INFLUENCE OF DIFFERENT FILTRATION METHODS APPLICATION ON A FILTERED SURFACE PROFILE AND ROUGHNESS PARAMETERS

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Abstract:

The measurements were performed on the surfaces made of different materials and typical of diversified character. Glass roughness standards with sinusoidal profile, approximately sinusoidal profile and metallic comparative standards after lathing and grinding were object of research. Analysis was performed including the surface and profile evaluation. Statistical analysis was conducted. Measurement sections and other filter parameters were selected in accordance with standards. Measurements were carried out with stylus tip contact method – using TOPO 01P device designed by The Institute of Advanced Manufacturing Technology, that uses diamond tip inductive sensor. Tip sensor radius is equal to 2 μm. The results of measurements were filtered by: Gaussian filter, Robust Gaussian regression Filter, Spline, Spline Wavelet, Morphological Filter. Gaussian Filter uses linear system based on Fourier wavelengths. Robust Gauss Regression Filter is similar to Gaussian Filter, but it is insensitive on the specified phenomena in input signal. Spline Filter is based on linear polynomial combination. Wavelet Filter decomposes profile on constant shape elements, but on different scales. Morphological Filter operates on the principle of filtered profile plotting using circular disc or horizontal line segment with a specified (respectively) radius or length. Selection of suitable filtration method is essential and one of the most important things to obtain reliable measurement results evaluation. Not all filters are suitable for each type of surface. Filter algorithms differ from each other and this influences in a greater or lesser degree on the roughness profile and hence on roughness parameters and waviness parameters related to it.

Keywords: topography, filtration, roughness profile

1. INTRODUCTION

Filtration has always played a significant role in surface geometrical structure measurements. It is a way to separate features of examined surface which we are interested in from insignificant features. Filtration can significantly change data registered while measurement. Depending on the tests purpose, methods and algorithms to prepare registered results for further analysis should be chosen in a conscious way. This includes removing form errors, pre-filtration ls of primary profile and application of different filtrations which are available in registered data processing programs.

Profile filters separate profile on long wave and short wave components. As is well known, the results' values largely depends on selected filter wavelength. Wrong filter can understate or overstate the parameters values in greater or lesser degree.

Whereas, how will the results be presented, when the same surface will be processed by correspondent filter cut-off length or other value specifying the filtration final effect, but with the use of different filtration algorithms and methods.

This is pre-presented in this paper. To illustrate the operation of various filtration algorithms, profile filters action comparison has been adopted for simplification..

During the study measurements were performed on diversified surface types, which were obtained by various methods of mechanical machining. Obtained data have been analyzed using filters: Gauss filter, Robust Gaussian regression filter, Spline filter, Spline wavelet, Morphological alternating disk filter.

2. PROFILE FILTERS

2.1 Gauss filter (FPLG)

Gaussian filtration is currently one of best-described, best-defined, the earliest recognized in ISO, and most often used input data processing algorithm. It results i.a. from the fact, that Gauss filter is characterized by relatively easy calculating and interpretation method and the fact that all digital devices are equipped with the filter in their input data processing programs. Gauss filter is defined by wavelength cut-off value. Calculations are based on Fourier transform. Sampling interval is consistent with Nyquist theorem (specifying sampling interval, which does not let to lose data) [1-2]. It does not show phase shifting and ringing effect [1-3].

Equation (1) describes Gauss filter weighting function for open profile.

$$s(x)=\frac{1}{\alpha\times\lambda_c}\times \boldsymbol{exp}\left[-\pi\left(\frac{x}{\alpha\times\lambda_c}\right)^2\right] \qquad (1)$$

where: x – the distance from the centre (maximum) of the weighting function, λ_c – the cut-off wavelength, α - a constant, to provide 50 % transmission characteristic at the cut-off λ_c (is approximately 0,4697).

Long wave components transmission characteristic is determined on the basis of Fourier transform of weighting function. Short wave components transmission characteristic is its compliment [2].

2.2 Robust Gaussian regression filter (FPRG)

Robust filters are insensitive on input profile discontinuities as: slope, step and spike (sudden hills or dales). Robustness is a relative property. It is said that one filter is more robust to a given phenomena than another [4]. Calculations of robust Gaussian regression filter are quite similar to Gauss filter calculations. Filter equation (2) is specified by:

$$w_k = [1\ \ 0\ \ 0] \times \left(X_k^T \times S_k \times X_k \right)^{-1} \times X_k^T \times S_k \times z \qquad (2)$$

where: X_k - the regression function (given by matrix), Sk - the space variant weighting function, z – is the vector of dimension of the profile before filtering [5].

2.3 Spline filter (FPLS)

Spline process consists in linear combination of piecewise polynomials with a smooth fitting between the pieces. The degree of the spline is equal to the degree of the highest degree of all polynomial which were used. Equation (4) is non-periodic spline filter equation applied to open profiles.

$$\left[1 + \beta\alpha^2 P + (1-\beta)\alpha^4 Q\right] w = z \qquad (4)$$

where: β – the tension parameter, P, Q – the matrixes, w - the vector of dimension of the filtered profile, z – the vector of dimension of the profile before filtration [6].

Vector of dimension of the filtered profile gives long wave profile components values. Short wave components are complementary to the long wale components [6]. Spline filter is defined by cut-off wavelengths. Besides filtered profile extraction further it can remove noise [1].

2.4 Spline wavelet filter (FPLW)

For wavelet analysis it is necessary to investigate signal properties related with time and frequency [3]. Spline wavelet filter besides filtered profile extraction further can delete noise. It is easy to calculate. Similarly to Gauss filter it uses Nyquist sampling, however it is faster. Further, it is not necessary to remove form deviation and distortions which occur as end effects in filtered profile, before filtration [1].

Spline wavelet filter decomposes profile on linear wavelet combination with constant form and various scales, derived from mother wavelet and depended on it (we can notice similarity to Fourier analysis) [7].

Equation (3) describes discrete wavelet transform with mother wavelet:

$$S(i\Delta x, a) = \Delta x \sum_j s[(i - j)\,\Delta x]\, g_{a,\, j\Delta x}(j\Delta x) \qquad (3)$$

Spline wavelet filter is a multiresolution filter, i.e. having series of approximation models (ladder rungs) smoothing measured profile in different degree. Models sequence is equivalent to cut-off value, and relation accuracy depends on mother wavelet. Every rung of the multiresolution ladder is calculated in three steps: splitting, prediction, updating. Return to a lower rung (inverse transform) is also performed in three steps: update, predict, combine. The higher rung, the more smoothed filtered profile [7].

2.5 Morphological alternating disc filter (FPMAD)

Morphological profile filters are idempotent operations (multi-applying does not change output effect) and monotonically increasing. They are defined with the use of Minkowski's sums [8-9]. Morphological operations can be classified on primary morphological operations, i.e. dilation, erosion and secondary morphological operations, i.e. opening (which removes hills smaller than reference value), closing (which removes dales smaller than reference value). Morphological filters are combination of morphological operations [3-8-10-11]. Morphological disk filter is nonlinear and gives different results than filters based on Fourier transform [1]. Disk with specified radius is structuring element [8]. During morphological filter filtration there is no equidistant sampling compatible with Nyquist theorem. Sampling method and reduction of information loss is defined by theorems on morphological sampling series. In case of morphological disk filter sampling interval should be smaller than radius of the disc used in the filtration [8-12]. For open profiles before filtration there is applied an operation called umbra transformation converting profile in the area under profile graph [3-8-11]. After filtration there is no opportunity for direct reconstruction of primary profile – one can only determine range in which this profile was contained. There are available sampling methods for planes, as follows: orthogonal grid, polar grid, specified grid, stratified, spiral, spider web, points [8-12].

3. EXPERIMENTS AND SIMULATIONS

Research was conducted on surfaces chosen to be characterized by diverse nature and methods of the surface treatment, and also that the results were representative for real surfaces. Measurements were performed on selected surface areas. Contact profilometer TOPO 01P, designed by The Institute of Advanced Manufacturing Technology, that uses 2 μm radius diamond tip inductive sensor was used in the research. Depending on the surface parameters values measurement segment with length: 1,25 mm, 4 mm, 12,5 mm were chosen. Comparisons included:

- glass roughness standard, type C, with Ra = 0,31 μm,
- metallic benchmark – surface after milling
- metallic benchmark – surface after grinding
- metallic benchmark – surface after turning

4. RESULTS

Table 1 presents the results for glass roughness standard. Table 2 presents the results for metallic benchmark with surface after milling. Table 3 presents the results for metallic benchmark with surface after grinding. Table 4 presents the results for metallic benchmark with surface after turning.

Table 1: The results for glass roughness standard.

P/R	profile P	FPLG	FPLS	FPLW	FPRG	FPMAD
		λc = 0,25 mm				
Ra [µm]	0,299	0,299	0,297	0,328	0,299	0,299
Rz [µm]	1,028	1,026	1,036	1,119	1,028	1,028
Rt [µm]	1,053	1,051	1,086	1,135	1,052	1,053
Rp [µm]	0,491	0,49	0,495	0,539	0,491	0,491
Rv [µm]	0,537	0,536	0,541	0,58	0,537	0,537
Sm [µm]	79,278	79,399	79,343	79,34	79,397	79,279
Rmr(c)	0,511	0,512	0,516	0,509	0,512	0,511

Table 2: The results for metallic benchmark with surface after milling.

P/R	profile P	FPLG	FPLS	FPLW	FPRG	FPMAD
		λc = 2,5 mm				
Ra [µm]	7,274	6,583	6,126	7,159 6,752***	6,646	7,242* 2,279**
Rz [µm]	33,759	31,85	30,342	33,407 32,22***	32,155	33,03* 5,197**
Rt [µm]	41,311	35,44	34,019	38,079 37,19***	35,728	40,69* 10,025**
Rp [µm]	18,582	17,966	17,075	18,688 18***	18,14	18,197* 2,211**
Rv [µm]	15,177	13,884	13,267	14,719 14,21***	14,015	14,833* 2,298**
Sm [µm]	377,05	344,1	325,78	374,83 354,8***	345,04	406,334* 100,83**
Rmr(c)	0,451	0,461	0,461	0,452 0,452***	0,461	0,451* 0,673**

* radius = 0.2 mm ** radius = 2 mm *** λc = 8 mm

To emphasize the difference in filtration parameters selection, the results for FPLW and FPMAD are given for similar to λc value recommended for FPLG and for the carefully balanced value. It results from the fact that spline wavelet filter and morphological alternating disc filter are calculated in different way than others. Figure 1 presents graphs for benchmark with surface after grinding containing profiles: primary, roughness and waviness. Used Filters: Gauss filter, spline filter, spline wavelet filter, robust gauss regression, morphological alternating disc filter, for which the results presented in Table 3.

Table 3: The results for metallic benchmark with surface after grinding.

P/R	profile P	FPLG	FPLS	FPLW	FPRG	FPMAD
		λc = 0,8 mm				
Ra [µm]	0,488	0,454	0,44	0,469	0,459	0,362* 0,461**
Rz [µm]	3,424	3,292	3,203	3,345	3,323	2,091* 3,066**
Rt [µm]	4,547	4,159	4,029	4,277	4,217	2,882* 4,192**
Rp [µm]	1,61	1,516	1,471	1,556	1,529	1,054* 1,478**
Rv [µm]	1,814	1,776	1,731	1,789	1,793	1,038* 1,588**
Sm [µm]	46,31	44,53	42,48	45,27	44,37	121,08* 55,85**
Rmr(c)	0,543	0,513	0,514	0,529	0,513	0,515* 0,552**

* radius = 1 mm ** radius = 0,1 mm

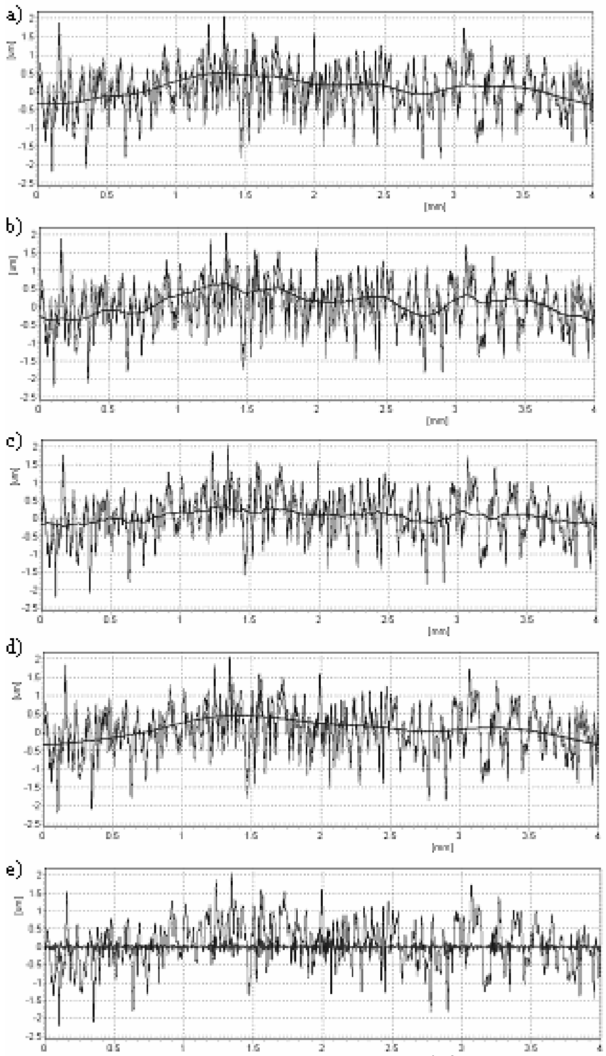

Fig. 1: The results for surface after grinding: a) FPLG, b) FPLS, c) FPLW, d) FPRG, e) FPMAD.

Table 4: the results for metallic benchmark with surface after turning.

P/R	profile P	FPLG	FPLS	FPLW	FPRG	FPMAD
		λc = 0,8 mm				
Ra [μm]	0,784	0,778	0,779	0,77	0,781	0,768* 0,306**
Rz [μm]	3,738	3,62	3,634	3,617	3,677	3,582* 1,789**
Rt [μm]	4,105	3,984	4,064	3,983	4,018	3,887* 2,122**
Rp [μm]	1,981	1,933	1,938	1,93	1,96	1,872* 0,894**
Rv [μm]	1,757	1,687	1,696	1,686	1,718	1,71* 0,895**
Sm [μm]	62,10	62,00	62,161	62,16	62,15	62,105* 71,19**
Rmr(c)	0,455	0,462	0,467	0,459	0,462	0,459* 0,614**

* radius = 0,1 mm ** radius = 1 mm

5. DISCUSSION

Questions that come to mind are: when is filtration necessary and when is not, which filters should be used for specific surface treatments, how to choose filtration parameters for different filter types?

While measurements performing always should be considered which profile or surface features interest us. In some cases filtration is not indicated. In some cases even should not be applied. When we decide to use the filters – firstly we have to think which filtration type will be suitable. The next important and worth thinking matter is selection of filter parameters. Ill-conceived and improper use of filtration may lead to big distortions of our results.

6. CONCLUSIONS

Irrespective of filter type, with appropriately selected filter parameters, similar parameter values was obtained. Whereas profiles after filtration apparently differ (Figure 1).

The advantage of Gauss filter is sampling in accordance with Nyquist theorem which allows filtered profile reconstruction. Negatives are: necessity of form deviations removal and end effects occurance. Gauss filter is sensitive for slope and steeps.

The advantage of robust Gaussian regression filter is that it does not deform the profile even when deep and wide dales and high, slope and wide hills exist.

Spline filter uses sampling in accordance with Nyquist theorem. It is easy to compute and does not require form removal.

Spline wavelet filter can be used for short profiles. The disadvantage of this type of filtration is difficulty in interpreting. Filtered profile is different from that obtained with Fourier transform. Filter parameters should be selected on a different principle then cut-off value.

The use of morphological disk filter does not cause end effects. Like the spline wavelet filter it does not require form deviation removal. Algorithm is faster than Gauss filter's one. Length of disc radius should be much smaller than cut-off value which was used for the same profile. The bigger morphological disc filter radius, the more information is filtered out. Selection of too big radius and application of morphological alternating disc filter on surfaces with unsymmetrical profile is usually cause of results underrate .

In general, for very regular profiles, none of the applied filters has shown significant differences. For turned and milled surfaces big values of morphological filters change roughness parameter values significantly and spline wavelets filer values insignificantly. Only profile roughness parameter values after filtration analysis may lead to false conclusions. Shape of profile, before and after filtration, should also be analyzed to check which components are deleted.

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