The Effect of Tip Size in Calibration of Surface Roughness Specimens with Rectangular Profiles

J. Song\textsuperscript{1}, T.B. Renegar\textsuperscript{1}, J. Soons\textsuperscript{1}, B. Muralikrishnan\textsuperscript{1}, J. Villarrubia, A. Zheng\textsuperscript{1} and T.V. Vorburger\textsuperscript{1}
\textsuperscript{1}National Institute of Standards and Technology (NIST)
Gaithersburg, MD 20899, USA

ABSTRACT

Different periodic profile roughness specimens are defined as Type C roughness specimens in ASME B46-2009 \cite{ASME} and ISO 5436-1:2000 standards \cite{ISO} for calibration of stylus instruments. Those include specimens with triangular, sinusoidal, arcuate, rectangular and trapezoidal profiles. It is well known that the size and shape of the stylus tip affect measured surface geometry and roughness parameters. For the measurement of engineering surfaces with fine surface texture, increasing tip size may decrease the measured Ra value because the enlarged tip may not come into contact with the bottom of sharp valleys. However, for the calibration of some Type C roughness specimens with wide and flat profile bottoms, such as specimens with arcuate, rectangular and trapezoidal profiles, the major effect of tip size may come from the increase of peak width and decrease of valley width caused by the increase of the tip size. That may have a significant, and at times counter-intuitive, effect on the measured Ra value. For example, it was observed that an arcuate profile roughness specimen calibrated by a 0.4 \(\mu\)m tip showed an Ra value of 1.260 \(\mu\)m. When the tip size increased to 5 \(\mu\)m, however, the Ra value did not decrease, but rather increased to 1.332 \(\mu\)m \cite{example}. The uncertainty for both calibrations was estimated to be less than (1.5 \%) Ra. The Ra difference (0.072 \(\mu\)m, or 5.7 \% Ra) was almost 2.7 times as large as the combined calibration uncertainty.

The same effect may also happen in the calibrations of rectangular and trapezoidal profile roughness specimens, which are among the most widely used Type C specimens for calibration of stylus instruments. For a given rectangular profile with amplitude A and wavelength Sm, the maximum roughness Ra value, or the “nominal Ra,” comes from the “nominal profile” with the same peak width Sp and valley width Sv: \(Ra(\text{max}) = A\) (when \(Sp = Sv\)). Either wider (\(Sp > Sv\)) or narrower (\(Sp < Sv\)) peaks result in Ra less than the “nominal Ra”. The difference depends on the profile shape, or the ratio of Sp and Sv. If Sp and Sv show significant differences, the Ra value will show significant decreases compared to the “normal Ra”, or \(Ra(\text{max}) = A\).

For the calibrations of rectangular and trapezoidal profile roughness specimens using different tip sizes, the Ra difference depends on the profile shape. If the profile peak width is larger than the valley width (\(Sp > Sv\)), increased tip size makes the measured peak width even larger, which decreases the measured Ra value. On the other hand, if the peak width is smaller than valley width (\(Sp < Sv\)), increased tip size increases the peak width towards the “normal profile” \(Sp = Sv\), which increases the measured Ra value. When the peak and valley width of the calibrated specimen have significant differences, the Ra offset caused by the tip size difference can be significant. Both theoretical analyses and experimental results have shown that the Ra offset caused by tip size difference sometimes can be larger than the measurement uncertainty, even for a very small tip radius difference, for example \(r = 2 \mu\)m and \(r = 1.5 \mu\)m.

That raises a question as to whether the measured surface parameters should be corrected for the significant tip size effect. According to GUM \cite{GUM}, correction is required for any significant systematic effects in measurement results: “It is assumed that the result of measurement has been corrected for all recognized significant systematic effects and that every effort has been made to identify such effect.” In the ISO/FDIS 25178-2:2011(E) standard \cite{ISO}, the “mechanical surface” is defined as “boundary of the erosion, by a spherical ball of radius \(r\), of the locus of the center of an ideal tactile sphere, also with radius \(r\), rolled over the skin model of a workpiece.” That also implies...
the use of correction for significant systematic effects caused by the tip size difference in surface measurements.

Most National Metrology Institutes (NMIs) currently do not use tip size correction for report of surface measurements. In some cases, it may be one of the major contributors to measurement differences. In order to achieve measurement agreement in calibration of rectangular and trapezoidal profile roughness specimens using different tip sizes, it is suggested to conduct correction for the significant effects caused by tip size differences.

Keywords: Surface metrology, roughness calibration, rectangular profile, stylus radius, roughness specimens.

REFERENCES