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Measurement noise as a component of uncertainty measurements of the surface texture

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One of the sources of errors affecting the uncertainty of measurements of the surface texture is the measurement noise, called dynamic noise, which is a combination of the internal noise of the measuring instrument and the influence of the external environment. The article presents the comparison of measurement noise for instruments using various methods of measuring the surface texture that were used during the implementation of the project No. PBS2/A6/20/2013/NCBiR/24/10/2013 “Research and evaluation of reliability of modern methods of surface topography measurements in micro and nano scale”.

KEYWORDS: measuring noise, optical measurements, contact measurements, surface texture

In recent years, there has been a rapid development of new methods for measuring the geometric structure of the surface, enabling the assessment of surface stereometry in both the micro- and nanoscale. Many publications have been written on the subject of measurement methods and evaluation [1-4]. The most commonly used methods of measuring surface stereometry are contact profilometry with a mapping blade, profilometry using confocal heads, coherent scanning interferometry, confocal microscopy and atomic force microscopy.

The obtained values of the surface geometrical structure parameters are influenced - regardless of the measurement method used - by many factors that are components of the measurement uncertainty. One of them is the measuring noise, which is a component of the output signal. Sources of its formation can be divided into those resulting from the principle of the device operation itself and from the impact of the external environment on the measurement process. The most important factors generating measuring noise include: instability of electronic systems, vibrations caused by mechanical drives, external vibrations at the place of the device installation, air movement caused by ventilation or air conditioning, and electromagnetic disturbances. Value and nature of the measurement noise depend on the design of the instrument and the measurement method used.

One of the methods of assessing the measuring noise of instruments for measuring the geometrical structure of the surface is to measure the AFL type standard (flat interference plate) [5, 6]. Parameters that characterize the measuring noise value can be the square root of the ordinates of the primary profile Pq or the roughness profile Rq :

$$Pq, Rq = \sqrt{\frac{1}{n} \sum_{i=1}^n z_i^2}$$

where: n - number of ordinates in the roughness profile, z - value of the ordinate of the roughness profile.

Surface measurements with low roughness are particularly sensitive to disturbing factors. It is therefore important to include noise value in the uncertainty budget of this type of measurement.

Measurement results

Measuring noise studies were carried out in several research centers in Poland. They were carried out on fourteen instruments for assessing the geometric structure of the surface, representing the first two classes of methods, in accordance with the classification system presented in PN-EN ISO 25178-6: 2011 [7], because they give the output in the form of a linear profile $z(x)$ or in the form of spatial topography $z(x, y)$. For the purposes of research, the instruments were divided into two groups: representing optical methods (symbol O) and contact methods (symbol S). The list of devices and their symbols is included in tab. I.

TABLE I. List of instruments used in the tests

No.	Instrument	Measurement method
1.	O1	Profilometric – confocal head, range 130 μm
2.	O2	Profilometric – confocal head, range 130 μm
3.	O3	Profilometric – confocal head, zakres 400 μm
4.	O4	Coherent correlation interferometry
5.	O5	Profilometric – confocal head
6.	O6	Laser confocal microscope
7.	S1	Contact profilometry – induction head
8.	S2	Contact profilometry – interferometer head
9.	S3	Contact profilometry – interferometer head
10.	S4	Contact profilometry – induction head
11.	S5	Contact profilometry – optomechanical head
12.	S6	Contact profilometry – induction head
13.	S7	Contact profilometry – induction head
14.	S8	Contact profilometry – induction head

During measurements of the geometric structure of the surface with the use of profilometric instruments using the AFL standard, due to the long time of these measurements, a clear impact of cyclic changes in ambient temperature on the results obtained was also observed, which was manifested by the occurrence of corrugation in the direction perpendicular to the axis of measurement [8]. This effect can be weakened by the use of thermal shields [9].

Measurement of AFL type standard on atomic force microscope

In order to check the geometrical structure of the AFL type standard, it was measured by means of an atomic force microscope using a SCANASYST-AIR type microbe (cantilever) (fig. 1). Basic dimensions of the microprobe blade according to the manufacturer's data are as follows: blade height $2.5 \div 8 \mu\text{m}$, front angle $15 \pm 2.5^\circ$, rear angle $25 \pm 2.5^\circ$, nominal radius 2 nm.

Fig. 1. SCANASYST-AIR micro-probe: a) lever, b) micro-probe blade (www.brukerafmprobes.com)

Measurement of the standard was carried out in the area of $90 \mu\text{m} \times 90 \mu\text{m}$, with the sampling interval $\Delta X = \Delta Y = 0.175 \mu\text{m}$. The obtained isometric image of the pattern is shown in fig. 2, while tab. II sets out the basic parameters of surface stereometry of the AFL standard.

Fig. 2. Isometric image of the AFL type standard

TABLE II. Surface stereometry parameters of the AFL pattern

Parameter	Description	Value
Sq , nm	Mean square surface deviation	1.61
Ssk	Surface asymmetry	1.60
Sku	Surface kurtosis	7.73
Sp , nm	Maximum peak height of the surface	9.98
Sv , nm	Maximum depth of surface valley	3.79
Sz , nm	Maximum surface height	13.77
Sa , nm	Arithmetic mean surface deviation	1.15

Fig. 3 shows the ordinate distribution, the Abbott-Firestone curve, and the directional structure of the surface of the pattern. Five hundred and twelve profiles were extracted from the measured surface, for which the average values of basic parameters of the primary profile and the roughness profile were calculated using the Gauss filter $\lambda c = 0.025$ mm (tab. III). An example of a primary profile is shown in fig. 4, and its frequency spectrum in fig. 5. Based on the analysis of the results, it can be concluded that geometrical structure of the AFL pattern is random, isotropic, with inequalities with an amplitude of several nanometers.

Fig. 3. AFL pattern: a) distribution of surface ordinates and Abbott-Firestone curve, b) structure directionality

TABLE III. Average parameters of the AFL pattern profile

Parameter	Description	Mean value	Standard deviation
Pq , nm	Mean square deviation of the primary profile	1.6	0.12
PSm , μm	Mean groove width of the primary profile	1.4	0.1
Rq , nm	Mean square roughness profile deviation	1.3	0.11
RSm , μm	Mean width of roughness profile grooves	1.6	0.1

Fig. 4. Example of extracted primary profile **Fig. 5. Frequency spectrum of the extracted primary profile**

Investigation of the influence of the mapping blade feedrate on the measuring noise value

An important parameter that should be selected before measuring with a contact profilometer is the speed of the mapping blade. In order to determine the influence of the tip feedrate of the measuring tip on the value of the measuring noise, measurements of the AFL type standard were performed. For this purpose, a contact profilometer with an interferometric head was used, equipped with a measuring tip in the form of a $2\text{ }\mu\text{m}$ diamond needle with a 90° cone angle. The sampling interval was $\Delta X = 0.125\text{ }\mu\text{m}$. Measurements were made for the following speed of the mapping blade v : 0.1; 0.25; 0.5; 1; 2 mm/s.

Fig. 6 shows the obtained roughness profiles for selected mapping blade feedrates. Tab. IV, however, contains values of Pq and Rq parameters (after applying a Gaussian filter $\lambda_c = 0.08\text{ mm}$) depending on the feedrate of the mapping blade.

Fig. 6. Roughness profiles obtained for the mapping blade feedrate: a) $v = 0.1$ mm/s, b) $v = 0.5$ mm/s, c) $v = 1.0$ mm/s, d) $v = 2.0$ mm/s

TABLE IV. Values of the parameters of the primary profile and roughness profile for the AFL pattern depending on the mapping blade feedrate

v , mm/s	0.1	0.25	0.50	1.0	2.0
Pq , nm	3.6	3.6	3.7	7.0	14.1
Rq , nm	2.9	2.6	2.9	6.4	12.8

Based on the results obtained, it can be stated that up to the feedrate $v = 0.5$ mm/s, the value of measuring noise remains constant, while for velocity $v = 2$ mm/s, it is almost four times higher.

Comparative measurements of measuring noise

Comparative measurements of measuring noise were carried out for six optical instruments and eight contact instruments. The measuring section with a length of 1.25 mm was analyzed. Roughness profiles after the application of the Gaussian filter $\lambda_c = 0.08$ mm, obtained for optical and contact instruments respectively, are shown in figs. 7 and 8.

Fig. 7. Roughness profiles of the AFL pattern obtained when using optical instruments

Fig. 8. Roughness profiles of the AFL pattern obtained when using contact instruments

Fig. 9. List of measuring noise (Pq and Rq parameters) for optical and contact devices

Fig. 9 presents values of Pq and Rq parameters obtained when using optical and contact devices. Optical instruments O1, O2, O3 and O5 as well as the S1 contact device are profilometric devices, in which the feedrate is carried out by the XY table. In their case, the highest measuring noise values were obtained. The distribution of the ordinates of the measured profile on the AFL standard is usually similar to the normal distribution. The exception is even distribution profile obtained with the S6 contact device.

Summary

The study showed that of all instruments, the O4 optical device using the method of coherent correlation interferometry is characterized by the lowest measuring noise value. The measured values of Pq and Rq are

even smaller than when using the atomic force microscope. This may be due to the fact that the sampling distance for this instrument was $\Delta X = 1.66 \mu\text{m}$, i.e. it was more than ten times larger than for the atomic force microscope.

Among the contact devices, the smallest values of measuring noise are characteristic for S2 and S3 devices, equipped with interferometric heads.

The highest measuring noise values are characterized by optical instruments O1, O2, O3 and O5, equipped with confocal heads, and an S1 contact device with an induction head. The high noise figure for these instruments is due to the fact that the horizontal axis feedrate is realized by the XY measuring table.

For the O6 instrument, i.e. the confocal laser microscope, periodic disturbances can be observed on the roughness profile, resulting from errors in joining individual measurements due to the need for using the stitching function suitable for optical instruments.

Conducted tests confirmed that for many instruments, measuring noise is a significant component of the uncertainty budget of the measurements of the surface geometric structure. For this reason, it is advisable to check noise to ensure reliable measurements.

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