Introduction to Surface Finish Metrology

T.V. Vorburger
Precision Engineering Division
National Institute of Standards and Technology
Gaithersburg, MD 20899-8212, USA
tvtv@nist.gov

Abstract: A number of methods are available to measure surface finish; methods of stylus profiling and optical profiling are emphasized here. Documentary standards for measurement of surface texture and comparisons between methods are also discussed.

OCIS codes: (120.3180) Interferometry; (120.3930) Metrological instrumentation

1. Classification of methods for measuring surface finish

Surface finish and *surface texture* are terms used for the fine scale peaks and valleys of the surface topography. The surface finish is important to the function of industrial components ranging from extreme ultraviolet mirrors to six lane highways. Appropriately, there is a wide range of methods that can be used to characterize surface finish. It is useful to group the methods into three classes [1]: *line-profiling*, *areal- topography*, and *area-integrating* (see Fig. 1), and this classification is now part of an international documentary standard [2]. Examples of different current methods in each class are also shown in Fig. 1. Line-profiling and areal-topography classes are emphasized here among which methods of stylus profiling, various types of optical profiling, and scanned probe microscopy are widely used. For each of these methods it is important to determine the bandwidth limits, which characterize the range of spatial wavelengths that can be measured [3]. Height resolution is another important measure of instrument performance, and for several types of methods the height resolution has already reached sub-nanometer levels.

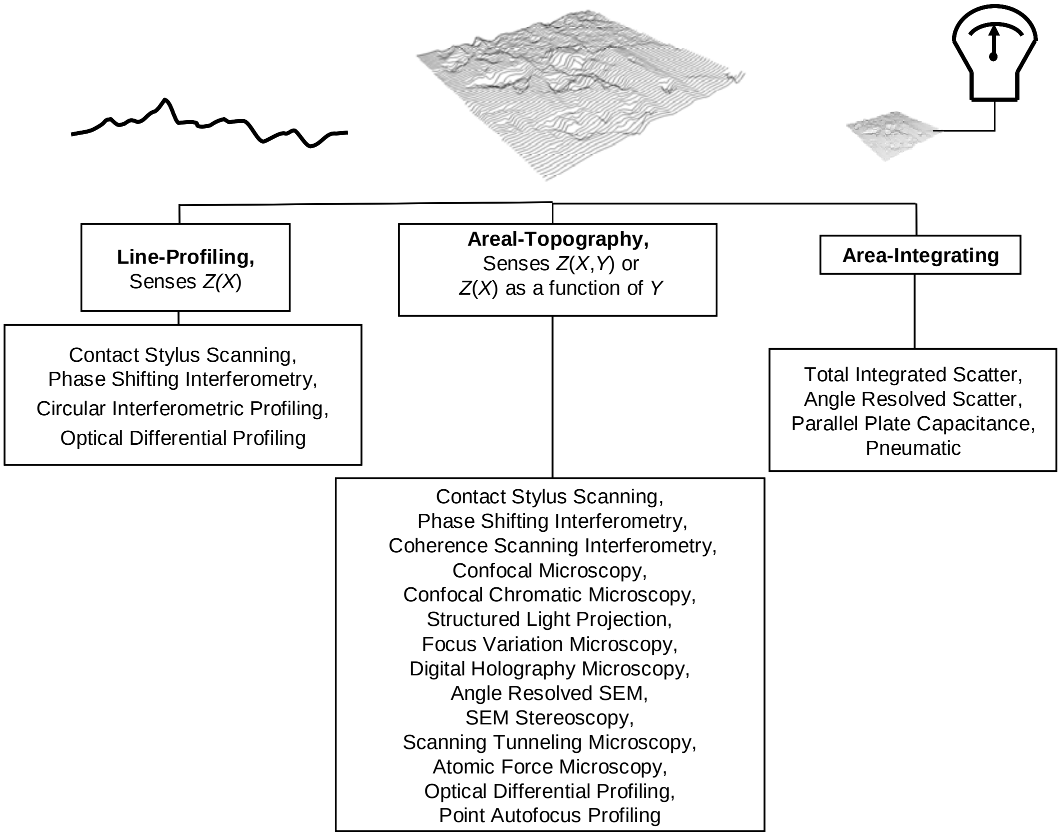

Fig. 1. A classification of surface texture measurement methods with examples [1,2]

Line-profiling and areal-topography methods are used to produce surface profiles and topography images, respectively. These profiles and images may then be filtered to enhance the measured surface structure over a spatial wavelength range of interest to the user and de-emphasize other spatial wavelengths. The resulting filtered profile or image may be characterized by a number of statistical parameters or functions. Many of these are defined in national and international documentary standards. The most widely used parameters are likely the roughness average *Ra* and the root mean square roughness *Rq* [4,5] calculated from surface profiles, and their areal counterparts, *Sa* and *Sq*.

2. Documentary standards and software for surface finish measurements

Besides containing definitions of surface parameters, documentary standards describe
- instrument properties that can affect the accuracy of surface finish measuring instruments,
- physical standards and methods for calibration,
- methods for indicating surface finish specifications on mechanical drawings, and
- digital filters, used to control the range of surface spatial wavelengths to be evaluated.

A Working Group of Technical Committee (TC) 213 in the International Organization for Standardization (ISO) is addressing these standardization topics for areal surface texture measurement and has formed a Project Team to develop standards for optical methods.

A recent development in modern instrumentation is the need to assess the accuracy of the software used to calculate statistical parameters and to filter measured profiles and images. Documentary standards are part of this effort. In addition, three national measurement institutes (NMIs), the National Institute of Standards and Technology (NIST), the National Physical Laboratory (NPL), and the Physikalisch-Technische Bundesanstalt (PTB) have constructed interactive Websites containing software for calculation of surface parameters with which users may check the accuracy of their own software [6-8]. The NIST site is called the Surface Metrology Algorithm Testing System (SMATS) [6]. It contains software to calculate a number of parameters from profiles, profiles with several calculated parameters, software for calculating parameters from topography images, and topography images with several calculated parameters. Users have the flexibility either to download the profiles and images to their own computers or upload their own profiles for calculation using the NIST software. Recently NPL led a comparison of surface parameters obtained from the three NMI websites and from three commercial software packages for five profiles: cosine, electrodischarge machined (EDM), milled, polished, and ground [9]. The differences in the calculated parameters among the three NMIs were very small (see for example Fig. 2 for the parameter of roughness average *Ra*) except for the parameter *RSm*, the mean spacing of peak irregularities, likely because of the ambiguity of the definition of *RSm* in documentary standards [10].

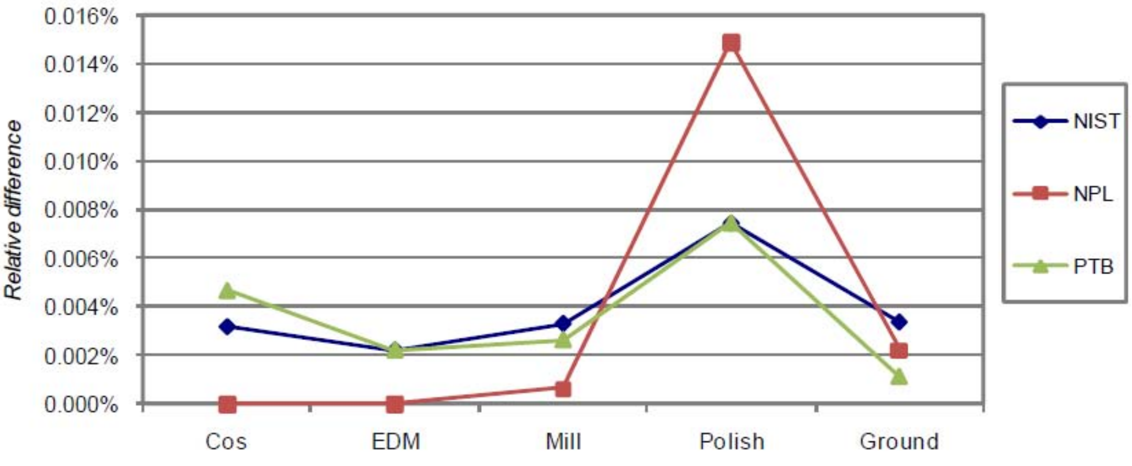

Fig. 2. Differences with respect to the mean of the calculated *Ra* of five model profiles using NIST, NPL, and PTB software [9]

3. Comparisons of different methods

Optical methods are increasingly used for measurement of surface texture, particularly for areal topography measurements where the optical methods are generally faster. Some widely used optical methods are confocal microscopy, phase shifting interferometry (PSI), and coherence scanning interferometry (CSI)—also called scanning white light interferometry or vertical scanning interferometry. Our group at NIST has compared surface profiling results obtained with PSI, CSI, and confocal microscopy with those obtained with the stylus method for surface roughness in the 14 nm to 500 nm range of roughness average *Ra* [1,11] (Note: The roughness samples used for these studies include both sinusoidal profile specimens with *Ra* ranging from ≈ 60 nm to 500 nm and random specimens with *Ra* ranging from ≈ 14 nm to 130 nm.). Discrepancies between CSI and the stylus method were observed for surface roughness measurements in the 50 nm to 300 nm range of roughness average *Ra*. Figure 3, for example, shows a comparison of surface profiles obtained by the four techniques on a sinusoidal profile surface with nominal *Ra* of 100 nm and nominal spatial period of 10 μm. As can be seen in Fig. 3, the biggest discrepancy with respect to the stylus profile is observed for the CSI profile. For one type of surface the discrepancy in calculated *Ra* value is as large as 80 % of the value obtained with the stylus method. By contrast, the results for PSI over its expected range of application are essentially in good agreement with those of the stylus method. Roughness measurements for a Nipkow-disk confocal microscope have also been compared with these results. For the sinusoidal surface shown in Fig. 3, the measured amplitude is comparable to that measured with the stylus, but the structure is more jagged.

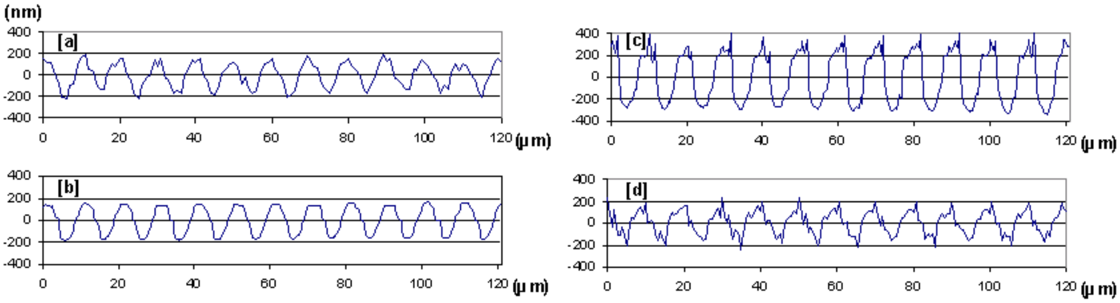

Fig. 3. Surface profiles of a 100 nm *Ra* sinusoidal grating obtained with: [a] stylus method, [b] PSI, [c] CSI, and [d] confocal microscopy [1]

A second comparison has been performed for surfaces in the 500 nm *Ra* range; in this range the correlation between three optical techniques and the stylus technique is good, especially for the confocal microscope. The cross-correlation function is a useful way to characterize the similarity of surface profiling results obtained with different methods.

[1] T.V. Vorburger, H.-G. Rhee, T.B. Renegar, J.-F. Song, and A. Zheng, "Comparison of Optical and Stylus Methods for Measurement of Rough Surfaces," Int. J. Adv. Manuf. Technol. **33**, 110-118 (2007); DOI 10.1007/s00170-007-0953-8.

[2] ISO 25178-6: 2010, *Geometrical product specifications (GPS) — Surface texture: Areal — Part 6: Classification of methods for measuring surface texture* (International Organization for Standardization, Geneva, 2010).

[3] E.L. Church, T.V. Vorburger, and J.C. Wyant, "Direct Comparison of Mechanical and Optical Measurements of the Finish of Precision Machined Optical Surfaces," Opt. Eng. **24**, 388-395 (1985).

[4] ASME B46.1-2002, *Surface Texture (Surface Roughness, Waviness, and Lay)* (American Society of Mechanical Engineers, New York, 2003).

[5] ISO 4287:1997, *Geometrical Product Specifications (GPS) — Surface texture: Profile method — Terms, definitions and surface texture parameters* (International Organization for Standardization, Geneva, 1997).

[6] S.H. Bui and T.V. Vorburger, "Internet Based Surface Metrology Algorithm Testing System," http://syseng.nist.gov/VSC/jsp/index.jsp (January 2009) [Accessed February 11, 2010].

[7] D. Schulz, "Calibration of Roughness Parameters," http://www.ptb.de/en/org/5/51/515/rptb.htm (May 2008) [Accessed February 11, 2010].

[8] "Softgauges for Surface Topography," http://161.112.232.32/softgauges/AboutSG.htm [Accessed February 11, 2010].

[9] T. Li, R.K. Leach, L. Jung, X. Jiang and L.A. Blunt, *NPL REPORT ENG 16 Comparison of Type F2 Software Measurement Standards for Surface Texture*, (National Physical Laboratory, Teddington, UK, 2009).

[10] P.J. Scott, "The Case of Surface Texture Parameter RSm," Meas. Sci. Technol. **17**, 559-564 (2006).

[11] H. Rhee, T.V. Vorburger, J. Lee, and J. Fu, "Discrepancies between Roughness Measurements Obtained with Phase-shifting and White-light Interferometry," Appl. Opt. **44**, 5919-5927 (2005).