Analysis of roughness profile on curved surfaces

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Abstract. Production and control of accurate surface bring some issues. There are some technological limits of machining, but we have to know how to control these machined surfaces due to functional and life-time properties, which are affected mainly by roughness surface. Most important part of system of roughness surface measuring is suppression of nominal shape of scanned profile, its filtration according to standard ISO 4288 and evaluation according to the relevant standards. This article described process of filtration of roughness surface profile. If operator of the measuring instrument omits some important aspects at this stage, we obtain incorrect roughness surface profile, which significantly distorts the results of measurement leading to a rough error. The article is aimed at verifying roughness meters and indicates if a certain amount of data would be lost as if this loss affected the measurement result. Objectively, such a loss of data was simulated in the evaluation by considering every 7th scanned point at constant velocity of measurement.

Keywords: roughness surface, filter, wavelength

1 Introduction

The surface of each workpiece consists of different geometric elements, although it appears smooth and shiny at first sight. During the manufacturing process the number of effects occur (e.g. used technology, manufacturing process, human factor, etc.) that hamper the production of components ideal shape. Thus manufactured products show certain allowed deviations of desired geometry. Verification of such deviations is substantial in terms of functionality and interchangeability and is performed in compliance with GPS norms (Geometrical specifications and product verifications). If these norms are not respected, verification results are informative only. [1,2]

The quality of the manufactured surfaces can be assessed by the surface roughness as characteristics of slip, wear resistance, adhesion of protective coatings such as varnishes, corrosion resistance and fatigue resistance, among others, are related to roughness parameters. For accurate measurements of the surfaces, there is need to have an objective method of evaluation and roughness or quality parameter. [3,4]

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One of the important parameters that assess the quality of the products surface is roughness profile. To a certain extent, future durability, reliability, running accuracy, noise level, corrosion resistance, wear and correct functionality of product surfaces depend on this parameter. Relief created on the product surface is bearer of certain information as well as reflection of used technology. During each manufacturing process (machining, material coating) tools leave traces on the surface. The main parameter is the Rz parameter, which is also referred to as the height roughness parameter on the roughness standards for roughness meter verification. Those are spatially arranged and their verification is technologically difficult. Because of the difficulty, the most used method is simplified measuring of roughness (often called as 2D) in one section of measured profile. It is standardized method of surface profile verification. [5].

2 Filtration of primary profile

Before applying appropriate filter we must remove nominal shape of evaluated surface (Fig.1) resp. its tilt, which contains scanned profile (we usually use suitable mathematical method, e.g. method of least squares or polynomial of the n-th degree).

Shape of interlacing element are:

- In 2D: line, circle, arc, ellipse, parabola and others.
- In 3D: plane, cylinder, sphere, ellipsoid, paraboloid and others.

Actual filtering process is following: at first, short-wave filter λ_s is applied on scanned profile, through which are short-wave elements of profile (e.g. micro cracks, pores, scratches, corrosion and others) filtered. The primary profile is created.

Fig. 1. Removal of the nominal shape of evaluated surface

Transmission characteristics of roughness and waviness profiles are at 50 % level of cut-off wavelength. Main differences between roughness and waviness are illustrated in Fig. 2. Long-wave elements of profile are suppressed after applying of λ_c filter on primary profile. Roughness profile remains after separation of waviness element.

Fig. 2. Illustration of the profile filter transmission characteristics [6]

Fig. 3. Transmission characteristics for the roughness filter (blue) and waviness filter (red), for several cut-off values. These curves cross each other at 50 % of transmission. [7]

Phase-corrected filter is filter weighting function and has the equation of Gaussian density function with cut-off wavelength (filter transmission characteristic for long-wave profile elements). Transmission tolerance is not defined for these filters. Instead of tolerances there is stated graphical illustration of deviations of used filter in comparison to Gaussian filter (Fig. 3) in percentual values.

2 Roughness profile filtrations

The most important part of a surface roughness measuring system is filtration of scanned profile and evaluation according to given norm (attention, some roughness measuring machines work with older norms, where calculations of roughness parameters are not in conformity with newer norms. Method further described allows to extract needed parameters calculated with older norms or perform other analysis of given profiles). If a software of surface roughness measuring machine fails at this point, we get wrong roughness profile and thus incorrect informations upon which we perform our decision.

For verification of informations gained by surface roughness measuring machine MahrSurf PS1 (Fig. 4), there was performed measurement. The measuring device is equipped with diamond tip with 2 μm radius. Device was placed in such direction, that it scanned transverse direction of surface relief. As an evaluation sample, we used sample which surface was formed by planning with periodic program.

Fig. 4. MahrSurf PS1 [8]

Data significant for verification measuring are saved in text file (ASCII data). These form input data for performing the filtration. Device recorded 11 200 points for measured length. These points form scanned profile in Mahr format. The device MarSurf PS1 measures 2 lengths more, i.e. 11 200 points contain 5 measured segments and 2 segments representing sensor onset and offset (onset and offset lengths depend on device producer).

Value λ_c was set to 0.8 mm, i.e. length of one segment is $l_r = 0.8$ mm. The overall evaluated length l_n (length of 5 measured segments – without onset and offset of sensor) equals 4 mm.

Fig. 5. Scanned profile

Another important step is to calculate the number of points on the base section l_n . It is known, that number of scanned points is 11 200 and overall length of scanning is $l_t = 5.6$ mm. The proportion of the total length and the number of scanned points creates sample distance between individual points, which is equal to 0.0005 mm. The number of points in one segment is then defined as quotient of one evaluated segment (0.8 mm) with sample

distance (0.0005 mm). This means that in every segment is 1600 points. The value of onset will be contained in 0 – 1600 points range and the value of offset will be contained in 8600 – 11200 points range. By removing onset and offset range, range of 8000 points remains.

Scanned profile in Fig. 5 consists of roughness, waviness and shape profile. The next task will be to obtain, by gradual filtration, separate roughness profile for definition of basic roughness parameters. In illustration of scanned profile can be seen a slope, which is likely to be due to inaccurate machining of sample resp. misalignment of sensor arm and evaluated surface (parallelism is required).

Such profile, however, cannot be evaluated and therefore we must align it. This is one of the first steps in obtaining roughness profile. Possible skew or nominal shape supression is removed through method of least squares. Scanned profile is interlaced with a line (trend line) represented by equation $y= k.x + q$. In Excel, the operation is performed directly in rendered graph. Click Add Trendlines and Show regression equation (Fig. 6).

Fig. 6. Scanned profile interlaced with trendline

After application of the method of least squares, regression equation is obtained by which we gain point distances resp. position of every point on Y-axis relative to interlaced line. The distance values of position changes in the Y-axis from scanned profile compile primary profile (Fig. 7).

Fig. 7. Primary profile

Now, the primary profile contains only these elements: roughness and waviness. The next task will be to decompile given profile to harmonic elements using Fast Fourier Transformation (FFT) see Fig.8., and create mathematical model of filter (long-wave Gaussian filter to obtain roughness profile). The advantage of the FFT is the ability to decompile any profile to baseband of sine and cosine with final length.

First row of FFT is phase shift. The following rows are corresponding harmonic elements. The advantage of FFT, in addition to decompiling of signal to harmonic sinusoids, is ability to define the order of harmonic sinusoids necessary to determine the individual wavelengths. Value of basic wave length of first harmonic element is 4 mm, with increasing the harmonic element grows the number of periods, leading to proportional decrease of wavelength. In our case, first harmonic element has 4 mm wavelength, second has 2 mm, third has 1.3333mm....and the last one has 0.0078125mm.

Fig. 8. Roughness of the profile

After defining all harmonic element wavelengths, we can continue with creating of long-wave filter. Using functions of Excel 2007 we have defined long-wave filter as: $1-(EXP((-PI()))*(POWER(((0,4697*\$I\$1)/K2);2))))$. This way we get element of long-wave filter for every wavelength used for removing waviness from primary profile. Afterwards, using function IMPRODUCT (used because of ability to product complex numbers with absolute) allows to merge filter elements with FFT harmonic elements after application of long-wave filter. The result is filtered roughness profile in certain frequency range (Fig.7).

For transition from frequency range to signal area we used a function inverse to FFT and so we have created data for filtered roughness profile (Fig. 8). Further evaluation of results is based on Rt (maximum height of profile) and Rz (average maximum height of profile) values. Table 1. shows very little difference between values obtained by program Excel and values obtained by device MahrSurf PS1.

Table 1. Rt and Rz values

Monitored values of surface roughness	Evaluated by MS EXCEL [μm]	Evaluated by device MahrSurf PS1 [μm]	Difference [μm]
Rt	7.48	7.54	-0.06
Rz	7.28	7.25	0.03

3 Summary

Setting of cut-off parameter and suppression of nominal shape of evaluated surface play important role in filtration of scanned profile. These settings have a decisive influence on the correct specification of surface evaluation and directly affect process of roughness profile filtration and thus its parameters. E.g. cut-off parameter sets the amplitude and phase shift, with which signal passes through evaluated profile. The results of the article can be used as a tool for verifying the accuracy of evaluation of roughness meter results.

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