ANALYSIS OF THE POSSIBLE INFLUENCE IN DETERMINING OF THE ROUGHNESS PROFILE IN REAL NON-PERIODIC SURFACES BY APPLICATION OF GAUSSIAN AND 2RC FILTERS

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ABSTRACT: *Non-periodic real etalon surfaces representative of grinding and lapping process are measured and considered. The function of Gaussian and 2RC filter in determining the roughness profile from the measured (total) profile are represented. The metrological characteristics are noticed on both filters. Comparisons of the roughness profile obtained by filtering by use of the Gaussian and 2RC filter are introduced. Imperfection and limitations of Gaussian filter and possible influences to determine of roughness profile for non-periodic real surfaces are analyzed. Emphasized is the phase distortion of filter mean line obtained using 2RC filter and its possible influences to determine of roughness profile for non-periodic surfaces. Influence of filtering process according to ISO 13565-1:1996 for roughness profile with have deep valleys for measured surfaces are analyzed. Advert to the new filtering techniques in surface metrology developed to overcome limitations arising from the use of Gaussian and 2RC filters.*

1. INTRODUCTION

Geometric structure of engineering surfaces can be reviewed on macro, medium and micro plan. Surface review on macro plan provides determination of deviations from desired form and dimensions. Surface waviness can be gained by review of surface on medium plan, while as roughness on micro plan. Review of geometric structure of surface of a surface layer as deviation from form, waviness and roughness is widely accepted and standardized [1,2,3]. The idea for such surface review comes from the fact that roughness, waviness and form have

various effects upon part functionality in many aspects. However, this review, imposes a dilemma where is the real boundary between roughness, waviness and form. Separation of roughness, waviness and form from measured total profile is provided by means of a filtration process. Two filtration methods are developed, known as E filtration system and M filtration system [4]. Implemented and defined are three types of profile filters λ_s, λ_c and λ_f. Procedure for obtaining roughness and waviness profiles and sequence of application of profile filters is standardized in ISO 4287:1997[5]. It should be underlined that the American national standard ASME B46.1-2002[6] does not define filter λ_f, i.e. it is considered that length at which roughness profile is determined is small in order to determine its form, as well. Division of filters into low-pass and high-pass ones is found in literature. As low-pass filter is considered the profile filter λ_s, while as λ_c is considered as a high-pass one [4].

2. METROLOGY CHARACTERISTICS OF GAUSSIAN AND 2RC FILTERS

2.1. 2RC filter

Analogue (hardware) 2RC filter is a electrical network of two capacitors and two resistors and is the oldest filter used in construction of analogue profilometers for measuring surface topography. With the occurrence of digital profilometers, Whitehouse and Reason in 1965 [4], a software solution is implemented as replacement for hardware 2RC filter. Basic metrology characteristics of digital high-pass 2RC profile filter are weighting function and transfer characteristic, standardized in ASME B46.1 -2002 [6]. In [6] are given graphic interpretations of weighting function and transfer characteristic. Nowadays, 2RC profile filter is discarded from International ISO standards. Weighting function of 2RC filter is given with [6]:

$$S(x) = \frac{A}{\lambda_c}\left(2 - A\frac{|x|}{\lambda_c}\right)\exp\left(-A\frac{|x|}{\lambda_c}\right) \tag{1}$$

where: A=3,64 for 75 % transmission at λ_c, x is the position in millimeters from the origin of the weighting function $(-\infty < x < 0)$, and λ_c is the long wavelength roughness cut-off.

Roughness profile could be gained by subtracted of filter mean line from primary profile. 2RC filter mean line is gained by convolving the primary profile with weighing function given in equation (1). Weighting function is generated in

interval $-2\lambda_c \le x \le 0$, since a nonsymmetrical filter is in question in terms of the start of profile filter [4,7].

Then, filter mean line of primary profile determined by using 2RC filter does not represent the waviness profile [4,7]. 2RC filter is characterized with some disadvantage that may limit its application. Its non-linear phase as a result of which a phase distortion of filter mean line in terms of primary profile occurs is the most mentioned disadvantage of 2RC filter. The phase distortion is mostly expressed by increase of cut-off length and contributes to occurrence of fictitious characteristic of roughness profile. Sensitivity of 2RC filter on deep valleys of primary profile causes pulled down of filter mean line from mean portion of profile towards the valley. Distortions of filter mean line towards ends of primary profile are also characteristics that could be considered as 2RC filter disadvantage. Due to this occurrence shortening of part of primary profile is practiced in length of $2\lambda_c$ from its start [4], which contributes to inapplicability of 2RC filter when measuring very short profiles.

2.2. Gaussian filter

Incomparably, nowadays most commonly used profile filter in surface metrology is the phase-correct Gaussian filter with metrology characteristics standardized in ISO 11562:1996 [8] and ASME B46.1 -2002 [6]. In [6,8] are given graphic interpretations of weighting function and transfer characteristic. Weighting function of Gaussian filter is given with [6,8]:

$$S(x) = \frac{1}{\alpha\lambda_c} \exp\left[-\pi\left(\frac{x}{\alpha\lambda_c}\right)^2\right] \tag{2}$$

where $\alpha = \sqrt{\ln 2/\pi} = 0.4697$, x is the position from the origin of the weighting function and λ_c is the long-wavelength roughness cut-off.

Roughness profile is gained as a difference between primary profile and filter mean line determined with Gaussian profile filter. Against ASME B46.1 - 2002 filter mean line, determined with Gaussian profile filter, presents the waviness profile.

Gaussian filter has a linear phase and does not cause phase distortion of filter mean line in terms of primary profile and therefore is mostly called phase-correct profile filter. Filter mean line determined with Gaussian filter has distortion on profile ends as a result of the openness of primary profile which is not the case when it is applied on closed profiles. The effect of this deviation of Gaussian filter mean line is removed by shortening roughness profile in terms of primary profile

for one length of λ_c , i.e. per one half of λ_c on both profile ends. Shortening parts of roughness profile in value of one λ_c makes Gaussian filter inapplicable when measuring very short profiles, which could be considered as its disadvantage. Sensitivity to deep valleys on primary profile results into pulled down of filter mean line from mean portion of primary profile towards the valley, and later on by creating a fictitious characteristic of roughness profile in valley proximity again another negative characteristic of Gaussian filter. For overcoming this disadvantage ISO 13565-1:1996 [9] foresees special filtration mode for primary profiles with deep valleys. The filtration process according to [9] is developed in several stages. Initially a filter mean line is determined for the primary profile by means of a phase -correct filter (Gaussian profile filter). Then, valleys of primary profile are removed below filter mean line thereby obtaining a new primary profile. A new filter mean line is determined on that new gained profile, which filter mean line participates in determination of roughness profile. It is significant to mention that standard ISO 13565-1:1996 provides much freedom in application of this filtration mode. Only condition for application of this filtration mode is primary profile to have deep valleys without precise defining how many should be in number in certain measuring length or how much should be the value of valleys in order to apply this process.

3. DETERMINATION OF FILTER MEAN LINES AND ROUGHNESS PROFILES ON REAL ETALON SURFACES BY APPLICATION OF MATLAB (R2009B)

It is clear that for forms of profiles wherein waviness and form profiles participate in high extent, disadvantage and limitations of Gaussian and 2RC filter are extremely expressed and their effects upon roughness profile are visually visible.

Usage of contact (stylus) profilometers, which have pick-up with skid provide obtaining primary profiles on which skid has already did mechanical filtration, wherein waviness and form profiles are removed from measured profile [10]. There of need is imposed for determining effects of disadvantage and limitations of Gaussian and 2RC filter on primary profiles gained by measuring real surfaces where waviness and form are not expressed. For the purpose real non-periodic etalon surfaces representatives of machining with grinding and lapping are measured. Stylus profilometer Surtronic 3+ with pick-up TYPE 112-2672 (DCN 001) with stylus radius of 2 μm and skid radius of 8.7 mm is used for measurements on real surfaces. Coordinates of points on primary profiles are gained by means of software TalyProfile, Version 3.1.4. Software TalyProfile is professional commercial software of closed type with fitted recommendations

against International standards, in which user does not have ability for overview and correction. Therefore software TalyProfile can not be used for determining roughness or waviness profile, which is going to have length equal to primary profile. Other limitation comes from the point that TalyProfile does not provide overview of filter mean lines gained by using profile filters, but only of waviness profile, which is not the same. Automatic filtration when calculating roughness parameters by means of Gaussian filter, without taking into account whether measured profile is gained with a profilometer with or without a skid is also a significant limitation of TalyProfile.In these researches, software package Matlab (R2009b) is used for simulating filtration process by means of Gaussian and 2RC profile filters and obtaining profile mean lines and roughness profile. Weighting functions of Gaussian and 2RC filter provided with equations (1) and (2) are used for obtaining filter mean lines. Primary profiles, filter mean lines and roughness profiles gained from non-periodic real etalon surfaces are presented on Fig. 1,2,3 and 4.

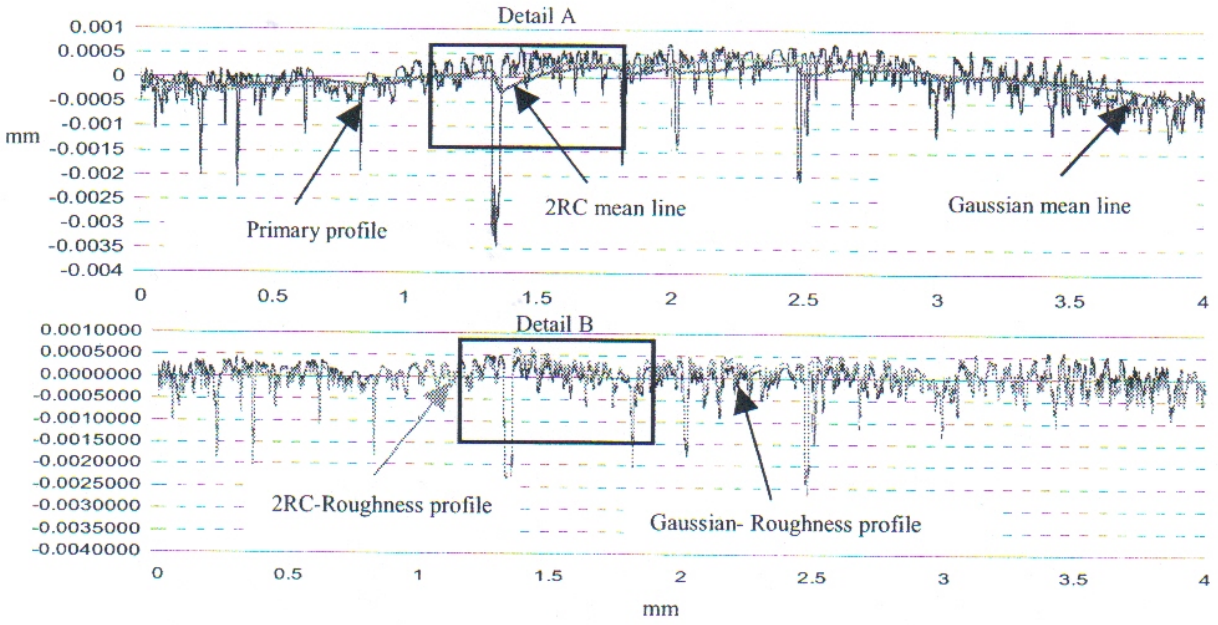

Fig. 1. Primary profile, filter mean lines and roughness profiles gained from non-periodic real surface- machining with grinding, with Ra=0.2 μm

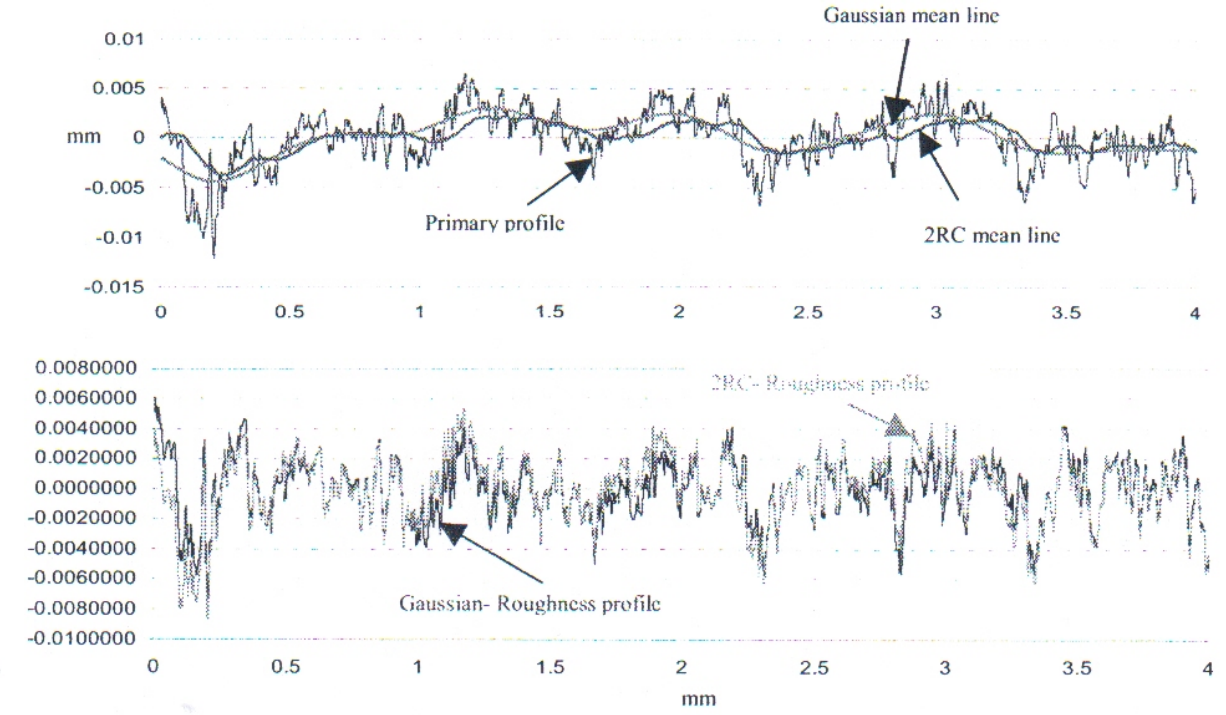

Fig. 2. Primary profile, filter mean lines and roughness profiles gained from non-periodic real surface- machining with grinding, with Ra=1.6 μm

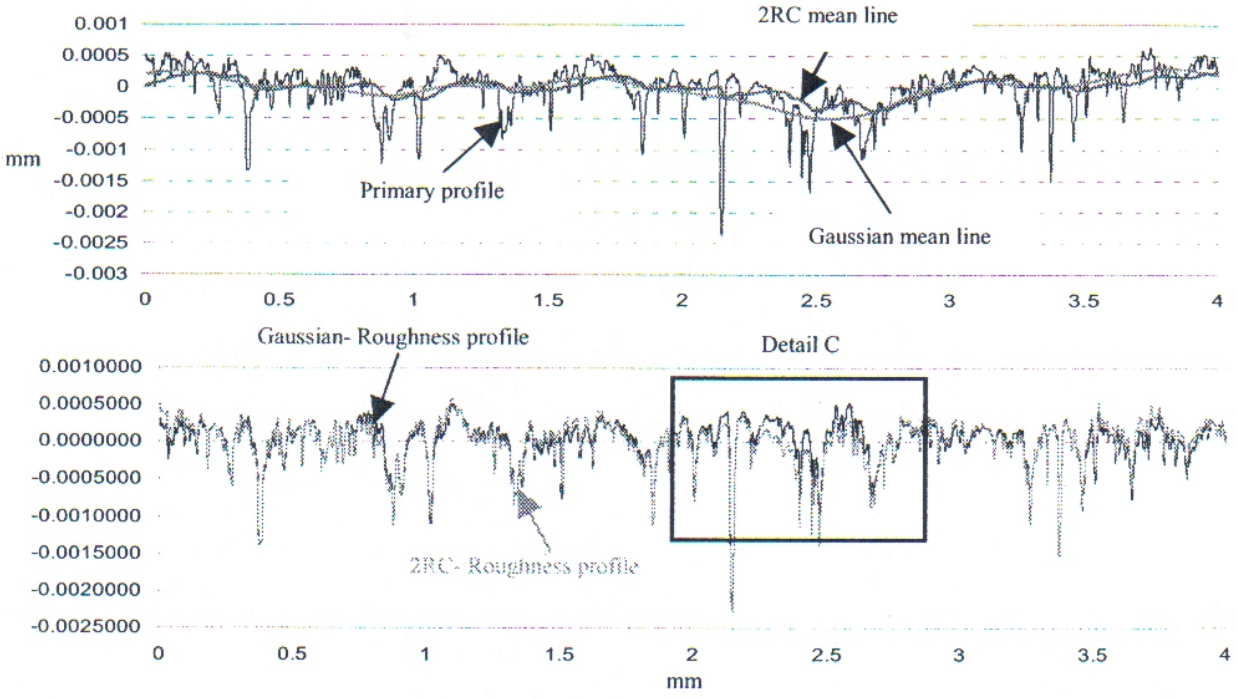

Fig. 3. Primary profile, filter mean lines and roughness profiles gained from non-periodic real surface- machining with lapping, with Ra=0.2 μm

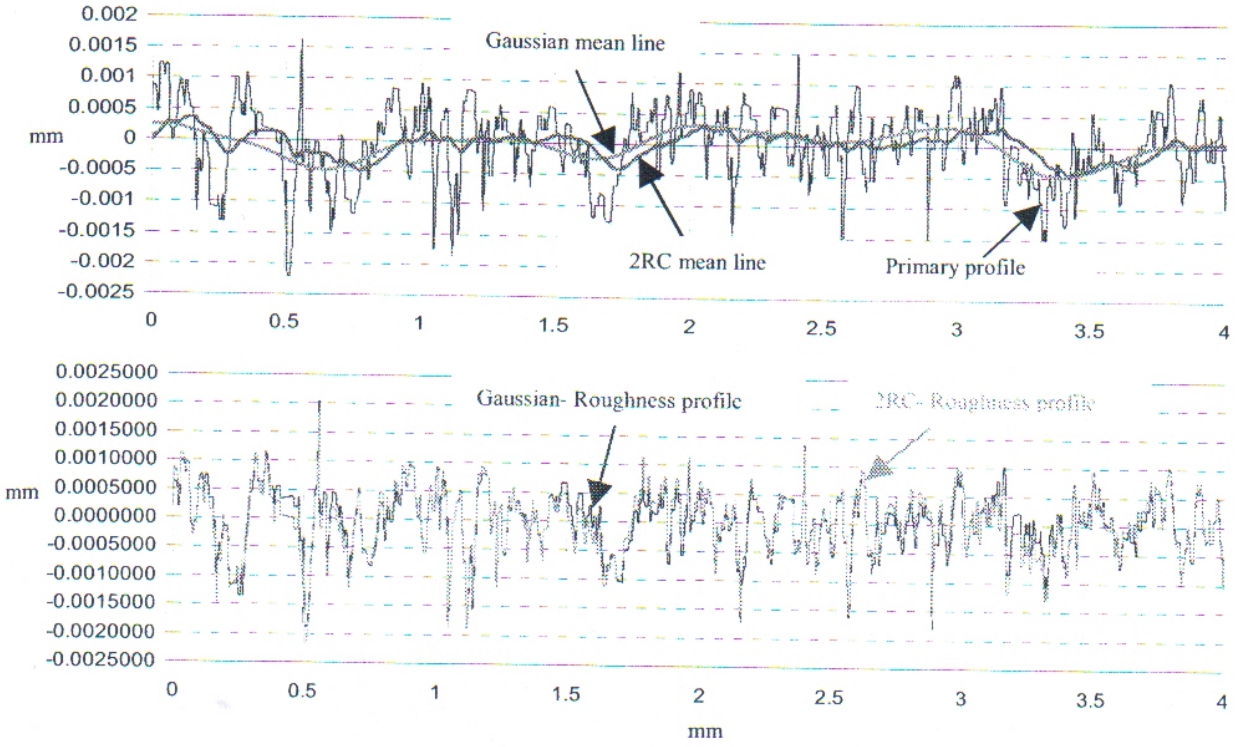

Fig. 4. Primary profile, filter mean lines and roughness profiles gained from non-periodic real surface- machining with lapping, with Ra=0.4 μm

4. ANALYSIS OF INFLUENCE OF PROFILE FILTER CHARACTERISTICS UPON GAINED ROUGHNESS PROFILES

Non-periodic primary profiles gained by measuring real etalon surfaces-representatives of machining with grinding with various values of Ra are presented on Fig. 1 and 2. The fact that the form of these profiles is non-periodic against whole profile length permits to see and conclude that disadvantage of Gaussian and 2RC profile filters shall be differently expressed against profile length. Primary profile on Fig. 1 characterizes with small presence of waviness and expressed individual valleys. Due to waviness absence and the position at start and end of primary profile around zero value per z-axis, distortions of mean filter lines on profile ends shall not have much effect therefore shortening of roughness profile in terms of primary profile is not of significant importance. Here, the high sensitivity of 2RC profile filter on individual valleys of primary profile, detail A, Fig. 1, has to be underlined, which results in pulled down of filter mean line from mean portion of primary profile towards the valley. This pulled down of mean line later on cause's distortion of roughness profile in valley proximity and creation of fictitious characteristic of roughness profile, detail B Figure 1. It can be also seen on same

Fig. that distortion in valley proximity is going to occur also when using Gaussian profile filter, however shall be smaller because filter mean line is not phase dislocated in terms of primary profile i.e. valley. Comparison of roughness profiles gained by Gaussian and 2RC profile filters indicates that there are segments of profiles wherein they overlap and segments wherein they differ. Roughness profile gained by Gaussian profile filter is already "smooth" in terms of zero value per z-axis. Differences of profile forms in some segments contribute to various location of mean line, with which roughness parameters are determined.

Expressed waviness per whole length of primary profile is present on profile presented on Fig. 2. In such case the effect of disadvantage of Gaussian and 2RC profile filters is obvious. Distortion at start of 2RC filter mean line is extremely expressed. Still, crucial role for discrepancy of roughness profiles against their whole length has the phase distortion of 2RC filter mean line. Here it can be also seen that roughness profile gained with Gaussian profile filter is more "smooth" in terms of zero value per z-axis.

Roughness profiles representatives of machining with lapping are characterize with deep valleys, Fig. 3 and 4. For such primary profile forms, sensitivity of filter mean lines on Gaussian and 2RC filters on deep valleys and phase distortion of 2RC mean line are main disadvantage that contribute to creation of fictitious characteristics of roughness profile, excessively expressed on detail C Fig. 3.

4.1. Filtration according to ISO 13565-1:1996

Presence of deep individual valleys on non-periodic profile, presented on Fig. 1, provides application of filtration process according to ISO 13565-1:1996 [9].

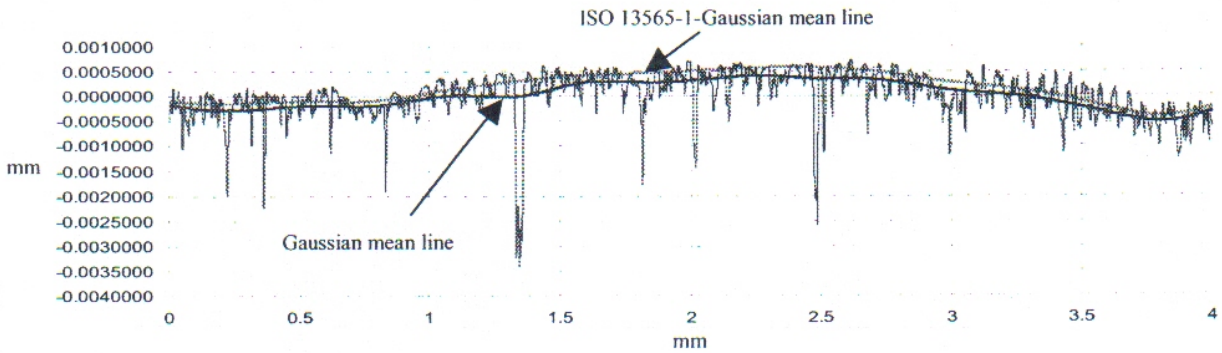

Fig. 5. Primary profile with Gaussian filter mean line and mean line determined by filtration process according to ISO 13565-1:1996

Fig. 5 clearly presents that a difference exists between filter mean line determined with Gaussian filter and filter mean line determined according to ISO 13565-1:1996. Therefore, roughness profiles determined with Gaussian filter i.e. against ISO 13565-1:1996 differ significantly. Filtration process according to ISO 13565-1:1996 provides obtaining "smooth" roughness profiles in terms of zero value per z-axis. Since roughness profiles are in question that do not coincide per their whole length, it can be concluded that there are two fully new and various profiles with different mean line in terms of which roughness parameters are expressed. In such cases a change can be expected almost on all roughness parameters.This indicates that filtration process according to ISO 13565-1:1996 maybe provides more real roughness profile when waviness is not present, however the large difference in roughness profile forms imposes a dilemma whether procedure should be applied or not. Maybe the dilemma is larger since on some professional software, as TalyProfile is, possibility for filtration against ISO 13565-1:1996 is not given. Mean line determined against recommendations in ISO 13565-1:1996 is also called Rk (Gaussian) filter mean line [4,7].

Besides Gaussian and 2RC filter, new filtration techniques used in surface metrology can be found in literature [4,7]. These new filtration techniques are developed for to overcome of disadvantages of Gaussian and 2RC profile filters and their unwanted effects upon form of roughness profile. Against [4], many of new filtration techniques shall be included in the International standards in future.

5. CONCLUSION

Analyzed literature and gained filter mean lines and roughness profiles impose following conclusions:

- Claim that filtration process has main and crucial role in determining roughness profile form was verified.Analysis of non-periodic profiles showed that classification of surface as "non-periodic" is not sufficient when determining effects of Gaussian and 2RC profile filters.
- It was indicated that if primary profile characterizes with deep valleys then distortion of filter mean line from profile core occurs when using both filters. Additional deviation and obtaining fictitious characteristic of gained roughness profile shall cause phase distortion of 2RC filter mean line.
- It was confirmed that roughness profile gained by filtration process according to ISO 13565-1:1996 differs per its whole length from roughness profile gained only by using Gaussian filter.
- Presence of waviness per whole length of primary non-periodic profile provides to underline all disadvantages of Gaussian and 2RC profile filters. Large deviations and creation of fictitious characteristics on roughness profile occur when

using 2RC profile filter. Therefore, this analysis provides conclusion that the application of Gaussian filter when obtaining roughness profile from non-periodic surface is justified.

- In future maybe researches are needed wherein the effect of profile filter size (cut-off) will be included for reduction of undesired consequences by the change of Gaussian and 2RC profile filters on non-periodic surfaces.

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WYDZIAŁ MECHANICZNY
KATEDRA TECHNOLOGII MASZYN
INSTYTUT OBRABIAREK
I TECHNOLOGII BUDOWY MASZYN

PODSTAWY I TECHNIKA OBRÓBKI ŚCIERNEJ

pod redakcją
Andrzeja Gołąbczaka
i Bogdana Kruszyńskiego

ŁÓDŹ 2010

Monografię przygotowano
w Katedrze Technologii Maszyn
oraz
Instytucie Obrabiarek i Technologii Budowy Maszyn
Wydziału Mechanicznego Politechniki Łódzkiej

po patronatem
Sekcji Podstaw Technologii Komitetu Budowy Maszyn
Polskiej Akademii Nauk

Recenzenci
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Opracowanie techniczne:
Włodzimierz Fiks, Marcin Gołąbczak

Prace poligraficzno - wydawnicze:
Agencja „MAGA"
www.agencjamaga.pl

ISBN 83-920269-4-2

Łódź 2010, wyd. I, ark. wyd. 35, nakład 100 egz., format B-5

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