Relations between different definitions of optical resolution

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Abstract

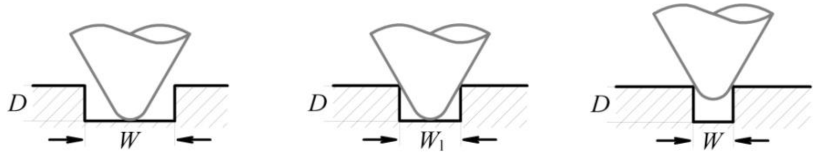
The capability to measure the height of small scale features is an essential metrological task of all surface topography measuring instruments. Starting with the Rayleigh definition of resolution as smallest distance of features distinguishable because of their intensity contrast, a model is developed that describes the smallest feature width, whose height is measured correctly. The advantage of this description is the close relationship to the resolution definition for contact stylus instruments in ISO 25178-601 named "width limit of full height transmission". The model is verified with a confocal microscope by measurements of chromium-glass resolution patterns in relation to topographical resolution patterns etched in Silicon. The intention of this article is to make plain, that in view of upcoming ISO 25178-600 series the described method is one potentiality beside a variety of other definitions of resolution each with good cause.

1 Introduction

Optical surface measuring instruments have the capability to measure vertical structures in sub - nanometer range. How reliable this measurement value is, particularly in the field of real 3D topography, is significantly influenced by instrument characteristics and measurement conditions. In this paper we will give a closer view on the issue of "spatial resolution".

2 Description of tactile resolution

As approach to this theme the "width limit of transmission of full height" for tactile measurement systems is referred. The low cutoff wavelength W_l, (cf. Figure 1 middle), is described in the ISO 25178 - 601 [1] as the smallest wavelength at which the height value is still transferred correctly.



Structure height D can be correct transferred | At low cutoff wavelength W_l structure height D can just be correct transferred | incorrect transfer of height value D

Figure 1: Description of the cutoff wavelength for tactile probing [ISO 25178-601]

This morphological transfer behavior of the hard tip cannot be fully transferred to optics. As presented by Hillmann [2] the optical resolution must be considered.

3 Definition of ”intensity resolution"

The classical resolution model of physics, the "Rayleigh - criterion" describes the minimum distance between adjacent points which can be distinguished (Figure 2, left). The intensity cut between both points is about 25 %. The “intensity resolution” of modern sensors typically are able to detect intensity differences smaller than 1 %. This allows these sensors to determine a smaller minimum distance between adjacent points as resolution limit, according to the “Sparrow-criterion”. It states that two points are spatially resolved, if their joint intensity function along the line connecting them has a minimum (Figure 2 right). In this paper this distance is called the "intensity resolution". This length W_i, determined as a property of the measuring instrument, is the basis to estimate the “topographic resolution” of that instrument.

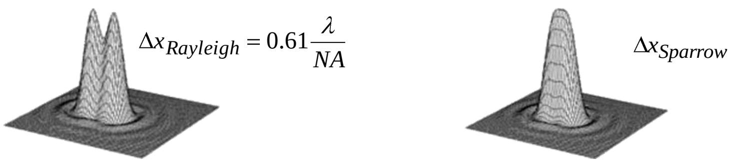


Figure 2: Comparison of the two resolution definitions

4 Adjacent measuring points of a topography measurement

To exclude unknown systematic optical distortions, a minimum of 3 supporting points on each level of the topography element “rectangular groove” is required in this model. The distance between these supporting points is the value of the intensity resolution W_i. The relation between intensity- and topographic resolution is schematically shown on a profile element in Figure 3.

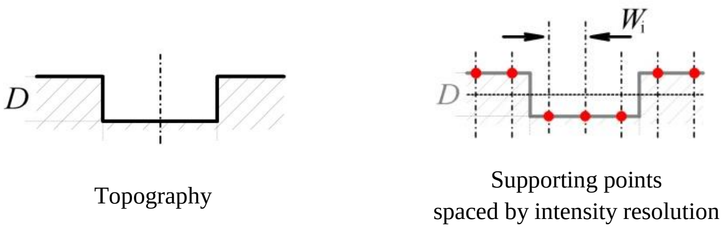


Figure 3: Relationship between intensity resolution and topographic resolution

By multiplying the intensity resolution distance W_i with the required number of supporting points, the topographic resolution is predicted. Analogous to the contact stylus definition the "width limit for full height transmission" of optical instruments has many influencing factors like e.g. the numerical aperture of the optics (A_N), the aspect ratio, the shape and imperfections of the structure surface (Figure 4).

Figure 4: Examples of influences on optical structure resolution

5 Practical investigations

Using the example of a commercial, areal measuring instrument (confocal laser scanning microscope, "Olympus - OLS 4000") the above described model has been verified. For this comparison the measurement were performed with different objective magnifications and for each lateral direction (X and Y). Different standards with lines of chromium on glass, according to ISO – 3334 [3] in the pitch range from 0.16 µm up to 1000 µm manufactured by companies Heidenhain and Supracon were used to determine the intensity resolution limit. The measured topography standards were manufactured by company Simetrics with different pitch values between 0.3 µm and 800 µm (step height 90 nm rsp. 190 nm), cf. Figure 5.

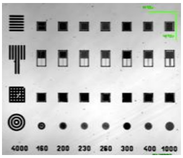
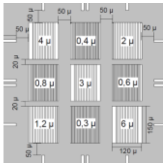
intensity standards		topography standards	
	Heidenhain (GN1) **Pitch:** 1.63 µm – 1000 µm Supracon **Pitch:** 0.16 µm – 4 µm		Simetrics (RS-M) **Height:** 90 nm **Pitch:** 4 µm – 800 µm Simetrics (RS-N) **Height:** 190 nm **Pitch:** 0.3 µm - 6 µm

Figure 5: pitch standards for the measurement series and representative pictures

6 Results

Table1: Comparison of predicted and measured topographic resolution

magnification	X - intensity resolution	Topographic resolution limit (model)		Topographic resolution limit (measured)
		periodic	single	periodic / heigth 190 nm
x 20	400 nm	2.0 µm	3.2 µm	3.0 µm
x 50	260 nm	1.3 µm	2.1 µm	2.0 µm
x 100	230 nm	1.15 µm	1.84 µm	1.2 µm & 2.0 µm

In Table 1 a selection of the resolution results determined by the Lext CLSM at the standards listed in Figure 5 are presented. It is a matter of course, that the discrete number of pitch values limites the closeness of the comparison values.

7 Summary

By the use of a physical model the topographic resolution is predicted by determination of the spatial intensity resolution. The model is verified by comparison measurement at both types of pitch resolution standards.

References:

[1] ISO 25178-601, Nominal characteristics of contact (stylus) instruments (2010)

[2] W. Hillmann, U. Brand, M. Krystek: Capabilities and limitations of interference microscopes; Measurement vol. 19,(1996), 2, pp 95 -102

[3] ISO 3334, Micrographics - ISO resolution test chart, Description and use (2006)