THE INFLUENCE OF SPIRAL SAMPLING ON SURFACE TOPOGRAPHY PARAMETERS – SIMULATION ANALYSIS**

In this paper, the author presents the result of simulating for surface measurement based on spiral grid using Matlab software. Most of the topography surface measurement instruments work using the parallel profiles to obtain surface texture. The novel stylus based measurement instrument that use the spiral sampling is the answer of the question of faster surface topography measurements method. The presented results of comparing three-dimensional surface parameters obtaining from simulating measurement surface based on a rectangular grid and based on a spiral grid is the first step to determine and characterize the influence of spiral sampling on surface topography parameters. It can make further possible to implement this method into industry as fast surface topography measurement method based on stylus profilometer.

Key words: spiral sampling, surface topography measurement

1. INTRODUCTION

First machine for the surface measurement was introduced in 1929 by Schmalz in Germany, in 1933 Abbott’s profilometer was conceived in USA [5]. Stylus profilometers based on this construction make possible characterize of the Surface just in two dimensions – surface is represented by a single profile. In recent years, it became clear that surface topography is the best way to proper characterisation of solid’s micro-geometry. Most of the topography surface measurement instruments work using the parallel profiles to obtain surface texture. Unfortunately, stereometric topography measurement is very much time consumption.

Division of Metrology and Measuring Systems of Poznan University have elaborated the novel stylus based measurement instrument [1, 2, 6, 7] that use the spiral sampling, as an answer to find faster surface topography measurements method – Fig. 1 (this project was sponsored by Polish Committee
for Scientific Research). In this way, stereo metric measurements surface is represented as a set of coordinates of grid points, basing on a grid constructed of the spiral of Archimedes. Currently, in all of the stylus profilometers, sampling is based upon a rectangular grid, which is easy to measurement execute and surface topography analyse. All of three-dimensional surface parameters are based on a rectangular grid, it is the cause for interpolation spiral grid to rectangular grid. Among other things this procedure must induce some difference between surface parameters obtained by spiral and rectangular grid.

Fig. 1. Measurement instrument that use the spiral sampling
Rys. 1. Profilometr wykorzystujący siatkę spiralną

The authors are focused to find the relationship between different spiral sampling and obtaining surface parameters. It is difficult to repeat surface measurement on exactly the same area, to eliminate this problem, we created application program, which simulates surface measurement based on spiral grid using Matlab software. Despite the fact, that spiral grid method is faster as the method based on rectangular grid, the surface measurement is very time consumption. It was the next reason of interesting the simulating way to preliminary characterise the raising problem. Of course, after that all result must be experimental confirmed.

2. SIMULATION PROCEDURE

It was use four kind of surface: glass plate after sandblasting and the surface machined by grinding, electrolytic machining and honing (Fig. 2). The data points for surface topography were collected by means of a Pherten stylus profilometer and surface topography was measured using rectangular grid 0.4 × 0.4 mm (matrix: 268 × 268 points). On this surfaces different spiral grids were
spread. We change the distance between spiral roll from 25 μm to 1.8 μm (16 to 222 spiral roll). For each spiral the parameters were calculated and saved into Matlab’s table. Below the simulation algorithm is introduced, it consists of six point. All of this was developed using Matlab’s programming language [9].

Fig. 2. Four kind of surface: glass plate after sandblasting and the surface machined by grinding, electrolytic machining and honing

Rys. 2. Cztery rodzaje powierzchni: płytka szklana po piaskowaniu oraz powierzchnie po szlifowaniu, obróbce elektroerozyjnej i gladzeniu

I – The first step:
Creating the spiral grid in polar coordinates. This is given by formula 1.

φ = r ⋅ ϕ,  \quad (1)

where: \( r \) – radius (max \( r = 0.2 \)),
\( ϕ \) – angle (max \( ϕ = π \times \) max number of spiral rolls).

So created spiral grid was transformed from polar coordinates to Cartesian by formula 2 and 3. The expression ‘(0.2)’ is added in order to transform the origin of coordinate to point (0,0) – in polar coordinates the value of radius changes in range ± 0.2 mm.

\[
\begin{align*}
x &= [r \cdot \cos(\phi)] + (0.2), \\
y &= [r \cdot \sin(\phi)] + (0.2).
\end{align*}
\]
II – The second step:
The spiral grid (in Cartesian coordinates system) is spread on the surfaces. Each surface (lapping, grinding, abrasive blasting, honing) is mapped at the same position and the same size.

III – The third step:
Interpolation spiral grid to rectangular grid – it was used Matlab function of two dimensional triangle-based data interpolation – based on a Delaunay triangulation of the data. Matlab has alternative interpolation method: linear – triangle-based linear interpolation, nearest – nearest neighbours interpolation, cubic – triangle-based cubic interpolation. In simulation algorithm were used cubic method.

IV – The fourth step:
After interpolation the spiral grid to rectangular grid, the surface topography on area that is approximate to circle which diameter is 0.4 mm, was obtained. For further analyzing it is necessary to cut some part of area of surface to get the surface topography on rectangular area. We set the cutting area as square which circumscribed circle has 0.4 mm diameter. So, the new area of surface is square:

\[ a = \frac{0.4}{\sqrt{2}} = 0.282 \text{ mm} \]

V – The fifth step:
Calculate three-dimensional surface parameters. It was used parameters that characterise three major aspects of surface topography [3, 4]: amplitude property, spatial property, hybrid property (combinations of amplitude and spacing). In this paper, the authors present just some selected parameters.

As amplitude parameters representative are used:
\[ S_q \] – root-mean-square deviation of surface, it is a dispersion parameter defined as the root of the mean square value of the surface departures within the sampling area. It is given by digital formula (4):

\[ S_q = \sqrt{\frac{1}{MN} \sum_{j=1}^{N} \sum_{i=1}^{M} (h(i,j))^2} \] 

This parameter has a very insensitive meaning in statistics (standard deviation) and is also a very general and widely used parameter. However due to the squaring operation, is more sensitive to extreme data values than parameter \( S_a \).

The next amplitude parameters representative are used:
\[ S_{ku} \] – kurtosis of surface height distribution, it is a measure of the peaked-ness or sharpness of the surface height distribution. It is given by digital formula (5):
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\[ S_{bs} = \frac{1}{MNS_4^4} \sum_{j=1}^{N} \sum_{i=1}^{M} \eta^4(i, j). \]  

(5)

This parameter characterises the spread of the height distribution.

As spatial parameters the following representatives are used:

- \( S_{ds} \) – density of summits of the surface, it is number of summits of a unit sampling area. It is given by formula (6):

\[ S_{ds} = \frac{\text{Number of summits}}{(M-1) \cdot (N-1) \cdot \Delta x \cdot \Delta y}. \]  

(6)

There is a problem in definition of the summits. In order to have an objective definition of a surface summit, research used definition that is based on the geographical approach to classify the features of the earth relief as a family of summits, crests etc. This analysis algorithm supposes that every point on a surface can be identified and classified by analysis of its neighbors. In created application program to simulate surface measurement based on spiral grid the authors used the 24 neighbors summit identification, that was presented by Zahouani and others [9].

As hybrid parameters the following representatives are used:

- \( S_{\Delta q} \) – root-mean-square slope of the surface, it is defined as the root mean square value of the surface slope within the sampling area. It is given by digital formula (7):

\[ S_{\Delta q} = \left( \frac{1}{(M-1)(N-1)} \sum_{i=1}^{N} \sum_{j=1}^{M} \left( \frac{\eta(x_j, y_j) - \eta(x_{j-1}, y_j)}{\Delta x} \right)^2 + \left( \frac{\eta(x_j, y_j) - \eta(x_j, y_{j+1})}{\Delta y} \right)^2 \right)^{\frac{1}{2}}. \]  

(7)

All of this parameters were calculated two times. The first time for the input surface, and second time for the simulate surface (spiral grid).

VI – The sixth step:

Store procedure – all of obtained surface parameters were stored into Matlab’s table to further data analyzing and visualization.

VII – The seventh step:

All six steps were repeated for range from 16 to 222 spiral roll.

In Fig. 3 is shown: creating the spiral grid in polar coordinates; the spiral grid (in Cartesian coordinates system) is spread on the surfaces and interpolation spiral grid to rectangular grid.
Fig. 3. Visualization of three first steps of simulation algorithm
Rys. 3. Wizualizacja pierwszych trzech kroków algorytmu symulacyjnego
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3. RESULTS AND DISCUSSION

Basing on the result of the test comparison analysis of surface parameters from rectangular and spiral sampling was performed. To demonstrate in a clear way the issue, authors have created chart, where correlation is shown between surface parameters from rectangular and spiral sampling and number of spiral rolls. So, on axis of ordinates there is the expression: \((S_{q*}/S_q) \times 100\%\). In this expression \(S_{q*}\) is the parameter calculated for the input surface, and \(S_q\) for the simulate surface (spiral grid). On axis of abscissas there is number of spiral rolls. For each parameter the simulating procedure was taken two times. The first time for 16 to 222 spiral rolls and the second time for 65 to 222 spiral rolls (the step of change was smaller).

The amplitude parameters

\(S_q\) – root-mean-square deviation of surface Fig. 4; this amplitude parameter stabilize after about 100 spiral rolls (distance between spiral roll – 4 \(\mu\)m) for grinding and honing surfaces. The abrasive blasting change in all range but after about 60 spiral rolls (distance – 6.6 \(\mu\)m) its trend became probably linear. The most visible difference is for lapping surface, its trend grown and after 160 spiral rolls (distance – 2.4 \(\mu\)m) grown less.

For next amplitude parameters \(S_{ku}\) (kurtosis of surface height distribution) the result of simulation are similar like amplitude parameter \(S_q\) – Fig. 5.
The spatial parameter

$S_{ds}$ – density of summits of the surface Fig. 6; for this spatial parameter the difference between the parameter calculated for the input surface and for the simulate surface (spiral grid) has constant probably linear trend. It is remarkable that this trend is growing for all spiral rolls range and is similar for all surfaces.

The hybrid parameters

$S_{\Delta q}$ – root–mean–square slope of the surface; this hybrid parameter is very susceptible to number of spiral rolls (on the beginning quotient of $S_q^*$ and $S_q$ has
value of 200÷400%, but it stabilize after about 140 spiral rolls (distance between spiral roll – 2.8 μm). For grinding surface $S_{Δq}$ it stabilize faster as for others surfaces. It is interesting that for this hybrid parameter the trend is growing less from the beginning.

![Fig. 7. The result of the test – hybrid parameter $S_{Δq}$. Simulating procedure was taken two times: for 16 to 222 and for 65 to 222 spiral rolls (the step of change was smaller)](image)

**4. CONCLUSION**

Basing on this result of the simulating test some number of conclusions can be underlined:

– for each analyzing surfaces, it can be possible to observe the stabilize point or some trends (probably linear)

– the parameters from spiral grids have difference of values, but sometimes they become constant

– it is further possible to make the spiral measurement accurate by using table corrections for topography parameters (by define the difference between parameters obtained from rectangular grid and spiral grid, or by define the shift principle)

– the table corrections must be produced separately for each kind of surfaces

– in further research it is necessary to pay more attention to spatial parameters

The next step to understand and characterize the difference between the three-dimensional surfaces parameter, which are based on a rectangular grid and spiral grid, will be confirmation of observed trends by repeating simulation procedure for more as one surfaces of particular kind of machining. After that, all result must be experimental confirm.
If difference of sampling based on spiral for surface topography will be good determine, it make possible to take this method into industry and widen the topography assessment by means of stylus profilometers.

REFERENCES


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WPŁYW PRÓBKOWANIA SPIRALNEGO NA WYBRANE PARAMETRY PRZESTRZENNE – ANALIZA SYMULACYJNA

S t r e s z c z e n i e

W artykule autor zaprezentował rezultaty symulacji pomiaru topografii powierzchni z użyciem próbkowania spiralnego. Większość przyrządów do pomiaru topografii powierzchni oparta jest na pomiarze równoległych profili. Nowatorski profilometr wykorzystujący próbkowanie spiralne jest odpowiednikiem czasochłonnym pomiaru stereometrii powierzchni. Prezentowane rezultaty porównania parametrów przestrzennych uzyskanych z pomiaru topografii z wykorzystaniem siatki prostokątnej i spiralnej są pierwszym krokiem do określenia i scharakteryzowania wpływu próbkowania spiralnego na parametry 3D. W przyszłości pomoże to we wprowadzeniu tej nowej metody do przemysłu jako metody szybkiego pomiaru topografii powierzchni przyrządem stykowym.

Słowa kluczowe: próbkowanie spiralne, pomiary topografii powierzchni