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Comparison of parameters describing stratified surface topography

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Abstract. There are a lot of methods of two-process surface topography description. Some parameters can be computed from material ratio graph. There are included in ISO standards. The methods described in ISO standards 13565-2 (Pk, Ppk, Pvk, Pmr1 and Pmr2) and 13565-3 (Pmq, Pvq and Pmq) are compared in this paper. Profiles with given values of Pmq, Pvq and Pmq parameters and wavelengths were modelled. For these profiles, material ratio curve and Pk, Ppk, Pvk, Pmr1 and Pmr2 parameters were calculated. As a result, dependencies among parameters from ISO 13565-3 and ISO 13565-2 standard were found.

1. Introduction

Most engineering surfaces have approximately Gaussian height distributions. However two-process texture is more important from functional point of view. The precise description of manufactured 2-process surface is a problem of a great practical importance.

Parameters of two-process surfaces are often calculated using material ratio curve. One of the first methods originates from French automobile industry [1]. According to it, it is possible to calculate the height of: the run-in zone, the operating zone and the lubricant zone. Trautwein [2,3] defined the point which separated the core roughness region and the deep valleys region. It resulted of the cross-cut of a tangent to the curve in its middle part with the regression straight line describing the deep valleys region. The method described in German standard DIN 4776 (and then in ISO 13565-2) corresponded to Trautwein's description of the bearing length curve, but was more synonymous. The following parameters can be determined: the reduced peak heights Rpk, the reduced valleys depth Rvk, the core roughness depth Rk, and material ratios determined by the straight line separating the core roughness from the material side (Rmr1) and free from material side (Rmr1) [1]. Zipin criticised this method [4], since it can be used not only for two-process but also for one-process surfaces. Some parameters found in German standard are non-synonymous [5, 6], for example the slope of material ratio curve in its middle part affects the so-called oil capacity [6]. Nielsen found that honing process can be controlled by Rk parameters [7]. Augustyn [8] also expressed his doubts regarding the synonymously of determining parameters using Trautwein method. His proposal was to define the point of the passage from the core roughness to the deep valleys region as the point of maximum curvature of the normalised curve. Michalski and Pawlus [9] defined the limits of the characteristic profile regions in similar manner. They used different formula for approximation of the normalised material ratio curve.

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ISO committee incorporated also other alternative way in characterising two-process surface [10, 11, 12, 13]. It is based on the cumulative distribution plot on normal probability graph analysis. The intersection point on normal probability graph of abscissa Rmq defines the separation of plateau and base textures and is an important feature of the model. The proposed plateau roughness Rpq, valley roughness Rvq and Rmq are three parameters characterising plateau honed surface. This method was used previously to study running-in process [14]. In this approach, two regions of roughness exist: peak (plateau) and valleys. Contrary to parameters from Rk family, parameters Rpq, Rvq and Rmq can be calculated only for stratified textures. This method is conceptually simpler and more elegant than method described previously (ISO 13565-2), but the practical difficulty of the parameters Rpq, Rvq and Rmq computations exists [15, 16]. Parameters from standard ISO 13565-3 can be obtained in different way [17].
Figure 1 shows the parameters included in ISO 13565-2 standard. A2 is the so-called oil capacity. Figure 2 presents parameters described in ISO 13565-3 standard. The plateau depth Pd (ordinate of plateau-to valley transition) is also included.

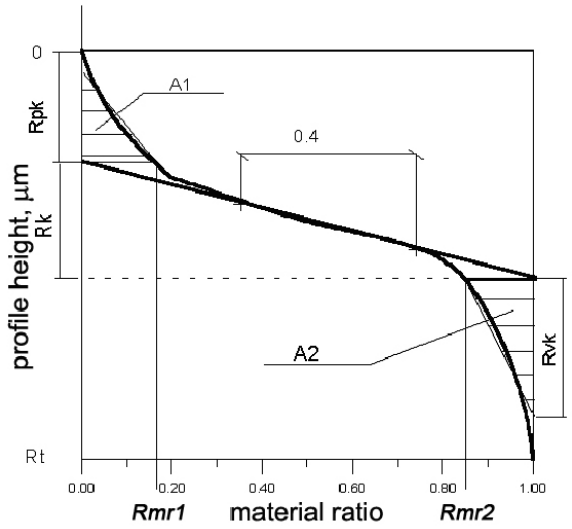


Figure 1. Parameters included in ISO 13565-2 standard.

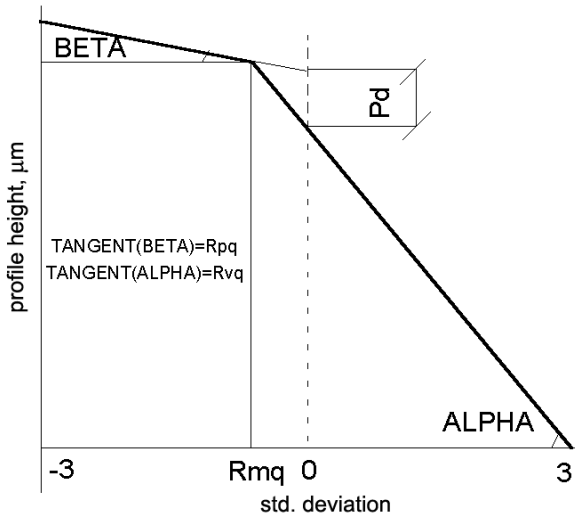


Figure 2. Parameters included in ISO 13565-3 standard and plateau depth Pd.

Rosen et al. [18] analysed cylinder surfaces and compared parameters from ISO 13565-2 and 13565-3 standards using regression and correlation analysis methods. The special tests were done in order to compare Cummins and Rk methods [19]. Measured cylinder surfaces from VOLVO engines were analysed. The obtained results [18, 19] suggest that optimum parameter set describing 2-process cylinder surface topography has not been found yet.
Usually the shape of the profile ordinate distribution can be described by parameters Rsk and Rku. However these parameters are sensitive on the local peaks and valleys existence. They were used with regard to their statistical significance. The so-called emptiness coefficient can be alternative to Rsk. The Ra/Rq and Rda/Rdq parameters are the alternatives to Rsk or Rp/Rt.

2. Simulation of two-process profiles

Because of sound theoretical basis of probabilistic method, it is possible to computer generate stratified cylinder profile when the values of parameters Ppq, Pvq and Pmq (of primary profile) are known. This can be done be superimposition of two profiles of Gaussian ordinate distribution when their standards deviation of height and depth of plateau Pd (transition characteristic from one process to another) are known. Each profile of normal ordinate distribution is characterized by 2 parameters: standard deviation of height and horizontal parameter – correlation length (the distance, at which autocorrelation function slowly decays to 0.1 value).
The aim of this research is to find the effect of changing of one parameter from Rk family: Ppq, Pvq and Pmq on parameters from the Rk family: Pk, Ppk, Pvk, Pmr1 and Pmr2 when the other parameters from Rq group were constant.
Each two-process profile is characterised by the following 5 parameters: Ppq, Pvq, Pmq, CLp (correlation length of plateau profile part) and CLv (correlation length of valley profile part). Parameters Ppq, Pvq, CLp and CLv as well as plateau depth were input parameters. The Pd parameter depends on Ppq, Pvq and Pmq parameters.
Three cases were analysed. In the first of them the correlation length of valley part was larger than of valley part: CLp = 8 μm, CLv = 40 μm – it is the case typical for plateau honed cylinders. The second case was opposed: horizontal parameter of valley part was smaller than that of plateau part: CLp = 40 μm, CLv = 8 μm – typical for surfaces from elements after a low wear process (when wear was within the limit of the original surface topographies). In third case correlation lengths of plateau and valley part were the same: CLp = CLv = 40 μm.
In each three cases first the Pmq parameter increased from 40% to 95% with step of 5%, when Ppq and Pvq parameters were the same. Calculation were done for various Pvq/Ppq ratios: 4.5, 9 and 18. Then for constant Pmq parameter (84.3%) and Pvq parameter (of the following values: 0.45 μm; 0.9 μm and 1.8 μm) the Ppq parameter increased from 0.04 μm to 0.4 μm with step of 0.01 μm. Finally, for constant Pmq parameter (84.3%) and Ppq parameter (0.1 μm) va;ues the Pvq parameter changed from 0.45 μm to 1.9 μm with step of 0.05 μm. The Pmq parameter of 84.3% corresponds to standard deviation of 1 and is typical for plateau honed cylinder profile.

3. Results and discussion

First two process profiles of larger values of correlation length of valley part comparing to plateau part were studied. Increase of the Pmq parameter (when the Ppq and Pvq parameters are the same) causes decrease of the Pk parameter; higher for smaller values of Pmq. The effect of Pvq parameter on the values of the core height Pk is evident for smaller value of the Pmq material ratio; for higher Pvq the Pk is larger. Increase of the Pmq parameter causes also decrease of Pvk; the Pvk value is proportional to the Pvq value. Differently to the Pk parameter, larger changes of the Pvk were found for higher values of the Pmq ratio. The effect of Pmq increase on value of Ppk parameter is negligible. Increase of the Pmq causes increase of Pmr1 and Pmr2 material ratios; this proportionality was more evident for the Pmr2 parameter. For the small Pmq parameter increase of Pvq causes decrease of Pmr2. Figure 3 presents the relation between Pmq parameter and parameters from the Sk family.

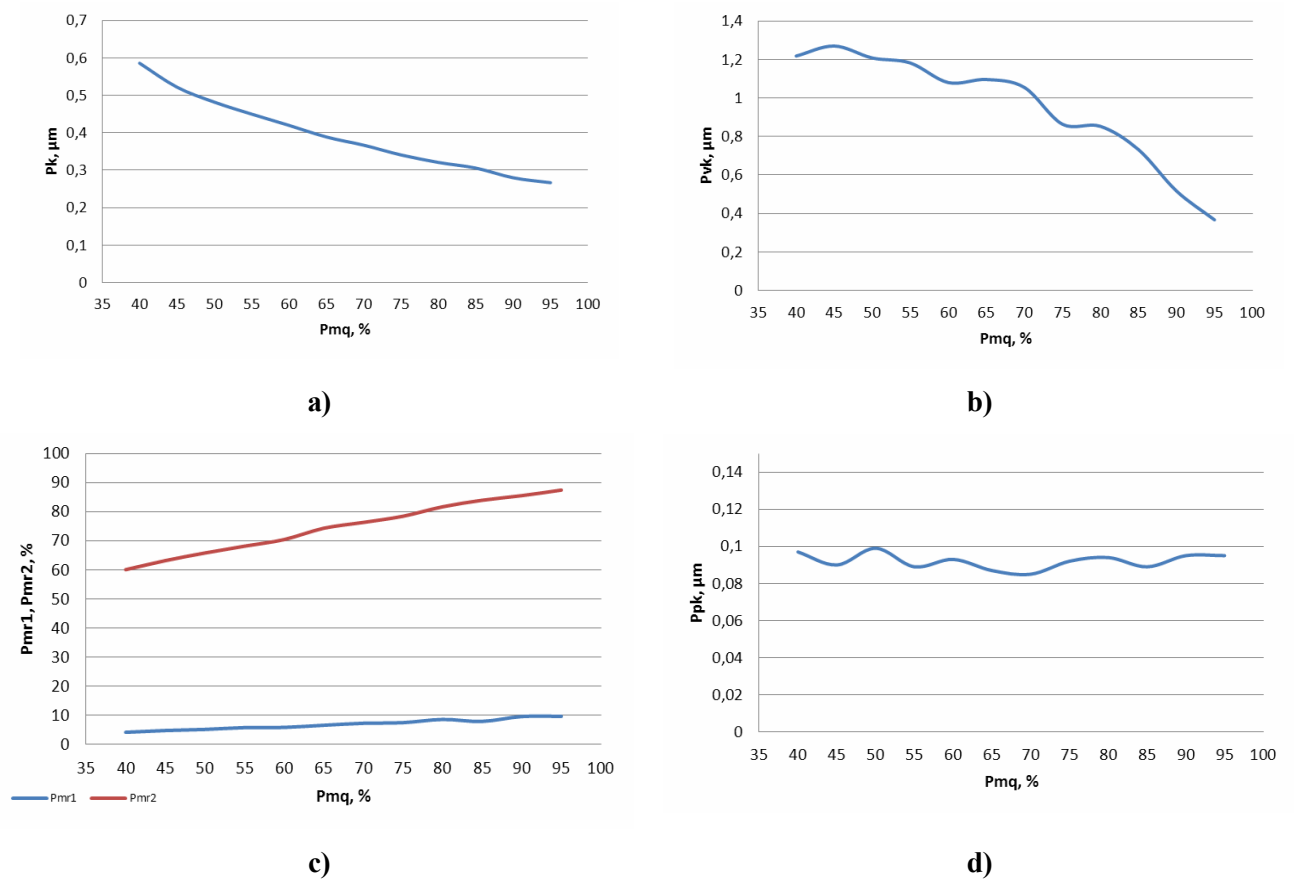


Figure 3. The effect of Pmq parameter on the Pk (a), Pvk (b), Pmr1, Pmr2 (c), Ppk (d), CLp = 8 µm, CLv = 40 µm, Ppq = 0.1 µm, Pvq = 0.9 µm.

Increase of the Ppq parameter (when Pmq and Pvq were constant) causes increase in the Pk parameter, for higher Pvq value Pk is larger for high values of Ppq. Similar, increase of the Ppq parameter causes also increase of the Ppk parameter. The tendency was found that increase of the Ppq parameter caused decrease of the Pvk parameter; this trend is more visible for smaller values of Pvq. Due to increase of Ppq, material ratios Pmr1 and Pmr2 increased; this trend is more visible for smaller values of the Pvq parameter. Dependence between Ppq parameter and parameters Pk, Ppk, Pvk, Pmr1 and Pmr2 is presented in Figure 4.

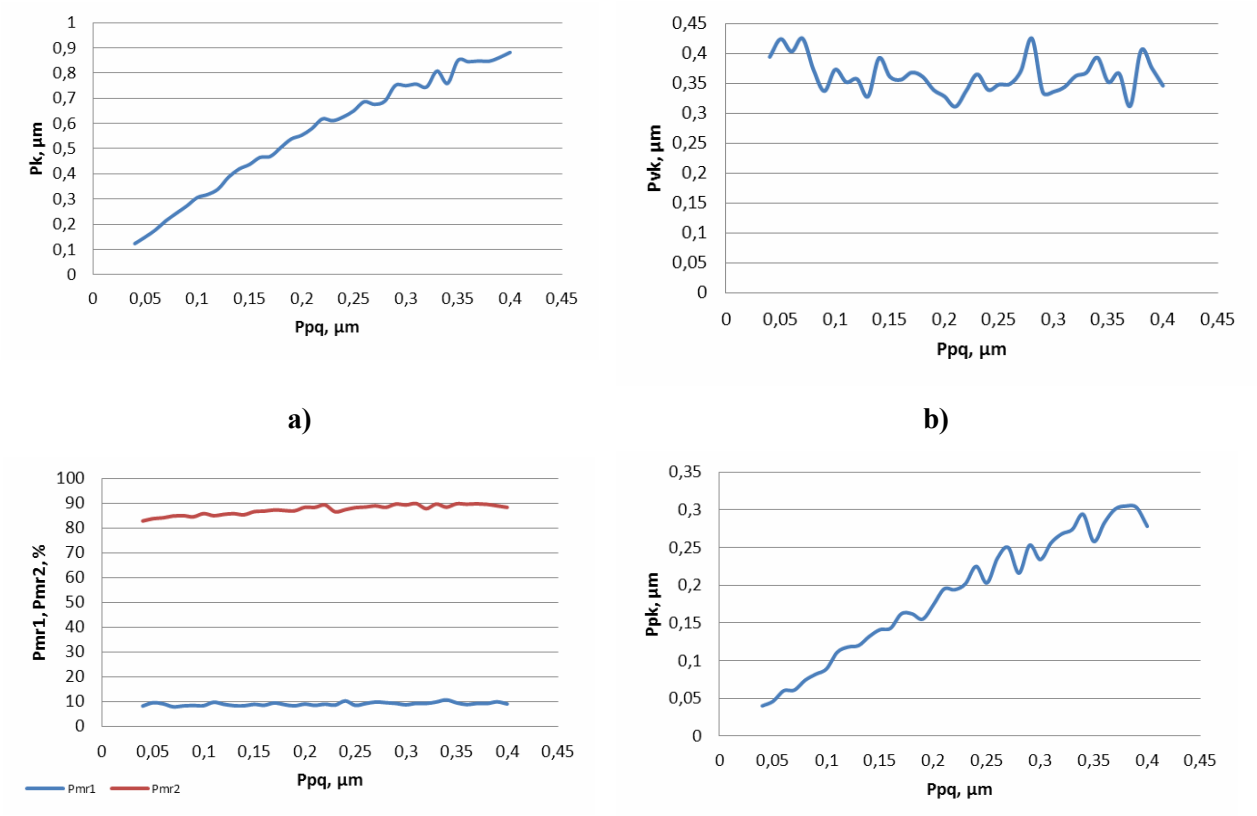
Increase of the Pvq value (when Pmq and Ppq are constant) causes increase of the Pvk parameter. The tendency was found that Pmr1 and particularly Pmr2 parameters decreased due to Pvq increase. The influence of Pvq change on the Ppk and Pk parameters is small, with tendency of the Pk increase due to Pvk increase (see Figure 5).

For profiles of the same correlation length of plateau and valley parts the observed previously effects of increase of the Pmq parameter on the Pk, Pvk, Pmr1 and Pmr2 were confirmed. The small dependence between Pmq material ratio and the Ppk parameter was also confirmed for high Pvq values; for smaller ones the tendency was found that increase of the Pmq caused also increase of Ppk.

The characters of dependencies between change of the Ppq parameter and the Pk, Ppk, Pmr1 and Pmr2 parameters found previously were confirmed, similarly to trend of decrease in Pvk due to increase of Ppq.

Increase of the Pvq caused increase of Pvk parameter. The effect of Pvq change on the Ppk value was small. The tendency obtained previously that Pvq increase causes decrease of Pmr1 and Pmr2 was confirmed.

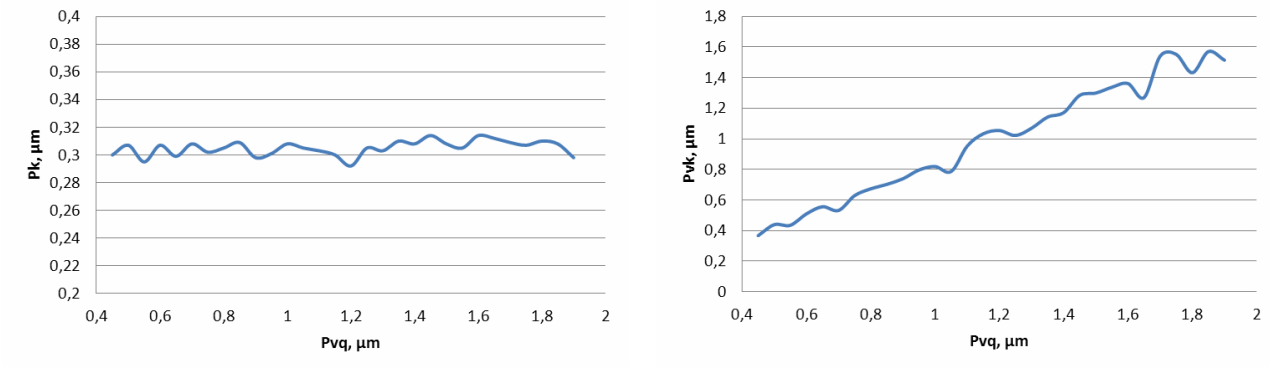
Generally, the tendencies of changes of parameters of two-process profiles with smaller values of horizontal length of plateau part comparing to valley part were confirmed for profiles of similar correlation lengths of 2 profile parts. In addition, the trend of increase of Ppk due to increase of the Pmq for small Pvq/Ppq ratio was found (see Figure 6).



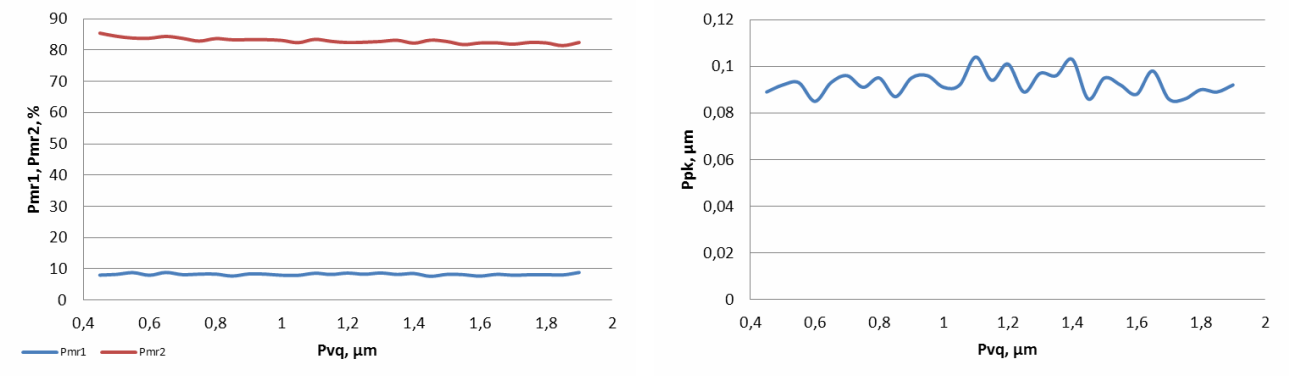
a) **b)**

c) **d)**

Figure 4. The effect of Ppq parameter on the Pk (a), Pvk (b), Pmr1, Pmr2 (c), Ppk (d), CLp = 8 µm, CLv = 40 µm, Pvq = 4.5 µm, Pmq = 84%.

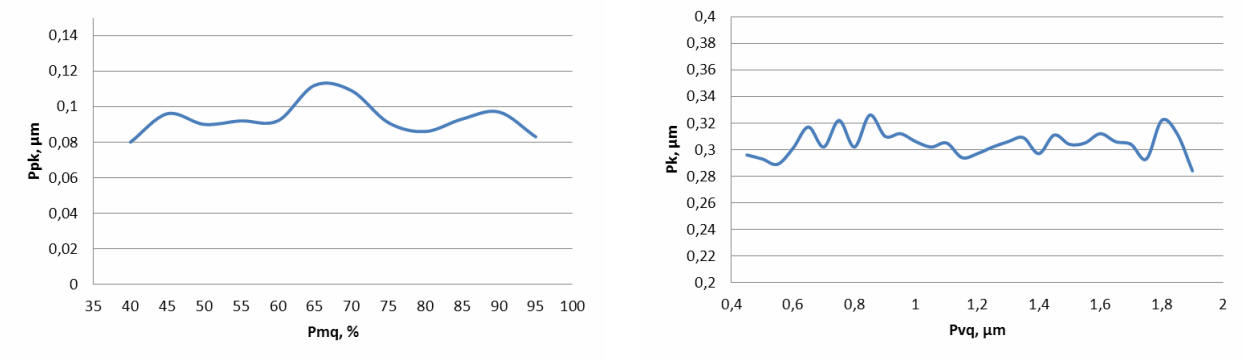


a) **b)**



c) **d)**

Figure 5. The effect of Pvq parameter on the Pk (a), Pvk (b), Pmr1, Pmr2 (c), Ppk (d), CLp = 8 µm, CLv = 40 µm, Ppq = 0.1 µm, Pmq = 84%



a) **b)**

Figure 6. The effect of Pmq parameter on Ppk parameter for Ppq = 0.1 µm, Pvq = 0.45 µm (a), the effect of Pvq parameter on Pk parameter, Pmq = 84%, Ppq = 0.1 µm (b), CLp = Clv = 40 µm.

The effects of the Pmq parameter increase and Pvk change on values of the parameters from the Sk family found for profiles of the same correlation lengths of plateau and valley parts were confirmed also for profiles of smaller correlation length of valley part comparing to plateau zone. The character of dependencies between increase of the Ppq parameter on parameters from the Sk group found for two analysed previously profiles sets was also confirmed.

Similar results were obtained in other similar research [22]. Figure 7 presents examples of modeled profiles.

The effect of changing parameters from the Sq group on other parameters was also studied. When Ppq/Pvq was the same, the increase of Pmq caused decrease of the statistical height parameters height (Pa, Pq) and of Rq/Rt ratio. In this case Psk, Pp/Pt, Pda/PΔq, Pa/Pq decreased and Pku increased.

When Pmq was the same, Ppq/Pvq decrease caused decrease of Pp/Pt, Psk, Pk/Pt, Pda/PΔq, Pa/Pq, increase of Pku and increase of Pvk/Pt.

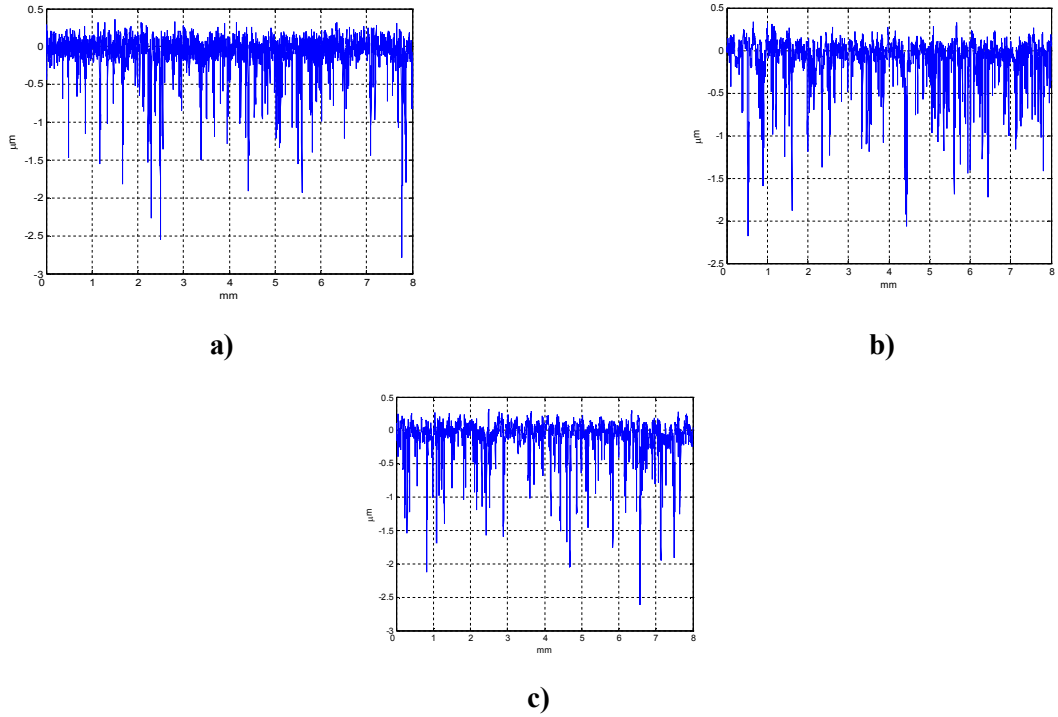


Figure 7. Two-process profiles characterized by the following parameters: Ppq = 0.1 µm, Pvq = 0.9 µm, Pmq = 84%, CLp = 8 µm, CLV = 40 µm (a), CLp = 40 CLV = 8 µm (b), CLp = 40 µm, CLV = 40 µm (c).

In addition, the values of linear correlation coefficient were computed (see Table 1). Only part of findings obtained previously was confirmed. It was found that Pmq parameter is correlated only with Pmr1 and Pmr2 material ratios, Ppq with Ppk and Pk and Pvq with Pvk. Parameters from ISO 13565-3 standard are not inter-correlated contrary to those from ISO 13565-2 standard (only Pvk is independent parameter).
It is evident from this research that plateau profile part from ISO 13565-3 standard is connected with core and peak parts from ISO 13565-2 standard.

Table 1. Values of linear correlation coefficient between analysed parameters.

	Pmq	Ppk	Ppq	Pvk	Pvq	Pk	Pmr1	Pmr2
Pmq	1							
Ppk	0.109	1						
Ppq	0.085	0.977	1					
Pvk	-0.21	0.023	0.081	1				
Pvq	0.001	0.081	0.101	0.87	1			
Pk	-0.073	0.95	0.972	0.148	0.151	1		
Pmr1	0.757	0.32	0.271	-0.411	-0.239	0.102	1	
Pmr2	0.769	0.43	0.345	-0.612	-0.43	0.211	0.845	1

4. Conclusions

Increase of the Pmq parameter causes decrease of the Pq parameter, with larger changes obtained for smaller Pmq values. The effect of the Pmq parameter change on the Ppk parameter is negligible. Increase of the Pmq parameter causes decrease of the Pvq parameter; the changes are higher for larger Pmq material ratios. Due to Pmq increase, the material ratios Pmr1 and Pmr2 also increases.

Increase of the Ppq parameter causes increase of Ppk, Pk, Pmr1 and Pmr2 parameters and decrease of the Pvk parameter,
Increase of the Pvq parameter causes increase of the Pvk parameter. The Pvk parameter is the most independent parameter from the Rk group (ISO 13565-2 standard).
The obtained dependencies were found for various horizontal parameters of plateau and valley profile parts. They were partly confirmed by correlation analysis of parameters. For profiles, for which correlation length of plateau part was not smaller than that of valley part the tendency that due to Pmq parameter increase the Ppk parameter increased was additionally found.

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