Study the influence of selected new filtration methods on roughness of standard surfaces

Badania wpływu wybranych nowych metod filtracji na chropowatość powierzchni wzorcowych

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Paper presents the results of research in order to determine the impact of selected new filtration methods on roughness results of standard surfaces – sinusoidal (C type) and random (D type). Three filtering methods were chosen: robust Gaussian filter, spline filter, morphological filters. Studies with use contact method and confocal profiling method (optical) were made. Results of selected height roughness profile and surface parameters were analysed.

KEYWORDS: new filtration methods, robust Gaussian filter, spline filter, morphological filters, surface texture

The Gauss filter is currently best described, relatively easy to calculate and interpret, and used in all instruments that analyze the geometry of the surface. The sampling interval in the Gaussian filter satisfies the Nyquist theorem, therefore no loss of data and the input signal can be reconstructed. Filtration is described using the weight function and transfer characteristics. The Gauss filter is defined by the *cut-off* wavelength and calculated from the Fourier transform. The selected *cut-off* value determines which components of the profile or surface are moved as roughness and which are blocked. It is normalized and associated with roughness parameters: R_a, R_z - for profiles and random surfaces, S_m - for profiles and periodic surfaces. Among the new methods of filtration, two most similar to the standard Gauss filter appeared:

- resistant Gaussian regression filter,
- filter with spline functions.

Resistant filters are insensitive to the discontinuities of the input profile in the form of inclines, pitches and peaks (violent inclinations or hollows), which positively affects the roughness of the profile or surface. The weight function and hence the transfer characteristics are dependent on the value of the profile.

The spline filter consists of a spline, a combination of polynomial segments with a smooth fit on the joints. The degree of filtering with glued functions is equal to the highest degree of all polynomials used. Despite the great similarity to the Gaussian filter - due to its handling characteristics (50% *cut-off* attenuation) - it is not usually described by the weight function. Filtrated filters, in addition to the extraction of the filtered profile, additionally remove the noise [1,2].

Morphological filtration has been and is commonly used in image processing, but in metrology the surface geometry is novel. The morphological filter is based on encapsulating the measured data with a structured element - usually a disk (profiles) and a sphere (s) with a defined radius. Morphological filtration can consist of one to several morphological operations based on Minkowski summation. The four basic ones are: widening, erosion, opening, closing. They are divided into two groups: basic operations (widening and erosion) and complex operations (opening and closing). Opening and closing operations are the least complex morphological filters. To obtain a morphological opening filter, it is necessary to perform erosion and then expand. The opening filter removes elevations less than the diameter of the structuring element. The result is below the input. In order to obtain a morphological closure filter, it is necessary to reverse - rather than open - the enlargement and subsequent erosion. The closing filter removes the indentations smaller than the diameter of the structuring element. The result is above the input.

In addition to the two basic morphological filters, there are also more complex, called alternating morphological filters. They are used when there is a need to simultaneously eliminate slopes and recesses smaller than the structuring element. Norms propose four sequences of alternating morphological filters:

- closing and then opening,
- opening and then closing,
- closing, then opening and closing again,
- opening, then closing and reopening.

Since morphological filtration does not satisfy the Nyquist theorem, it is not possible to find universal, equilateral sampling that would not result in loss of data [3-6].

Measurement method and parameters

Measurements were made using the TOPO 01P contact profilometer (fig. 1a) and the confocal profiling method available in the AltiSurf 520 optical system (fig.1b). The TOPO 01P profilometer is equipped with an inductive measuring head with a diamond tip cone of 2 µm radius and a 90° angle and the AltiSurf 520 with a 130 µm confocal sensor and a vertical resolution of 8 nm.

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The influence of the parameters of the new filtration methods on the resulting roughness parameters has been analyzed. AltiMap 6 was used for this purpose. Altitude parameters of surface roughness (*Sq, Sp, Sv, Sz, Sa*) and profile (*Rp, Rv, Rt, Rt, Ra*) were calculated. Two control roughness standards were selected for the tests:

- random (type D) of HALLE produced with *Ra* = 0,213 µm and *Rz* = 1,671 µm (fig.2a),
- sinusoidal by MAHR (periodic, C type), with *Ra* values = 0.90 µm and *Rz* = 3.12 µm (fig.2b).

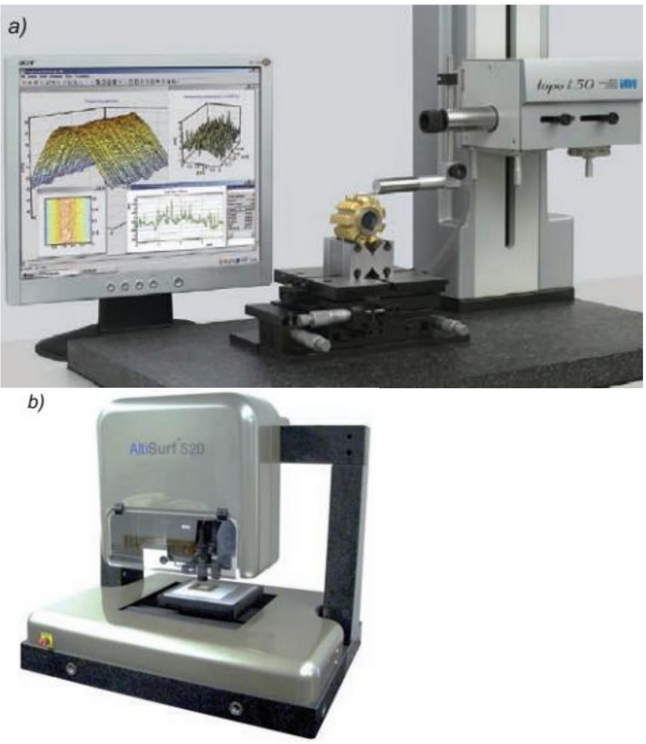

Fig. 1. TOPO 01P contact profilometer (*a*) and AltiSurf 520 optical system (*b*)

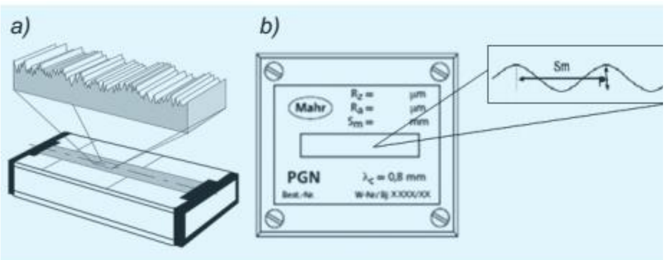

Fig. 2. Roughness standards: *a)* type D, *b)* type C

Measurements of two areas of 4 × 4 mm (one per pattern) at a speed of 0.5 mm/s and scan density (d*X* × d*Y*) were measured: 0.5 × 10 µm; 0.5 × 5 µm and 1 × 1 µm. In addition, a series of measurements was made at the same location on the selected surface with the specified measuring area and scan density to check the reproducibility of the results. Statistical analysis was performed.

Results

Fig. 3 and fig. 4 illustrate the results obtained using the robust Gaussian filtration, figs. 5-7 - filtration with spline functions and fig. 8-11 - morphological filtration.

The graphs in fig. 3 represent the selected roughness parameters for a D-pattern, after applying a robust Gaussian filter with different *cut-off* values.

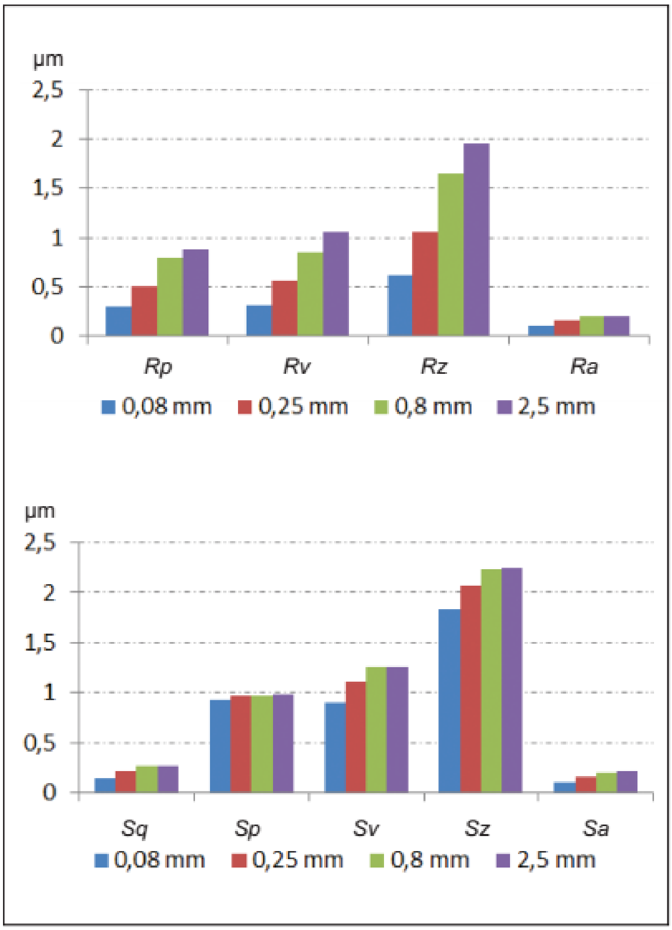

Fig. 3. Results of roughness parameters for the D-pattern after applying a resistant Gauss filter with different cut-off values (4 × 4 mm area, dX = 0.5 µm, dY = 10 µm, median filtration)

Fig. 4 shows the variation in surface roughness parameters resulting from the use of a Gaussian resistant or standard Gaussian filter, obtained for the surface of the D-pattern, containing a high peak associated with the measurement method (confocal profiling).

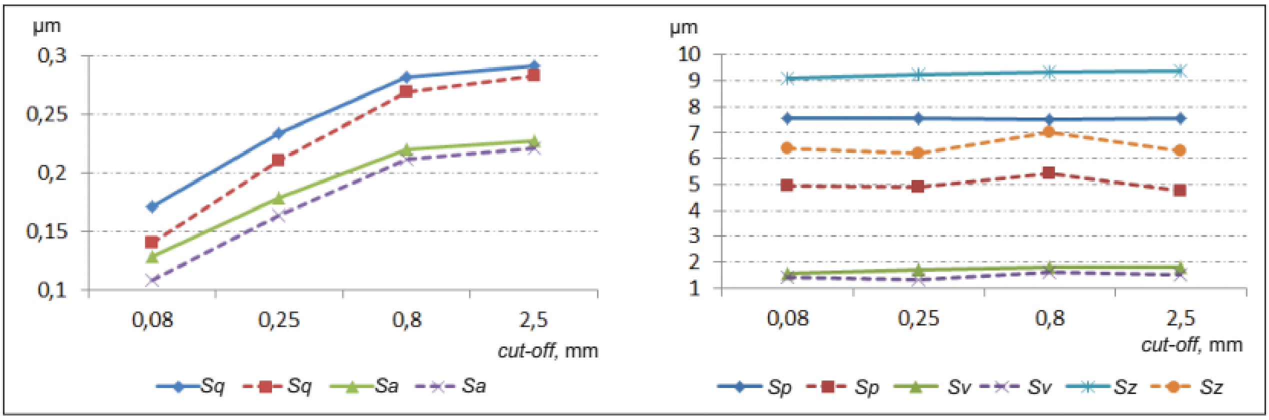

Fig. 4. Differences in the surface roughness parameters for a D-pattern (area 4 × 4 mm, dX = 0.5 µm, dY = 10 µm, without median filtration), obtained using a resistant (continuous line) and standard (dashed line) Gaussian filter

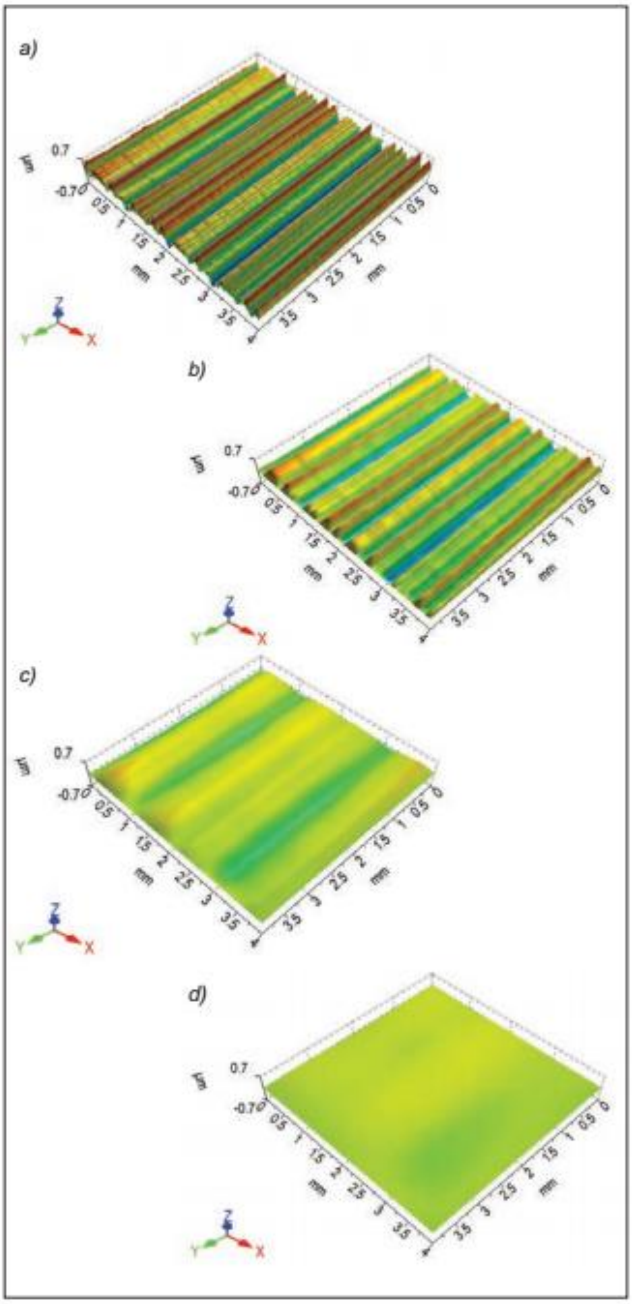

Fig. 5. Effect of change in cut-off value of spline filter on the surface of the D pattern: *a)* cut-off = 0.08 mm, *b)* cut-off = 0.25 mm, *c)* cut-off = 0.8 mm, *d)* cut-off = 2.5 mm

Based on the obtained results it can be stated that as the cut-off value increases, the roughness parameters increase. The robust Gaussian filter does not bend the profile and corrugated surface for deep recesses and high hills, so the roughness values are much higher than the standard filter. Resilient Gaussian filtration works when surfaces such as high elevations, deep recesses, or surface deflections are included on the surface to be included in the roughness assessment.

The way in which the corrugated surface changes with the change of the *cut-off* value of the glue-type function for the D-pattern is shown in fig. 5.

Examples of roughness parameters for a C-pattern after applying a spline filter with different *cut-off* values are shown in fig. 6.

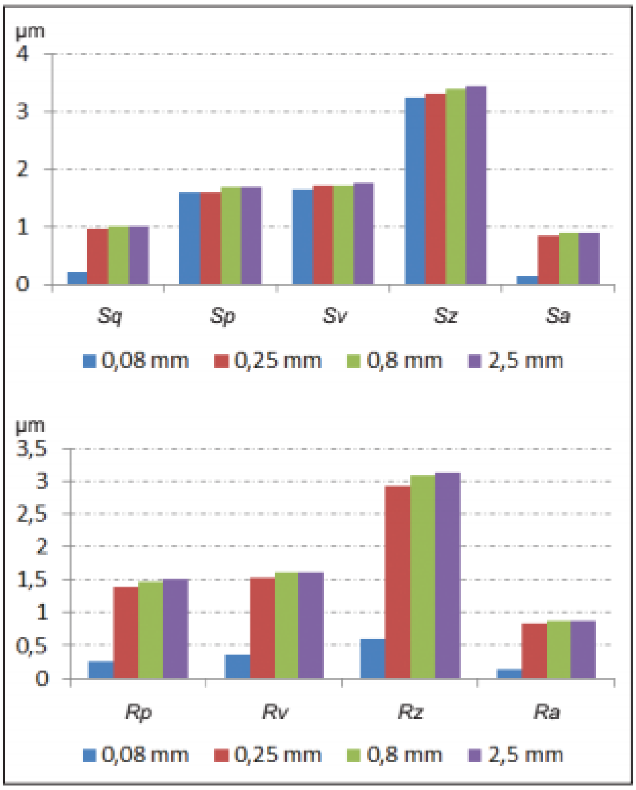

Fig. 6. Results of roughness parameters for the C-pattern after applying the filter to spline functions with different cut-off values (area 4 × 4 mm, dX = 0.5 µm, dY = 10 µm)

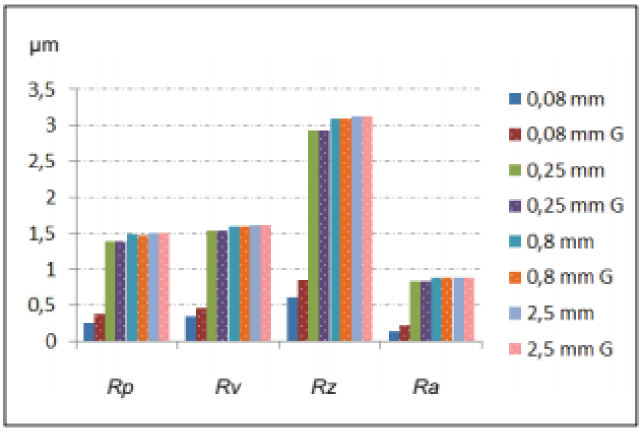

Fig. 7. Differences in the profile roughness parameters obtained for the C-pattern (area 4 × 4 mm, dX = 0.5 µm, dY = 10 µm) resulting from the application of filtered spline functions and Gauss filter (dotted bars, marked with G)

Fig. 7 depicts the difference in the roughness profile between the glue filter and the standard Gaussian filter for the C-pattern surface. As with the robust Gaussian filter, the roughness parameters here also increase as the *cut-off* value increases. The wavy profile obtained with the gluing filter is more suited to the primary profile than the standard Gaussian filter. Roughness values obtained using a glue-type filter are less or similar to those obtained using the standard Gaussian filter.

Fig. 8 and fig. 9 respectively show the roughness parameters for a D-pattern after applying a morphological closure and opening filter with different radius values, and in Figure 10, the roughness profiles after using a morphological opening filter with different radius values. Figure 11 shows an example of the roughness parameters for a C pattern using an alternating morphological filter (open-close) with different radius values.

Both for the morphological closure filter and the alternating morphological filter (closing-opening), along with the increase in the filter radius decrease the values of the 2D and 3D parameters, especially the parameters associated with the recesses. The parameters associated with elevations do not change much. If the measured surface contains high and narrow elevations, they are further emphasized by the filter - they become wider. On the other hand, for the morphological opening filter and the alternating morphological filter (opening-closing) along with the increase in the filter radius, the values of the 2D and 3D parameters, especially the parameters related to the gradients, decrease. If the measured surface contains deep and narrow recesses, they are further emphasized by the filter. These phenomena are more evident in case of D pattern analysis. For C pattern changes, the changes are minimal until the filter radius is equal to or greater than the indicated *Sm* spacing.

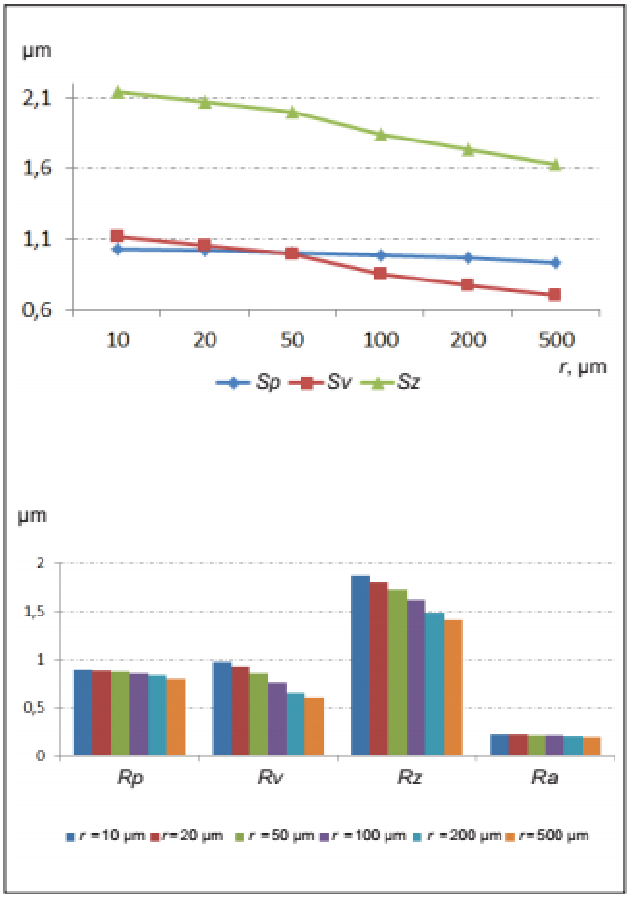

Fig. 8. Results of roughness parameters for the D-pattern after applying a morphological closure filter with different radius values (4 × 4 mm, dX = 0.5 µm, dY = 10 µm)

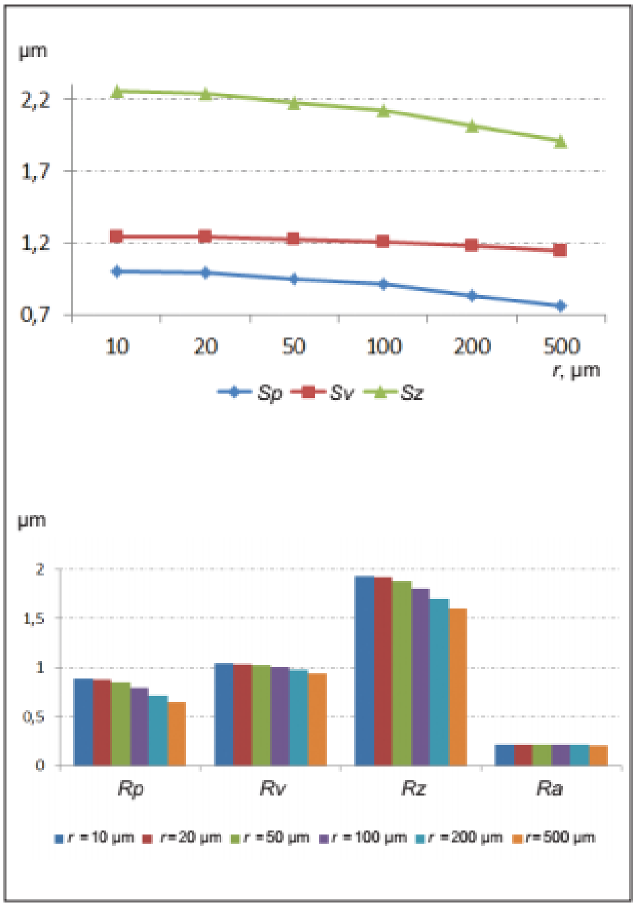

Fig. 9. Results of roughness parameters for D-pattern after applying morphological opening filter with different radius values (area 4 × 4 mm, dX = 0.5 µm, dY = 10 µm)

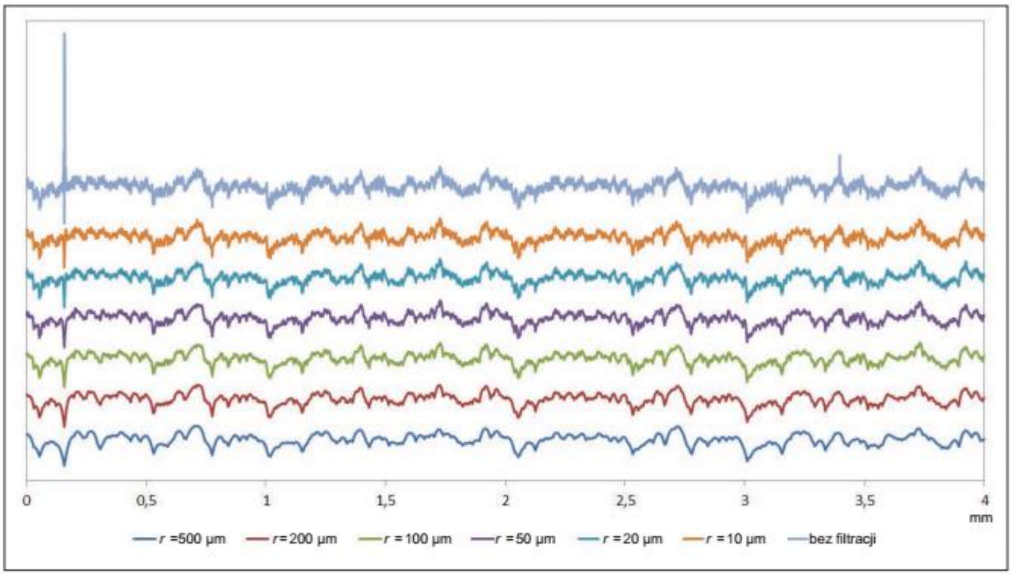

Fig. 10. Results of morphological opening filtration for different disk radius values (area 4 × 4 mm, dX = 0.5 µm, dY = 10 µm)

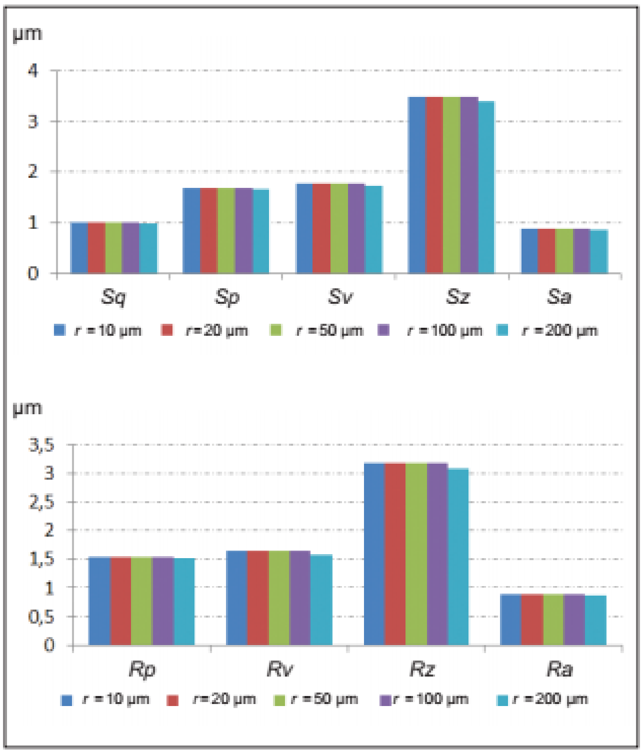

Fig. 11. Results of roughness parameters for the C-pattern after the use of alternating morphological filter (opening-closing) with different radius values (area 4 × 4 mm, dX = 0.5 µm, dY = 10 µm)

Conclusions

The use of new filtration methods has more effect on the results of the roughness parameters obtained from the control measurements of the D roughness pattern compared to the measurements of the C-pattern.

With the increase in the *cut-off* value of the resistant Gaussian filter and the spline function, the values of the roughness parameters increase. Resistant Gaussian filtration does not bend the profile and surface for deep recesses and high hills. The spline filter can be useful if you can not filter some slots or hills using the standard Gaussian filter.

For all types of morphological filters, the roughness values fall as the filter radius increases. Depending on what components of the profile you want to filter out - hollows or hills - use filtration that begins with the closing or opening operation, respectively.

The shortest calculation times were recorded for the filter with spline functions, and the longest - for a resistant Gaussian filter.

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