

Calibration of the geometrical characteristics of areal surface topography measuring instruments

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Abstract

The use of areal surface topography measuring instruments has increased significantly over the past ten years as industry starts to embrace the use of surface structuring to affect the function of a component. This has led to a range of areal surface topography measuring instruments being developed and becoming available commercially. For such instruments to be used as part of quality control during production, it is essential for them to be calibrated according to international standards. The ISO 25178 suite of specification standards on areal surface topography measurement presents a series of tests that can be used to calibrate the metrological characteristics of an areal surface topography measuring instrument. Calibration artefacts and test procedures have been developed that are compliant with ISO 25178. The material measures include crossed gratings, resolution artefacts and pseudo-random surfaces. Traceability is achieved through the NPL Areal Instrument – a primary stylus-based instrument that uses laser interferometers to measure the displacement of the stylus tip. Good practice guides on areal calibration have also been drafted for stylus instruments, coherence scanning interferometers, scanning confocal microscopes and focus variation instruments.

Keywords: areal surface texture, calibration, GUM uncertainty framework

1. Introduction

An areal surface topography measuring instrument provides a three dimensional (3D) map of a surface. The 3D map is made up of a set of points measured with respect to three orthogonal length scales. The scales of the areal surface topography measuring instrument should be aligned to the axes of a Cartesian co-ordinate system. The axes are physically realized by various components that are part of the metrological loop of the instrument. Hence the quality and the mutual position of these components partially confer the quality of the co-ordinate measurements. The co-ordinate measurements produced by areal surface topography measuring instruments are also affected by other influence factors such as ambient temperature, mechanical noise and electrical noise. The effect of a single influence factor, or a combination of influence factors, on the quality of the areal measurements should be quantified by experimentally determining the metrological characteristics of the instrument. Amongst these characteristics of areal surface topography measuring instruments are the noise of the instrument; the linearity, amplification and resolution of the scales; the deviation from flatness of the areal reference and the perpendicularity of the axes. The effect of the influence factors on an areal measurement can have a different magnitude for different sizes of measuring area and sampling distance, that is to say the measurement bandwidth.

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The choice of measurement bandwidth is application dependent and is based on the selection of S-filters and L-filters/F-operators, each having a range of preset values called nesting indexes [1, 2]. The calibration of the instrument should be performed using the same conditions as those used on a daily basis.

This paper presents a way of calibrating the scales of areal surface topography measuring instruments. The calibration of the scales consists of a series of relatively simple tasks that evaluate the magnitude of the uncertainty associated with the metrological characteristics of the instruments whilst assuming well-defined measuring conditions. The calibration process also requires the use of artefacts designed for calibrating surface topography measuring instruments. A coherence scanning interferometer (CSI) has been used as an example instrument [2, 3]. The CSI was equipped with a one mega-pixel camera, a Mirau type 50× magnification objective lens with a working field of view of 0.35 mm by 0.35 mm and a 0.1 mm range piezo-electric scanner. The areal data was analyzed using commercially available surface texture analysis software (TalyMap version 5).

2. Calibration steps

The main input quantities that influence the uncertainty associated with the co-ordinate measurements produced by areal surface topography measuring instruments are: measurement noise; flatness; amplification coefficient and the linearity of the scales (z and lateral scales); orthogonality of the axes; resolution.

2.1 Measurement noise

The magnitude of the measurement noise can be estimated by measuring the root mean square (RMS) of the scale limited surface Sq on a flat surface of less than or equal to 30 nm peak to valley (VDI/VDE 2617 [4]). The difficulty of the test is in separating the effect of the roughness of the flat surface from the instrument noise. VDI/VDE 2617 presents a method of separating the noise from the flat surface roughness. The method consists of subtracting two repeated measurements from each other. Another technique of error separation was developed elsewhere [5]. This technique is based on the assumption that the instrument noise contribution to the RMS of the average surface obtained from multiple measurements performed at the same location on the flat will decrease by the square root of the number of repeat measurements, so that the noise of the instrument can be estimated by equation (1)

$$Sq_{noise} = \sqrt{\frac{Sq^2 - Sq_n^2}{1 - \frac{1}{n}}} \quad (1)$$

where Sq is the measured RMS after one measurement, n is the number of repeated measurements, Sq_n is the measured RMS of the averaged surface and Sq_{noise} is the noise of the instrument.

The latter method was chosen to measure the noise of the CSI instrument because the instrument's acquisition software allowed for repeated measurements and averaging. The noise results of a transparent glass flat measured using the CSI showed that two repeated measurements ($n = 2$) are enough to determine the noise of the instrument. The Sq_{noise} does not differ significantly (less than 0.1 %) with the increase in the number of repeated measurements.

2.2 Flatness

An important quality of any areal surface topography measuring instrument is the flatness of its areal reference. Similarly to the measurement noise test, the flatness test is performed on a flat surface but the parameter that quantifies the magnitude of the flatness effect is the maximum height of the scale limited surface

(S_z). Unlike S_q , the value of S_z is highly sensitive to local height variations such as scratches or dirt. It is, therefore, difficult to completely separate the contribution of the instrument from that of the flat and other spurious measurement data. One way to overcome these issues is to measure the topography of the flat at different locations [4] without changing the instrument setup and to average the height measurement of each point of the topography. The contribution of the flat and any spurious data should diminish whereas the quality of the areal reference should be preserved. It is difficult to recommend the exact number of repeated measurements because the number depends on the rate at which the value of S_z stabilises. The measurements can be repeated until the value of S_z stabilizes.

S_z is 3.26 nm for the CSI instrument after averaging ten measurements. In this case the magnitude of S_z is dominated by a virtual scratch present in the areal reference of the instrument (see Fig 1), which is inherited from the flat that was used to adjust the instrument. A better quality flat would have produced a better quality areal reference. S_z is 4.69 nm after averaging four measurements, that is sufficient if the measurement uncertainty along the z direction does not need to be better than 10 nm.

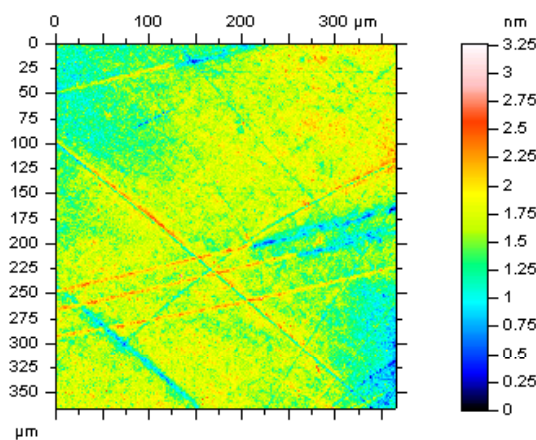


Fig 1 Flatness of the areal reference of the CSI used to measure a transparent glass flat - result after ten repeated and averaged measurements

2.3 z axis calibration

The z axis calibration consists of a series of measurements of different step height artefacts with various depths to establish the relationship between the ideal response curve and the instrument response curve. This calibration provides information about the z axis linearity and amplification coefficient. The linearity of the z axis is given by the maximum deviation of the instrument response curve from the linear curve where the slope is the amplification coefficient.

The step height artefacts should cover the entire z axis range of the instrument or at least they should range from the minimum to the maximum height of interest. The linearity and amplification coefficient can be extracted from the measurement results of multiple calibrated step heights of different values by simply performing a linear fit.

Often the z axis calibration is performed using a single step artefact that is also used to adjust the software of the instrument. This situation is potentially very dangerous because it could only shift the response curve in such a way that it crosses the ideal response curve only at that particular measured point. Unless the response curve is perfectly linear, one calibration artefact does not provide sufficient information about the quality of the instrument's z axis scale and it will underestimate its contribution into the uncertainty calculations. The z axis scale should be calibrated at regular intervals because the instrument characteristics could change over time.

The squareness between the areal reference and the z axis behaves as an amplification error.

2.4 xy scales calibration

Traditionally the calibration of the lateral axis of a roughness measuring instrument is performed using a grating with a known pitch. The pitch measuring technique can be applied to calibrate instruments that measure areal topography but the analysis has to be performed in profile mode. The drawback of pitch measurements is that they only estimate the local characteristic of the instrument's scale and do not give information about the instrument response curve. Areal material measures such as cross gratings [6] or pyramidal structures [7] are better suited for calibration of the lateral scales of areal topography measuring instruments.

The x and y axes amplification and the squareness can be measured using a calibrated cross grating artefact. By measuring the positions of the centre of gravity of the cross grating's squares with a traceable areal surface topography measuring instrument [8, 9] allows for stable and traceable length measurements along the x and y axes. Additionally, the squareness of the x and y axes can be measured by measuring the angle between two nominally orthogonal rows of square holes whose squareness is known. The orientation of each row of squares can be calculated by fitting a line through the centre of gravity of the corresponding squares.

2.5 Resolution

The resolution of the lateral scales is defined as the smallest lateral separation between two points that can be distinguished. This is a useful definition of the lateral resolution for a 2D microscope or when making lateral measurements. However, for areal surface topography measurements, where the distance between two adjacent points could affect their relative height difference, this definition becomes impracticable. The width limit for full height transmission has been defined [10] to overcome the problem with the lateral resolution definition but is still under debate. Experimentally the width limit for full height transmission is measured on gratings or crossed gratings with the pitch value close to the resolution of the instrument. A 3D star pattern [6, 11] can be used to find the approximate value of the width limit for full height transmission before measuring a grating with a predefined pitch.

Other definitions of lateral resolution could be used where the width limit for full height transmission is not appropriate for a specific application. ISO/TC213-WG16 is looking to introduce an umbrella term *spatial height resolution* defined as the ability of a surface topography measuring instrument to distinguish closely spaced surface features [3].

3. Uncertainty

The calculation of uncertainties for surface topography measuring instruments is a very complex task that is often only carried out at National Measurement Institutes. It is often possible to calculate the instrument uncertainty, that is to say the uncertainty in measuring (x, y, z) , but when the effect of the surface is taken into account this uncertainty value may significantly increase, often in an unpredictable manner. Where possible the guidelines in the GUM [12] should be applied to calculate instrument uncertainties and the effect of the surface should be considered in as pragmatic a manner as possible. Until now little work has been carried out for the uncertainty associated with areal parameters [13].

When the instrument uncertainty has been calculated it is then often necessary to find the uncertainty in a parameter calculation. Once again this is far from trivial and often the guidelines in the GUM cannot be easily applied [14]. The problem is that for roughness parameters, some characteristics of a roughness measuring instrument have an obvious influence on a roughness parameter, but for others this is highly unclear [15].

4. Conclusions

This paper presents a simple way of calibrating the scales of an areal surface topography measuring instrument. The calibration consists of measuring the noise and flatness of the instrument, amplification coefficients, linearity and squareness of the scales. More details on calibration procedures and calibration results will be published in several NPL Good Practice Guides.

It is important to point out that measuring the above metrological characteristics is not enough to qualify an areal instrument for the measurement of complex, rough surfaces. For this, the spatial frequency response of the instrument needs to be calibrated and such methods are still in their infancy [16, 17, 18]. The effect of the filters employed for a specific application also has to be studied. For example the CSI instrument used in this paper can accurately measure very small step heights because the mathematical algorithm used to estimate the step value reduces significantly the effect of the noise and flatness errors.

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