measuring its vertical positioning deviation, whilst focused on an optical flat, but without scanning laterally. During the investigation, the instrument proved to be sensitive to environmental temperature disturbance, which introduced a significant distortion in the measured topography and resulted in relatively high measurement noise. The spatial frequency of the distortion in the topography was found to be consistent with the frequency of temperature fluctuation in the measurement chamber. Similarly, static noise and autofocus sensor repeatability were affected by temperature fluctuation. However, after applying the built-in drift correction routine in the instrument software during measurement, the effect of temperature fluctuation was significantly reduced from a measurement noise of 20 nm to 2 nm, with a sampling frequency of 30.6 Hz. In this paper, we specify measurement noise along with the corresponding measurement bandwidth.

Keywords: measurement noise, point autofocus instrument, static noise, autofocus repeatability, noise bandwidth specification

1. Introduction

Macroscopic properties of materials are affected by microstructures or textures on the surface. Surface texture is often manipulated to control and improve part performance in a variety of applications in, for example, optics, automobile engines and medical implants [1–4]. To assure product quality, high confidence is required in the accuracy of the measured surface topography. This can be achieved by establishing traceability, i.e. evaluating the metrological characteristics (MCs) of the measurement instrument and their contribution to measurement uncertainty [5]. This study is the first of a series of investigations to establish traceability of a point autofocus instrument (PAI). The measurement noise of a commercial instrument MLP-3SP (Mitaka Kohki) is evaluated and specified along with the measurement bandwidth to provide a proper reference for comparison with other types of instruments. Also, static noise and autofocus repeatability are assessed [6].

A PAI is a non-contact, optical surface texture measuring instrument that automatically focuses a laser beam onto a single point on the surface and measures surface height at that point. Areal topography measurement is achieved by raster scanning along a scanning and a stepping direction, similarly to a contact stylus instrument. The instrument characterised in this work achieves autofocus using the beam-offset method, described elsewhere [7].

Section 2 describes the evaluation methodology; section 3 discusses results; and section 4 draws conclusions.

2. Methodology

In ISO/DIS 25178-600 [5], measurement noise is defined as the noise added to the output signal occurring during the normal operation of the instrument; therefore, it includes dynamic noise due to the scanning motion, the internal noise of the instrument and environmental disturbances. The combined effect of these influence factors is determined by measuring a calibrated optical flat (NPL-BNT 019), and evaluating measurement noise NM on the measured topographies using the subtraction and averaging methods introduced elsewhere [8]. Fifteen repeated areal measurements of a 100 µm × 100 µm area were performed in a temperature controlled environment. Measurement settings are shown in Table 1.

In order to provide proper reference for performance specification comparison, NM is specified along with the measurement bandwidth, given the noise sensitivity to sampling and measurements duration [9]. It can be accounted for by evaluating the noise per root square hertz, obtained by normalising NM with respect to the time sampling frequency.

To provide more insight into the various noise sources involved, the static noise and repeatability of the autofocus mechanism (RAF) were also evaluated. Static noise indicates the fluctuation in the vertical axis when lateral scanning is not performed. In this study, static noise is determined by focusing onto an optical flat surface and recording surface height. This method is commonly used to assess contact styli [10], and is suitable for PAI due to its point-by-point measurement nature. Static noise is recorded in a 15 minute duration and sampled at 2 Hz. Autofocus repeatability is a PAI-specific characteristic [6] and differs from static noise, in that it quantifies the internal noise of the AF mechanism in the absence of environmental disturbances. Autofocus repeatability is evaluated as the standard deviation of the position of the autofocus sensor when it is repeatedly focused on to an optical flat. A total of 1500 repeated measurements were performed in a time interval of 1.5 s. The procedure was repeated five times.

Table 1 Measurement settings for evaluating N_M.

Measured area	100 µm × 100 µm
Scanning pitch	0.1 µm
Stepping pitch	1 µm
Objective magnification	100×
Objective numerical aperture	0.8

3. Results and discussion

3.1. Environmental effect

The measured areal topographies of the optical flat surface deviated from the nominal topography; an overall waviness was apparent on the flat surface, as shown in Figure 1. Given the periodic nature and the spatial frequency of the deviation, it was suspected that the air conditioning system in the laboratory was its cause. To confirm this suspicion, the frequency spectra of both the deviation in the topography and the temperature in the measurement chamber were analysed. The deviation in the topography is represented by extracting the average surface profile along the stepping direction. In-chamber temperature was measured with a resistance temperature detector PT-1000 two wire probe, sampling at 1 Hz. As Figure 2 shows, a common harmonic at 2.3 mHz is observed, which confirms that the periodic deviation in the measured topographies was in fact drifting due to temperature variation during the measurement period (approximately 55 minutes for each areal measurement). Knowing the nature of the drift, the periodic deviation can be compensated by applying the built-in drift compensation routine in the instrument software.

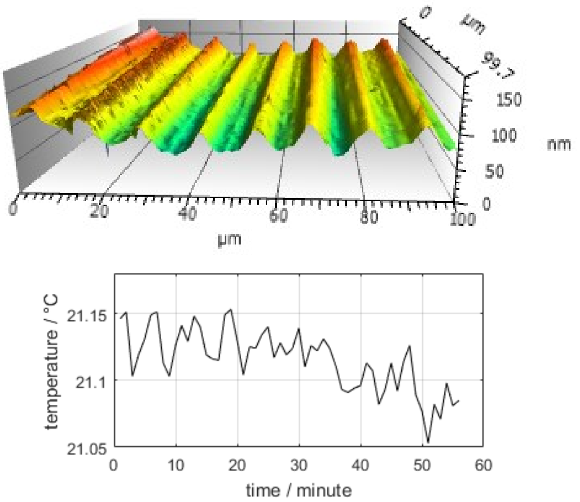

Figure 1 Measured topography of an optical flat surface (above) and recorded in-chamber temperature during measurement (below).

3.2. Measurement noise

Measurement noise N_M is determined using the subtraction and averaging methods described elsevhere [8] and section 2. Measurement of the optical flat was performed whilst applying the built-in drift compensation routine as recommended by the instrument manufacturer. Both averaging and subtraction methods result in N_M of 2 nm, with a sampling frequency of 30.6 Hz, thus resulting in 0.4 nm/$\sqrt{\mathrm{Hz}}$. Furthermore, the removal of the periodic deviation in the topography by the built-in drift compensation routine is found to reduce N_M from 20 nm to 2 nm.

3.3. Static noise and autofocus repeatability

As the drift compensation routine cannot be activated during the evaluation of static noise and R_{AF}, the periodic drift described in section 3.1 was also present in the recorded surface height signals. Therefore, it was necessary to remove the drift component sing a high-pass filter with a cut-off frequency that is equal to the fundamental frequency of the in-chamber temperature variation during the measurement time. As a result, static noise and R_{AF} were determined (as standard deviation of the residual signals), to be 2 nm and 5 nm, respectively.

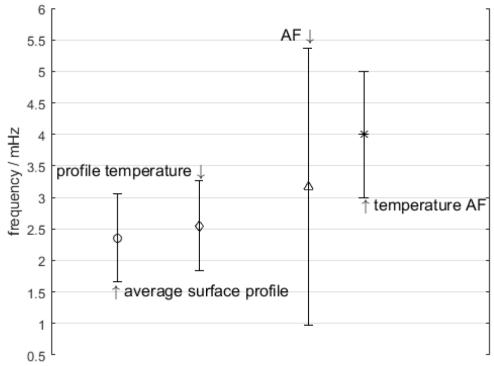

Figure 2 Frequency spectra of the periodic deviation in the topographies, repeated autofocus measurements and temperature during the measurements. Error bars show expanded uncertainty (k = 2).

4. Conclusion

In the presented work, the measurement noise of a point autofocus instrument is evaluated, along with the additional assessment of static noise and autofocus repeatability. Measurement noise is found to be 2 nm, which when expressed with the measurement bandwidth is 0.4 nm/$\sqrt{\mathrm{Hz}}$. Static noise and autofocus repeatability are determined to be 2 nm and 5 nm, respectively. The instrument is found to be sensitive to environmental temperature variation. However, when applying the built-in drift compensation routine in the instrument software, the periodic deviation in the measured areal topographies is effectively compensated, reducing measurement noise from 20 nm to 2 nm.

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