WPŁYW „END EFFECTS" NA PARAMETRY CHROPOWATOŚCI W KRÓTKICH NIEPERIODYCZNYCH PROFILACH

INFLUENCE OF THE END EFFECTS ON ROUGHNESS PARAMETERS FOR SHORT NON-PERIODIC PROFILES

MITE TOMOV
MIKOLAJ KUZINOVSKI
NEVEN TRAJČEVSKI
PIOTR CICHOSZ
HUBERT SKOWRONEK*

W pracy mierzono i analizowano krótkie nieperiodyczne profile chropowatości utworzone z jednego odcinka elementarnego. Pomiarów chropowatości dokonywano za pomocą profilometru stykowego. W celu filtracji programowej profili pierwotnych za pomocą filtru λ_c, zwiększono długość odcinka pomiarowego mierzonego profilu według zaleceń normy ISO/TS 16610-28:2010, uwzględniając takie metody jak: dopełnienie zerem, odbicie symetryczne względem linii oraz odbicie symetryczne względem punktu. Linie średnie profili pierwotnych zostały wyznaczone za pomocą programu Matlab, z wykorzystaniem filtru Gaussa. W ten sposób uzyskano różne profile chropowatości z jednego podstawowego profilu pierwotnego. Wartości parametrów chropowatości jakie otrzymano dla tak utworzonych profili oraz różnice między nimi przedstawiono w tabelach i zilustrowano graficznie.

SŁOWA KLUCZOWE: profil pierwotny, profil chropowatości, parametry chropowatości, nieperiodyczne profile, end effects.

In this paper are measured and analyzed short non-periodic primary profiles consist of one sampling length. The measurements were done using a contact (stylus) measuring system. In order to be realized □c software-filtration on the primary profiles, evaluation length of the measured profile are extended according to the recommendations in the standard ISO/TS 16610-28:2010, ie pursuant methods: zero padding, line symmetrical reflection and point symmetrical reflection. The filter mean lines for primary open profiles are determined by software Matlab using the Gaussian weighting function. In this way we obtained different roughness profiles from one same primary profile. The values of the roughness parameters and their mutual differences are shown in tables and graphics.

KEYWORDS: primary profiles, roughness profiles, roughness parameters, non-periodic profile, end effects

Introduction

Based on the recommendations contained in the International (ISO) standards [1, 2, 3, 4, 5, 6], and based on the research presented in [7, 8, 9] a procedure can be established by application of contact profilometers for obtaining roughness profile and roughness parameters, starting from the surface profile till the calculation of *R*-parameters. Although each action from the procedure has certain influence upon the process of determination of *P*, *R* and W parameters, it still seems that central place is taken by the process of software filtration by application of profile filters. Such opinion is confirmed by actual definitions, mathematical formulas and graphical interpretations of *P*, *R* and *W* parameters based on the M-system. This means that, determination of a reference mean line is necessary, as a preconditions so that *P*, *R* and *W* parameters can be expressed and determined. In the papers [9, 10, 11, 12, 13, 14] presented a detailed analysis of the characteristics (advantages and disadvantages) of the Gaussian filter, i.e. the most commonly applied filter.

Although, today there are quite a few ISO standards related to surface roughness, still, it must be pointed out that some of them have "free space" for acting freely and for interpretation when performing practical measurements. Here we will emphasize the freedom which the ISO/TS

*Ass. Professor Mite Tomov, Ph.D. (mite.tomov@mf.edu.mk), Professor Mikolaj Kuzinovski Ph.D. (mikolaj.kuzinovski@mf.edu.mk), ,,Ss. Cyril and Methodius" University in Skopje Faculty of Mechanical Engineering-Skopje, Macedonia; Ass. Professor Neven Trajcevski Ph.D. (neven.trajchevski@gmail.com), Goce Delčev University, Military academy, Skopje, Macedonia; Professor Piotr Cichosz Ph.D. (piotr.cichosz@pwr.edu.pl); M.Sc. Eng. Hubert Skowronek, PhD student (hubert.skowronek@pwr.edu.pl), Institute of Production Engineering and Automation of the Wroclaw University of Technology, Poland.

16610-28:2010 [6] standard allows. This refers to the selection of the method for profile extension in order to perform software filtration using a λc profile filter.

Namely, the ISO/TS 16610-28:2010 standard recommends several methods of profile extension with or without slopes, but it does not indicate which profile extension method is more suitable or more adequate for which profile type (periodic or non-periodic). The authors, relying on their own experience, can freely conclude that whichever profile extension method is chosen, in an event when the total profile consists of five sampling lengths, the impact will be insignificant. This is due to the averaging (of all five sampling lengths) when determining the roughness parameters or due to the shortening of the profile from both ends by $\lambda c/2$. However, one question needs to be answered: Whether, and to what extent will the various profile extension methods influence the position of the filter mean line when the total profile does not consist of five sampling lengths, and especially when it consists of one sampling length. In such circumstances it is not possible to shorten the profile. The answer to this question is expected be of direct practical significance, because industrial measurements involve determining roughness parameters of surfaces which do not have the necessary length of five sampling lengths, especially when using skidded instruments. The research in this paper should answer this question, especially in case of non-periodic profiles.

Experimental investigations

Primary profiles included in the research are gained by measurement of surfaces roughness standards representatives of the machining processes using tools with undefined geometry (grinding, lapping and super-finish). The measurements were done using a contact measuring system MarSurf XR20 (with MarSurf XR20 V1.30-5 software). Stylus with a tip radius of 2 μm is using for measurement. The measuring conditions (the sampling length, sampling spacing etc.) are compliant with the recommendations from the International standards. Only size of the evaluation length does not compliant from the recommendations in the International standards. The evaluation length contains one sampling length (instead of the recommended five sampling lengths). The measuring instruments in this research were used only to obtain the coordinates of the measures (total) profiles. The nominal form was removed using the Microsoft Excel software and the least square method, while the filtering was done using λc and λs profiles filters and the Matlab (R2009b) using the mathematical formulations provided in ISO 11562:1996 [4] and ISO 16610-21:2011 [5] for the weight functions of the profile filters. The Gaussian filter was used as the λc profile filter. The size (cut-off) of used profile filters is determined against recommendations in [2]. When determining the filter mean lines the length of the primary profile is increased for length $\lambda c/2$ on both sides of the primary profile in conformity with the recommendations in ISO/TS 16610-28:2010 [6] for profiles without slope. This involves the zero padding, line symmetrical reflection and point symmetrical reflection methods. This helps obtain three primary profiles with different starts and ends, with lengths $\lambda c/2$, as shown of Figure 1.

Since, after all the profiles have different forms, they will also have different forms (location) of the mean lines, especially at the beginning and at the end of the profiles. The different mean line forms indicate different values of the roughness parameters. The methods regarding sloped profiles have not been considered, because of the recommendation in [3], the sloped profiles cannot be obtained if the nominal shape of the profile is removed before the software filtration.

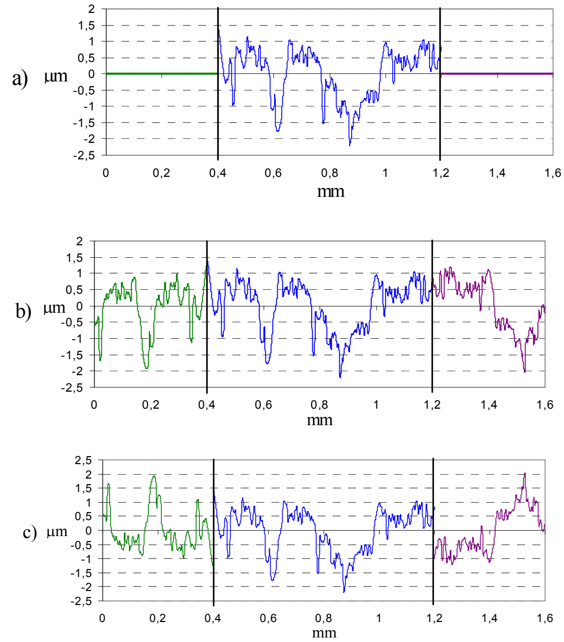

Figure 1. Increase of the primary profile length for $\lambda/2$ on both sides according to the methods: a) zero padding, b) line symmetrical reflection, c) point symmetrical reflection

Results and discussion

Figure 2, 3, 4, 5, 6 and 7 illustrate the considered primary profiles, as well as the Gaussian mean lines determined for the previously extended primary profiles, using the three methods.

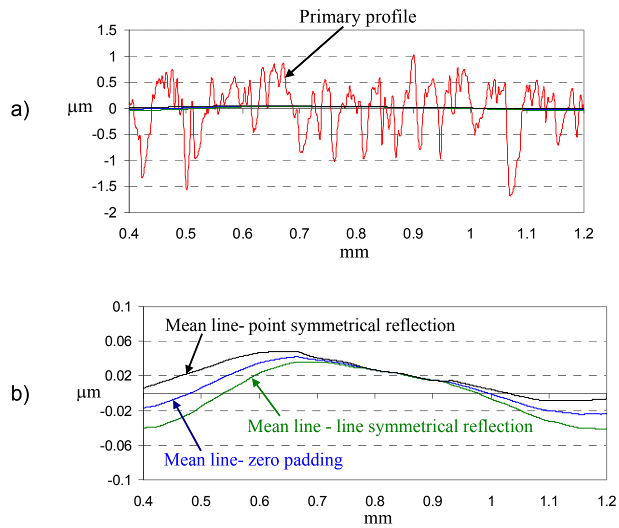

Figure 2. a) Primary profile with filter mean lines for etalon-surface representative of grinding with Ra = 0.4 μm. b) Filter mean lines for the extended primary profile according to the methods: zero padding, line symmetrical reflection and point symmetrical reflection

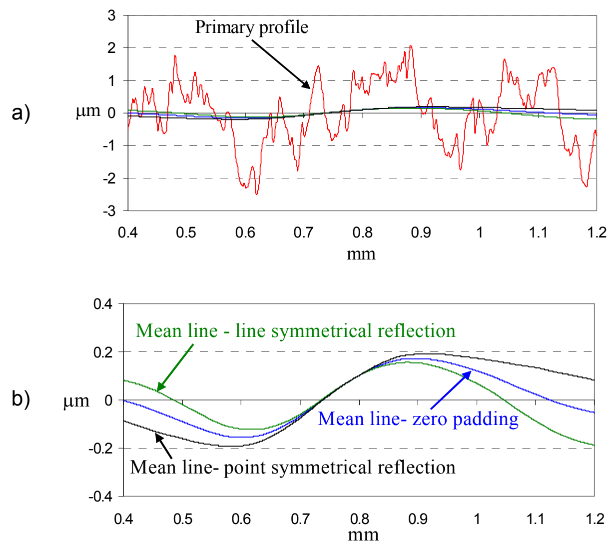

Figure 3. a) Primary profile with filter mean lines for etalon-surface representative of grinding with *Ra* = 0.8 µm. b) Filter mean lines for the extended primary profile according to the methods: zero padding, line symmetrical reflection and point symmetrical reflection

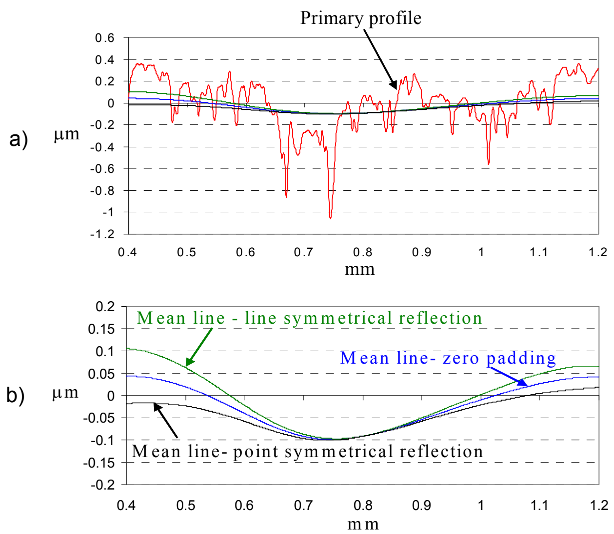

Figure 4. a) Primary profile with filter mean lines for etalon-surface representative of lapping with *Ra* = 0.2 µm. b) Filter mean lines for the extended primary profile according to the methods: zero padding, line symmetrical reflection and point symmetrical reflection

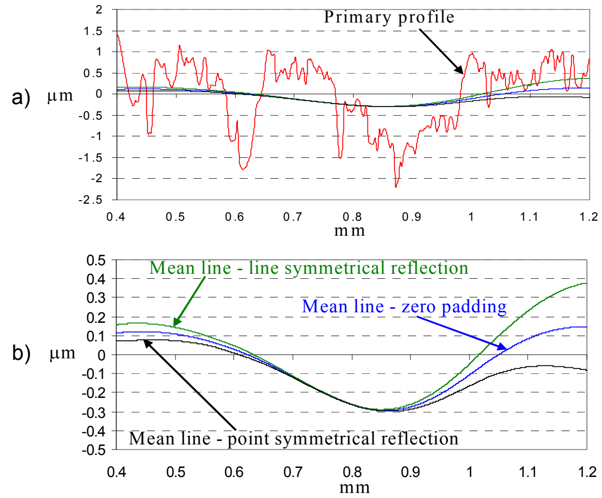

Figure 5. a) Primary profile with filter mean lines for etalon-surface representative of lapping with *Ra* = 0.4 µm. b) Filter mean lines for the extended primary profile according to the methods: zero padding, line symmetrical reflection and point symmetrical reflection

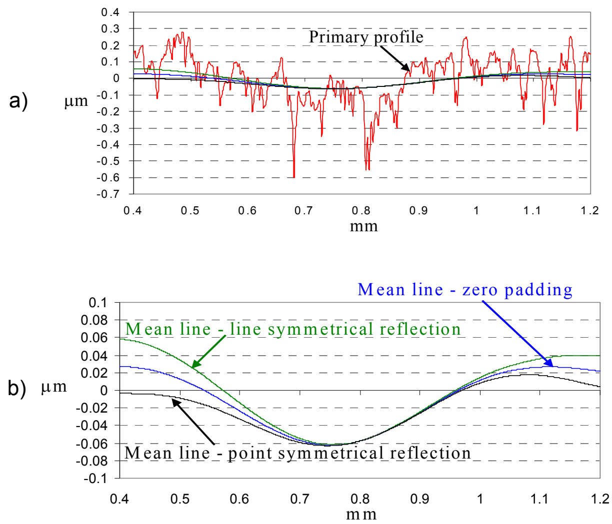

Figure 6. a) Primary profile with filter mean lines for etalon-surface representative of super-finish with *Ra* = 0.1 µm. b) Filter mean lines for the extended primary profile according to the methods: zero padding, line symmetrical reflection and point symmetrical reflection

Tables 1, 2, 3, 4 and 5 provide the values of the roughness parameters as well as the relative differences between them.

Table 1. Roughness parameters (for profile illustrate in Figure 2) and relative differences between them for etalon-surface representative of grinding with *Ra* = 0.4 µm.

Parameters	Zero padding (*ZP*)	Line symmetrical reflection (*LSR*)	Point symmetrical reflection (*PSR*)	Relative difference *ZP/LSR* (%)	Relative difference *ZP/PSR* (%)	Relative difference *LSR/PSR* (%)
Ra (µm)	0.396	0.396	0.396	0.0	0.0	0.0
Rq (µm)	0.506	0.506	0.507	0.0	0.2	0.2
Rp (µm)	1.006	0.997	1.016	0.9	1.0	1.9
Rv (µm)	1.646	1.646	1.646	0.0	0.0	0.0
Rt (µm)	2.653	2.643	2.662	0.4	0.3	0.7
RSm (mm)	0.0360	0.0360	0.0360	0.0	0.0	0.0

Table 2. Roughness parameters (for profile illustrate in Figure 3) and relative differences between them for etalon-surface representative of grinding with *Ra* = 0.8 μm.

Parameters	Zero padding (*ZP*)	Line symmetrical reflection (*LSR*)	Point symmetrical reflection (*PSR*)	Relative difference *ZP/LSR* (%)	Relative difference *ZP/PSR* (%)	Relative difference *LSR/PSR* (%)
Ra (μm)	0.795	0.791	0.801	0.5	0.8	1.3
Rq (μm)	0.959	0.956	0.967	0.3	0.8	1.2
Rp (μm)	1.898	1.902	1.92	0.2	1.2	0.9
Rv (μm)	2.335	2.376	2.334	1.8	0.0	1.8
Rt (μm)	4.233	4.278	4.255	1.1	0.5	0.5
RSm (mm)	0.0485	0.0485	0.0526	0.0	8.5	8.5

Table 3. Roughness parameters (for profile illustrate in Figure 4) and relative differences between them for etalon-surface representative of lapping with *Ra* = 0.2 μm.

Parameters	Zero padding (*ZP*)	Line symmetrical reflection (*LSR*)	Point symmetrical reflection (*PSR*)	Relative difference *ZP/LSR* (%)	Relative difference *ZP/PSR* (%)	Relative difference *LSR/PSR* (%)
Ra (μm)	0.160	0.155	0.165	3.1	3.1	6.5
Rq (μm)	0.209	0.202	0.216	3.3	3.3	6.9
Rp (μm)	0.301	0.317	0.334	5.3	11.0	5.4
Rv (μm)	0.978	0.961	0.994	1.7	1.6	3.4
Rt (μm)	1.279	1.278	1.328	0.1	3.8	3.9
RSm (mm)	0.0557	0.0557	0.0557	0.0	0.0	0.0

Table 4. Roughness parameters (for profile illustrate in Figure 5) and relative differences between them for etalon-surface representative of lapping with *Ra* = 0.4 μm.

Parameters	Zero padding (*ZP*)	Line symmetrical reflection (*LSR*)	Point symmetrical reflection (*PSR*)	Relative difference *ZP/LSR* (%)	Relative difference *ZP/PSR* (%)	Relative difference *LSR/PSR* (%)
Ra (μm)	0.573	0.558	0.596	2.6	4.0	6.8
Rq (μm)	0.699	0.684	0.718	2.1	2.7	5.0
Rp (μm)	1.278	1.285	1.27	0.5	0.6	1.2
Rv (μm)	1.948	1.904	1.991	2.3	2.2	4.6
Rt (μm)	3.226	3.19	3.202	1.1	0.7	0.4
RSm (mm)	0.1095	0.0876	0.1266	20.0	15.6	44.5

Table 5. Roughness parameters (for profile illustrate in Figure 6) and relative differences between them for etalon-surface representative of super-finish with *Ra* = 0.1 μm.

Parameters	Zero padding (*ZP*)	Line symmetrical reflection (*LSR*)	Point symmetrical reflection (*PSR*)	Relative difference *ZP/LSR* (%)	Relative difference *ZP/PSR* (%)	Relative difference *LSR/PSR* (%)
Ra (μm)	0.094	0.0918	0.0967	2.3	2.9	5.3
Rq (μm)	0.122	0.1195	0.125	2.0	2.5	4.6
Rp (μm)	0.252	0.237	0.266	6.0	5.6	12.2
Rv (μm)	0.541	0.535	0.546	1.1	0.9	2.1
Rt (μm)	0.793	0.772	0.813	2.6	2.5	5.3
RSm (mm)	0.0393	0.0393	0.0393	0.0	0.0	0.0

Obtained primary profiles and their mean lines, shown on the figures above, as well as the obtained values of the differences between the roughness parameters, justify the idea for this type of research. For profile representative of grinding, illustrate on Figure 2, can determine the great overlapping of the mean lines, which can be corroborated by the differences between the roughness parameters, presented in Table 1. In contrast, the profiles representative of lapping, illustrate on Figures 4, 5, and super finish, illustrate on Figure 6, show clear difference between the mean lines, which, in turn, leads to differences between the roughness parameters which, for some of the considered roughness parameters, reach to 10% or more. It is interesting to look at the profile representative of lapping, illustrate on Figure 5. This profile exhibits significant differences of the location of the mean line, especially in the end segment of the profile. The filter mean line, determined for the primary profile, illustrate on Figure 5, extended using the line symmetrical reflection method, especially its end, passes through the inside of the profile irregularities, which is not the case for the other two mean lines of the primary profiles extended using the zero padding and point symmetrical reflection method. The filter mean line, particularly its end segment, determined for the primary profile, illustrate on Figure 5, extended using the point symmetrical reflection method, does not pass through the irregularities of the profile. The comparative analysis of the effects of the primary profile extensions using the zero padding, line symmetrical reflection and point symmetrical reflection suggests significant differences between the values of the horizontal parameter *RSm*, presented in Table 4. Based on the shape of the primary profiles and the determined mean lines, the general conclusion is that larger deviations in the mean line locations, as well as larger differences between the values of the roughness parameters, can be expected for profiles with high level of waviness. However, this gives no indication which parameters (vertical, average or horizontal) exhibit bigger deviations.

Main objective that profile filters have to meet is the determined mean line to pass through the middle part of the irregularities that consist the profile through which same is determined. In general, it is not possible to say which of the three mean lines most closely follows the above requirements, but it seems that the mean filter line for the profile extended using the line symmetrical reflection method comes closest.

Conclusion

This research showed that the extension of short primary profiles, i.e. profiles comprising one sampling length, requires a certain level of caution. The change of the location of the mean filter line can have a direct impact on the values of all roughness parameters. The conclusion that larger differences in the roughness parameters values can be expected for profiles with high level of waviness, suggests the need for additional research in the future where the research in this paper will connect with the methods for profile characterization and classification.

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