Traceability for areal surface texture measurement

Richard K. Leach*, Claudiu Giusca*, Kazuya Naoi**

*National Physical Laboratory
Hampton Road, Teddington, Middlesex TW11 0LW, UK
**National Measurement Institute of Japan,
Umezono 1-1-1, Tsukuba, Ibaraki, 305-8563, Japan
Tel.: + 44 [208] 943 6303 Fax: +44 [208] 614 0420 E-mail: richard.leach@npl.co.uk

Abstract

The deterministic structuring of a surface is having a profound effect on many industrial products by allowing the manufacturer to significantly alter the way in which a surface functions. This has led to a clear need in industry and academia for traceable areal surface texture measurements. To address this need traceable transfer artefacts and primary instrumentation are required. The National Physical Laboratory (NPL) is working on two projects – one to develop areal transfer artefacts and one to develop a traceable areal surface texture measuring instrument. The authors describe the development of the artefacts and instrument, and present some of the challenges that are still required to be able to offer an areal traceability measurement service to industry. The instrument has a working volume of 8 mm x 8 mm x 0.1 mm and uses a co-planar air-bearing slideway to move the sample. It also uses a novel vertical displacement measuring probe, incorporating an air-bearing and an electromagnetic force control mechanism. The motions of the slideway and the probe are measured by laser interferometers thus ensuring traceability of the measurements to the definition of the metre. The artefacts were manufactured using a range of machining technologies and in a range of geometries suitable for stylus and optical based instruments.

Keywords: Areal surface texture measurement, areal transfer artefacts, traceability

1. Introduction

Surface texture plays a vital role in the functionality of modern engineered products. Traditionally, surface texture data has been used to monitor changes in a manufacturing process. For this form of monitoring, only a two-dimensional, profile measurement is required. Many industrial companies have a need to engineer or structure a surface in three dimensions to impart functionality into the surface and the resulting device. Examples include micro-lens arrays for modern displays, MEMS for sensing applications, and glasses that are patterned so as to make them hydrophobic and hence essentially self-cleaning. Three-dimensional or “areal” surface texture measurements have a number of advantages over profile measurements including:

- The areal approach comes closer to fully describing a “real” surface and the derived parameters usually possess greater functional significance.
- The areal technique allows parameters to be derived relating to area, for example, texture “strength” and direction, material and void volumes.
- Since the areal technique takes data from an area rather than a profile, the parameters often have greater statistical significance and better repeatability between different parts of the same surface.
- Areal measurements are visually more informative as a characterisation tool.

To control complex structured surfaces requires an areal measurement of surface texture. There are many instruments on the market that address this need, for example, vertical scanning white light interferometers or scanning stylus instruments, but there is currently no definitive, direct route to traceability for such measurements [1]. At present, traceability is inferred from calibrated artefacts and measurement strategies that were originally designed to calibrate profile measuring stylus instruments. Whilst this method of calibration may be adequate in some circumstances, there are characteristics of an areal instrument that cannot be determined from profile measurements alone (for example, the ability to measure areal parameters).

The UK National Measurement System has recently funded two projects that go a long way to establishing traceability of areal surface texture measurement. In the first project, NPL has collaborated with the Atomic Weapons Establishment (AWE), Rubert & Co. and Taylor Hobson to produce a set of prototype artefacts to address verification and calibration of various performance aspects of areal surface texture measuring instruments [2]. The second project aimed to develop a traceable areal surface texture measuring instrument and is described in detail in this paper. The paper will also discuss the current state of standardisation for areal surface texture and discuss what work is still required to establish traceable areal measurements.

2. Areal specification standards

In 2002, the International Organization for Standardisation (ISO) Technical Committee 213, dealing with Dimensional and Geometrical Product Specifications and Verifications, formed a working group (WG16) to address standardisation of areal surface texture measurement methods. WG16 is developing a number of draft standards encompassing definitions of terms and parameters, calibration methods, file formats and characteristics of instruments. The first published standards are expected some time in 2009. However, the change over to areal standards from profile standards (usually found on engineering drawings to define surface texture) will require a considerable amount of dissemination and education. Whilst this may be a difficult changeover for some industries, the rewards for embracing areal methods in product design and manufacture could be highly significant.

3. A traceable areal surface texture measuring instrument

The NPL Areal Instrument (Fig. 1) was designed to have a working volume of 8 mm × 8 mm × 0.1 mm and a target uncertainty of 10 nm × 10 nm × 1 nm. The instrument consists of an ABL9000 co-planar linear air-bearing stage (Fig. 1a) designed for this application by Aerotech on which is mounted a sample holder and Zerodur mirror block (Fig. 1b). The design of the stage is such that pitch, roll, yaw and orthogonality errors are less than two seconds of arc. The mirror block is reflectively coated on three sides and has sub-second of arc orthogonality errors and faces flat to less than 60 nm. Two further reference mirrors (Fig. 1c) are mounted on the probe body. The position of the mirror block in the *xy*-plane is determined by a commercial laser interferometer system utilising two linear and angular column-referenced interferometers (Fig. 1e) (Zygo ZMI2000 series). The surface being measured is mounted within the Zerodur block and the motion of a contacting stylus as it is scanned across the surface is detected by the plane mirror differential interferometer [3] (see Fig. 1e and Fig. 2).

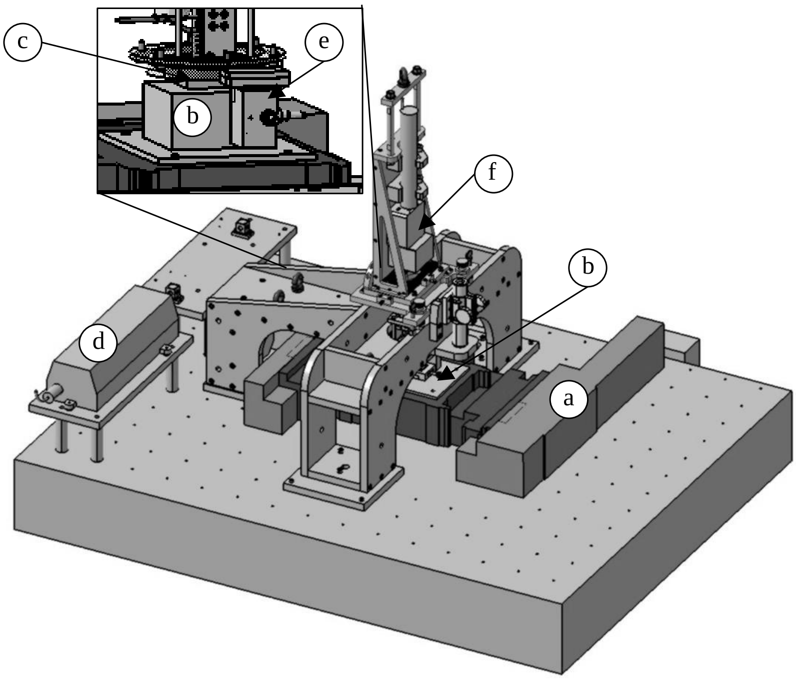

Fig. 1. Schema of the NPL areal instrument.

The interferometers for measurement of the motion in the *xy* plane measure a linear and an angular (yaw) degree of freedom. Therefore, if the mirrors were perfectly flat and orthogonal, one of the angular interferometers would be redundant. The light from a frequency-stabilised laser is input to the interferometers using beam-bending mirrors and the measurement signals are output to the processing electronics via fibre optic cables. The output from the *x* and *y* interferometers (and the *z* interferometer) are synchronised at the sub-microsecond level using bespoke hardware.

At the instrument design stage many types of probe design were considered. When performing areal measurements with a tactile probe, the measurement duration becomes an issue and the use of dry bearings is inappropriate due to their relatively slow motion (as on the NPL NanoSurf IV traceable profile measuring instrument [4]). In an industrial application an optical probe is generally much faster than a tactile probe but for a traceable instrument it is much easier to predict the surface-stylus interaction with a conispherical stylus. The probing system (Fig. 2) utilises an air bearing (developed by Fluid Film Devices) as a linear guide for a stylus with an electromagnetic force control device, akin to a probe design reported elsewhere [5]. The sample is mounted inside a Zerodur mirror block that is described above, so that it comes into contact with the probe (this is achieved with Zerodur spacers and a height adjustment stage). The stylus is attached to the end of a hollow cylindrical air bearing and consists of a Zerodur rod with a polished and aluminised end face with a conventional diamond stylus on the opposite end. The air bearing is hollow to keep the mass of the probe down and allow the passage of the measurement beams of the *z* interferometer. The stylus operates through a hole in the vertical reference mirror to make contact with the sample.

The static probing force is controlled by an arrangement of two electromagnets and a toroidal permanent magnet. The electromagnet design is that of a Maxwell pair (akin to a Helmholz coil but with the current passing in opposite directions in the two coils and a larger separation between the coils). This ensures a constant static probing force with respect to displacement in the *z* axis [6]. Note that this magnet and coil arrangement requires a current of more than 100 mA and needs to be water-cooled.

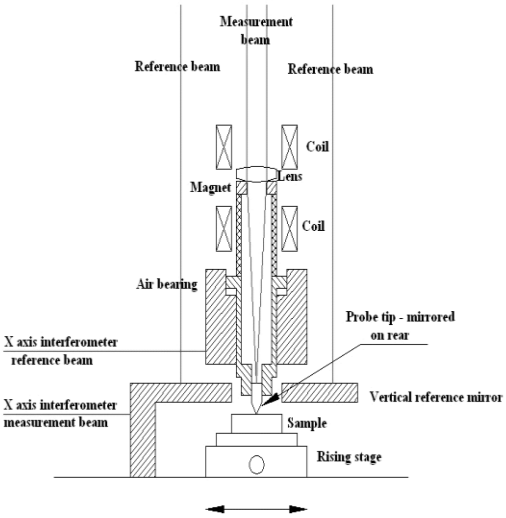

Fig. 2. Schema of the probe.

The displacement of the probe in response to the surface topography of the sample is measured by a differential plane mirror interferometer [3] where the measurement beams are focused onto the stylus mirror using an aspheric lens. The plane mirror interferometer system is referenced from the vertical reference mirror (see Fig. 2). This referencing scheme essentially removes the effect of thermal or mechanical instabilities in the steel metrology frame (although any effects of the spacers and rising stage are not removed). The probe is designed to have a resolution of 0.1 nm, an accuracy of 1 nm, a range of 0.1 mm (with some over travel) and to be capable of responding to structures with periods of 0.001 mm when scanning a surface at 1 mm s^{-1} (*i.e.*, 1 kHz).

At the time of writing only preliminary areal measurements have been carried out. The RMS noise level is less than 3 nm with the probe in contact with a surface and all air-bearings and water cooling running. Comparisons with other traceable instruments [3] and further system performance tests are showing good results and these will be presented in a future paper. A full uncertainty analysis of the instrument has been developed using a Monte Carlo approach.

4. Areal transfer artefacts

NPL has collaborated with AWE, Rubert & Co. and Taylor Hobson to produce a set of prototype artefacts to address verification and calibration of the various performance characteristics of areal surface texture measuring instruments. A primary consideration in the design of the artefacts was the need for compatibility with both contact and non-contact measuring instruments. This is important to many users, as it is very common to compare data from non-contact areal instruments and stylus profilometers. These artefacts are described elsewhere [2]. With the forthcoming publication of the ISO areal specification standards, NPL will develop ISO compliant transfer artefacts that can be calibrated on the Areal Instrument.

5. Current work on areal traceability

NPL now has a traceable instrument and prototype transfer artefacts for the measurement of areal surface texture. However, there is still a significant amount of research and development required to be able to offer a measurement service to industry. There are many commercially available instruments for measuring areal surface texture, mainly based on stylus or optical methods. ISO 213 is addressing the specification standards for these instruments, but research is still required into how to measure the large range of structured surfaces that will become available in the future. Such surfaces will present surface bandwidths that may be difficult to measure using some instruments and good practice guidance will be necessary. For example, coherence scanning interferometers may be very versatile instruments but they can give erroneous results without *a priori* knowledge of the structure of the surface being measured [7]. For this reason NPL, the University of Loughborough, the University of Huddersfield, IQE Ltd and Taylor Hobson has produced a good practice guide into the use of coherence scanning interferometers [8] and further guides will be produced.

Once the instrumentation and transfer artefacts are in place for areal traceability, software measurement standards will be required to ensure that instrument software for filtering and parameter calculations is correct. Also, new characterisation methods and parameters will be needed as the number of commercially utilised areal structured surfaces grows.

6. Acknowledgements

This work was funded by the DIUS National Measurement System Engineering Measurement Programme 2005 – 2008. Thanks are due to David Flack, Ben Hughes, Keith Jackson, Chris Jones, Mike Parfitt and Simon Reilly (NPL).

References

1. Leach R.K. *Some issues of traceability in the field of surface texture measurement.* Wear. 2007, 257, pp. 1246-1249.
2. J.A. Haycocks *et. al. Tackling the challenge of traceable surface texture measurement in three dimensions.* Proc. 5th Int. euspen Conf., Turin, Italy. May 2005, pp. 253-256.
3. M. Downs, J. Nunn. *Verification of the sub-nanometric capability of an NPL differential plane mirror interferometer with a capacitance probe.* Meas. Sci. Technol. 1998, 9, pp. 1437-1440.
4. R.K. Leach. *Traceable measurement of surface texture at the National Physical Laboratory using NanoSurf IV.* Meas. Sci. Technol. 2000, 11, pp. 1162-1172.
5. P. Thomsen-Schmidt, R. Krüger-Sehm. *Development of a new stylus system for roughness measurement.* Proc. XIth Int. Colloquium on Surfaces, Chemnitz, Germany. February 2004, pp. 79-85.
6. D. Bayliss, R.K. Leach, M. Hall. *Development of an electromagnetic spring for use with a high accuracy surface texture measuring probe.* NPL Report DEPC-EM 06. 2006, pp. 1-9.
7. F. Gao, R.K. Leach, J. Petzing, J.M. Coupland. *Surface measurement errors using commercial scanning white light interferometers.* Meas. Sci. Technol. 2008, 19, 015303.
8. R.K. Leach, L. Brown, X. Jiang, R. Blunt, M. Conroy and D. Mauger. *Guide to the measurement of smooth surface topography using coherence scanning interferometry.* NPL Measurement Good Practice. 2008, Guide No. 108.