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TOPOGRAPHY MEASUREMENTS USING SPIRAL SAMPLING

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ABSTRACT: In the paper surface topography measurements were presented. Collecting data using rectangular grid is rather slow in tactile profilometry. To avoid this problem sampling on a spiral was investigated. For this reason it is possible to use a conventional profilometer or a form tester, which offers much more versatile solutions, what was presented in the paper. Differences between results obtained with rectangular grid and spiral sampling were presented. Some problems emerging while sampling on a spiral were also shown.
KEYWORDS: topography, surface, spiral

INTRODUCTION

A traditional 2D surface profile analysis is - for some years now - still more often replaced with 3D topographical assessment [1]. It was reported by a many authors, including both - research problems and practical applications for various kinds of surfaces. Among many different methods of surface characterization stylus profilometry seems to be the most commonly used one, especially for engineering surfaces. It is based on multiprofile data tracking, giving as a result a set of points in three dimensions. There was quite a number of papers presenting surface images obtaining (both axonometric view and topographical map) and amplitude topography parameters, as well as full three - dimensional parametric analysis [2,3,4].

The aim of the project was to elaborate fast sampling methods enabling for a quick surface topography measurements by means of stylus profilometers. These devices are the most commonly used ones for assessment of surface asperities. Thus the surface is represented as a set of coordinates of grid points, basing on a grid constructed in a certain way. Most of the instruments work on a parallel multiprofile base, though some trials with concentric profiles were conducted as well. It is than sampling on a rectangular grid, and its benefit is that of simplicity in measurement execution. However, on the other hand its demerit is a large time of measurement resulting from a necessity of collecting a great number of measuring data. In order to obtain a reliable surface representation, the tracing speed must be low enough. If it is not than the stylus may lose a contact with the surface being inspected and a flight may occur [5]. A number of papers were devoted to this phenomenon [6,7] as its influence on the results of topography measurements is significant. If and when the flight occurs, depends not only on drive kinematic system but also on the stylus and surface geometry. The errors caused by the stylus not being in contact with the surface are the biggest obstacle in enlarging the scanning speed in multiprofile topography analysis. Thus still more and more often are the efforts to modify dynamics of the drive system in order to enable a fast scanning of the assessed surface.

One of the possibilities of reducing the time consumption in multiprofile topography measurement is to apply a non-rectangular grid [8,9]. The most popular grids are triangle one and hexagonal one, and especially the latter gives a nice time reduction as well as a smaller database. However, the benefits are not very significant (time reduction up to 15 %) while a sampling system has to be more complicated.

For this reason a spiral sampling was proposed as a potential solution of the problem. The solution is a novelty and does not exist in references neither in practical applications nor even in theoretical considerations. It should give a several times faster measurement, maintaining a good surface representation. For the sake of analysis it was necessary to create a mathematical base, an algorithm of data collection, transmission and converting as well as a construction of a device for a precise sample rotation and software for control and parameters calculation. This method was elaborated for nominally flat elements. It is based on a sampling that is a combination of two movements in the same time: a linear one and rotational one, giving a spiral as a result.

Spiral sampling is for some time now used as one of the strategies in NMR [10,11]. Also authors of [12] called this technique a spiral sampling, acknowledging it as a one of the fast method of image capturing. In work [13] authors pointed out its efficiency and continuous wave signal. Similarly like *during spiral sampling in surface metrology, also in NMR points on the spiral are translated to nodes of rectangular grid. There are some further research works on this topic still going on.*

SPIRAL SAMPLING

Let us start with a short description of a spiral in general. Spirals (not fully properly) are two dimensional curves for which in polar coordinates their leading radius depends on an angle of rotation (increasingly or decreasingly). In case of Archimedean spiral of radius is proportional to the angle. This means, that – for example - if a body will move with constant velocity starting from the center of a record rotating on a record player to an edge, it will certainly follow an Archimedean spiral. Apart from this spiral few other are also known: logarithmic spiral – where radius depends on angle exponentially and Fermatian spiral (parabolic), where radius is equal to the square root of angle. Mathematically, a spiral is known from ages, and it was used e.g. to solve one of the famous Deli problems, a square with an area equal to area of a circle.

An Archimedean spiral is a set of points on a plane determined by a point moving with a uniform motion along the half-line rotating around its origin with a constant angular velocity (Figure 1).

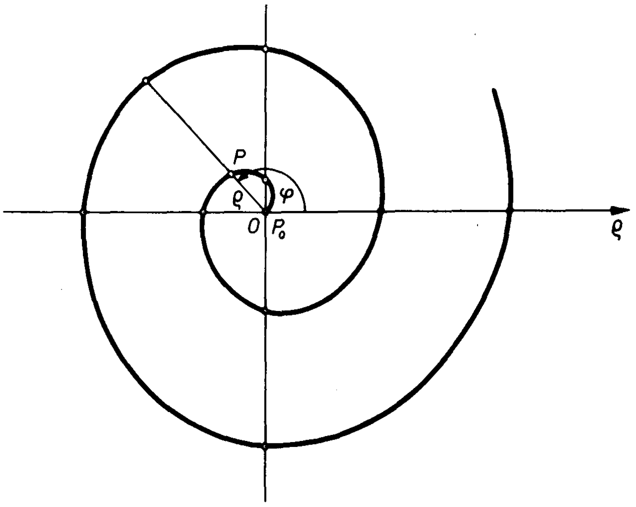

Figure 1 – The shape of Archimedean spiral

Assuming that initially a point P_0 moving along a half-line is in the pole, and the half-line is on the pole axis. Let the speed of the moving point be equal to c (expressed in mm/s or mm/min). A path ρ expressed in length units (e.g. mm or μm) covered by the point during a period of time denoted by t (in seconds or minutes) is equal to:

$$\rho = ct \tag{1}$$

Let the angular velocity of the rotating half-line be equal to ω. The angular path covered by the half-line during the same period of time t is: $\varphi = \omega t$. Thus, eliminating t one can obtain a polar equation of Archimedean spiral in a form of:

$$\rho = \frac{c}{\omega}\varphi \tag{2}$$

or:

$$\rho = a\,\varphi \tag{3}$$

where: $a = \dfrac{c}{\omega}$, $a \in \Re^{+}$, $\varphi \in \Re_0^{+}$

The Archimedean spiral has got some important properties [14]. The most important for spiral sampling is the one stating that every half-line that has a beginning in the pole of spiral crosses this spiral in certain points. Distances between this points form an arithmetic sequence.

Sampling on that line gives in a topographical analysis of a surface as primary benefit a much less time necessary to cover a certain area comparing with a rectangular grid. Furthermore, with a rectangular grid it is necessary to withdraw a measuring pick-up to a starting point after every single profile. Although this motion is normally much faster than a measuring run, from a point of view of efficiency it is only a waste of time. There are only a few devices that can collect data in both directions, but than a problem of hysteresis appears. After every profile it is also necessary to move the whole setup in a perpendicular direction at a certain distance, to collect the next profile.

This motion, though a very small one is relatively slow, and has to be repeated normally more than a 100 times during the whole measurement. With every single profile - from dynamic or filtration point of view - it is also necessary to have one or two cut-offs more than these taken into further evaluations. The first one takes place at the beginning of every trace and the second (appearing in some devices) at the end of a profile. With spiral sampling there is only one cut-off at the beginning of the whole spiral and one (depending on the device) at the end because the pick-up is all the time in the motion. Only thanks to eliminating these segments the time consumption can be up to 30% smaller, comparing with a rectangular grid.

One of the problems appearing in spiral searching is the fact, that during a measurement the distance between a pick-up and the geometrical center of spiral grows constantly. This leads to a continuous growth of the tracking speed (Figure 2).

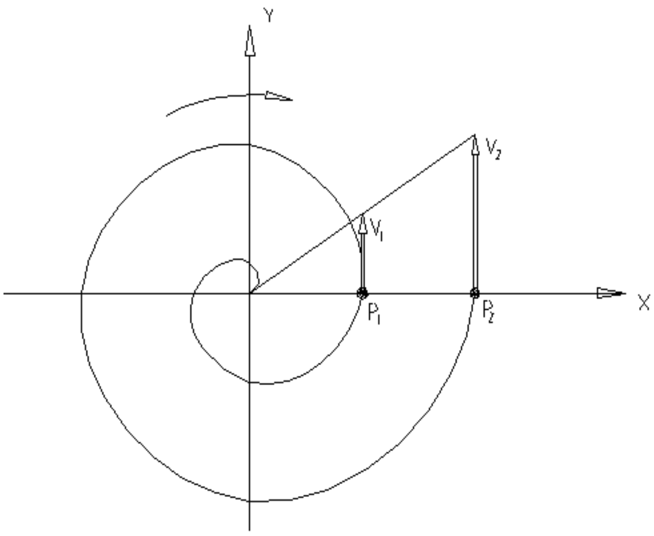

Figure 2 – Growth of the tracking speed during measurement in spiral sampling

If the whole measurement is to be performed at a constant angular speed, it must be chosen in such a way that a tracking speed at the end of a measurement will not be too big. Otherwise this may lead to destruction of a pick-up or at least distortion of a measuring signal due to a flight. Thus a measurement with a constant angular speed becomes quite inconvenient, as tracking is too slow at the beginning and too fast at the end.

During the initial phase of a measurement the table could rotate much faster and it wouldn't negatively influence the measuring conditions. Furthermore the time of measurement could be much shorter if the tracking speed was close to the certain optimal speed during the whole measurement.

Thus a concept of angular speed corrections was elaborated. The plot on a Figure 3 shows a measuring time change (regarding to 100 % with only one speed and no corrections) depending on the number of corrections. It is clearly visible that 3 to 5 changes of the angular speed can save about 40% of a measuring time. When a number of corrections reaches infinity the time save will reach as much as 50%. In this case the angular speed would have to be corrected continuously. In the elaborated prototype device the whole procedure with changing rotational speed is pretty straightforward to implement for control unit.

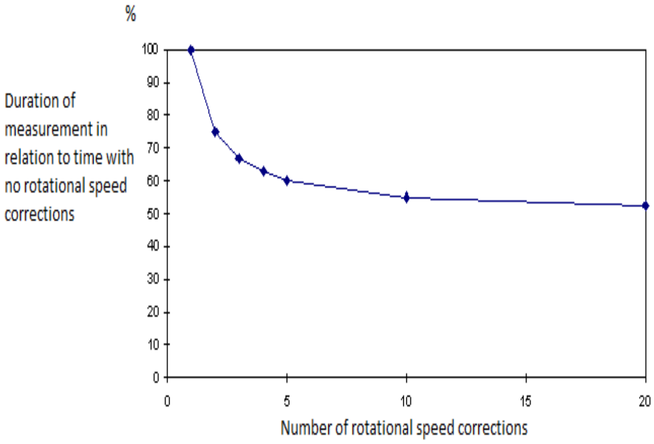

Figure 3 – Effect of corrections in angular speed on the total time of measurement

Another problem appearing when spiral sampling is applied is a special adjustment. For a proper measurement it is necessary to align the center of table rotation with the pole of Archimedean spiral. If the two points are not aligned, the pole of spiral is unknown what makes the calculation of points coordinates impossible. For this sake a special construction of a master can be used. Thus before the measurement takes place the whole setup is adjusted and the two points are aligned. In the described device this procedure is fast and done in automatic mode.

Similarly as for rectangular grid sampling conditions play an important role for measurement fidelity. For rectangular grid we have two sampling distances - in x and in y (Δx and Δy respectively), for spiral sampling very important is distance between convolutions k. An example of spirals with different convolutions was shown on figure 4 [15].

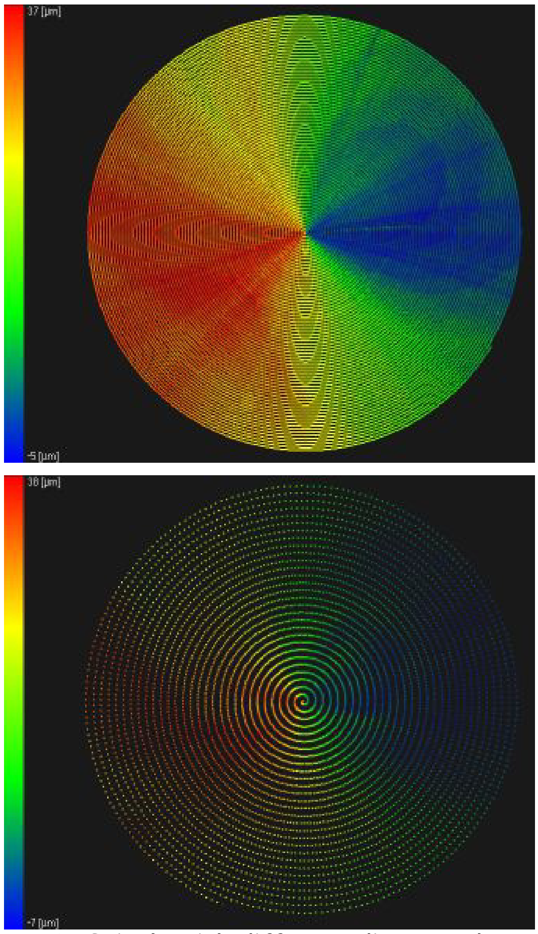

Figure 4 – Spirals with different distances between convolutions

MEASUREMENT SETUP

First trials with an application of spiral in surface metrology were mentioned by Mollenhauer [16], and a device enabling for that measurements was described by Nelle in his Ph.D. thesis [17]. He used two connected inductive gauges and a rotary table what made it possible to obtain profiles even as long as 30 meters. But the whole system was very complex and remained solely in a phase of prototype and initial tests, despite the fact that big number of points made it possible to get very stable results.

In the system proposed in this paper data points for topography analysis were collected by means of a stylus profilometer. The device was equipped with traverse drive on which rotary table was mounted. The output data were fed into a computer used for calculations. A scheme of the whole setup was shown on figure 5 while a picture of the device on figure 6.

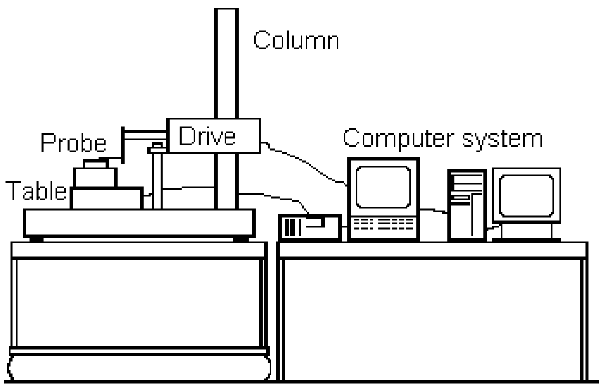

Figure 5 – A scheme of measuring setup

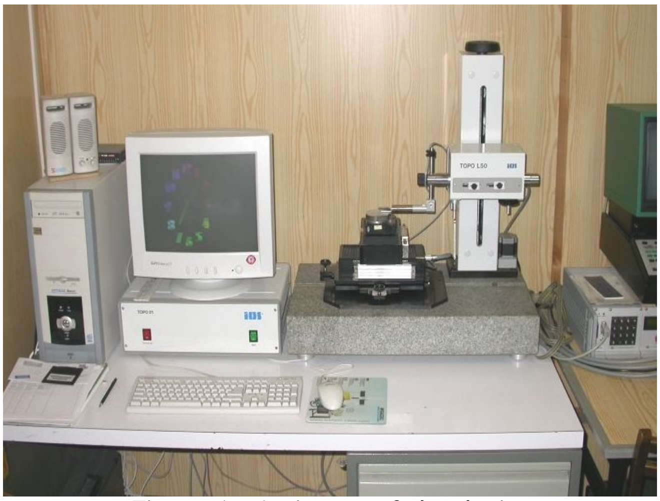

Figure 6 – A picture of the device

Measuring process is controlled by special software where all the conditions are programmed. There all the setup parameters for profilometer are defined: number of cut offs, number of measurement points etc. The program includes also commands sent to profilometer and to controller of linear and rotary drives. Collected data are transformed by software into coordinates, after calculating spiral radius in every point. Sampling points from spiral were transformed into net points of the rectangular grid using polynominal interpolation. Thanks to this, the same software was used for both grids to compute reference plane, parameter values and to present graphical image of the surface. It is also possible to extract a single profile from spiral grid in the direction corresponding to the one from rectangular grid. A comparison of these profiles – ensuring proper relocation – enables to observe similarities and differences in profiles obtained from both grids. From the sampled data points the following parameters were computed: Sq, St, Ssk, Sku, SΔq.

Comparison measurements were taken for both grids on surfaces after typical machining to get information regarding fidelity of representation [18]. They were performed with similar sampling density for both grids – about 84000 points per mm^2. Bearing in mind that square is included in spiral, the number of points from spiral sampling was a little bigger.

The measurements were taken on three flat samples machined by EDM, milling and grinding. Surface topography was measured on each of them using both: rectangular grid and spiral sampling. Creating a spiral it was assumed that the rectangular grid is included in the circle with a radius equal to the greatest radius of spiral.

RESULTS

Measurements were taken on different surfaces, respectively with determined, random and mixed lay. For determined structure a milled surface was chosen, for random an EDM one, while for mixed a ground plane. Sampling was made in two ways: either the biggest radius of spiral was inscribed in rectangular grid (Figure 7) or vice versa - a rectangular grid was inscribed in the biggest radius of spiral. Thus two different rectangular grids were created.

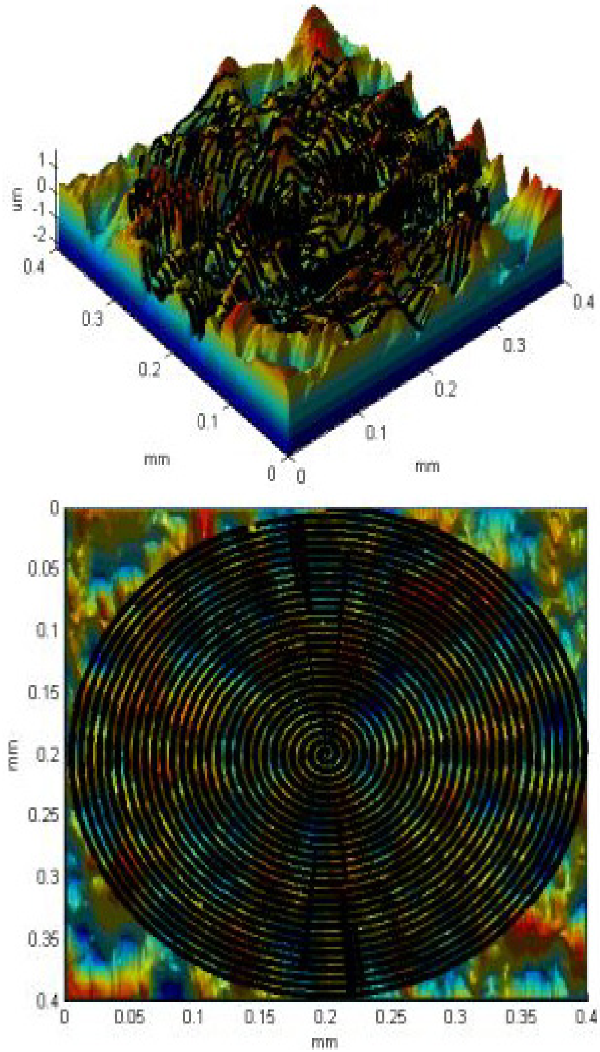

Figure 7 – A spiral inscribed in rectangular grid

As it turned out the values of surface topography parameters for both grids were pretty close to each other. The biggest differences were observed for milled surface while the smallest ones took place for surface obtained by grinding. For this surfaces not only height parameters were very similar (from 3,2% for St to 9,8% for Sq), but also the ones connected with shape of irregularities, e.g. SΔq (7,5%) which in other cases tend to differ between grids. For EDM surface the same differences were bigger: 9 – 11% for height parameters 40% for wavelength and over 80% for slope. The biggest differences in height parameters took place for milled surface (15 to 50%), though wavelength is quite similar. There were no significant differences between skewness and kurtosis for all inspected surfaces, what means that spiral grid managed to maintain and represent surface characters very well.

Steep irregular slopes and pitches are the features of EDM surface. This can be an effect of different approach to slope representation for both grids (difference in direction of movement through slope). The results of slope measurements for other surfaces were much closer as in these situations asperities are much more regular. In most cases the differences between height parameters were rather small. For spiral grid Sq and St values were greater what may be caused by different nominal surface orientation.

A comparison of profiles obtained in the same direction from both grids showed their compatibility as far as character of asperities is concerned.

In most cases results of parameters measured by means of spiral sampling were a little smaller than for rectangular grid. This is most probably due to the fact, that spiral has a bit more averaging effect for high peaks, as with this strategy a pick up tends more to slide down on them than with straight lines constructing rectangular grid. For determined or mixed surface direction of climbing peaks using rectangular grid is perpendicular to general lay, whereas for spiral sampling it is different. For the same reason in spiral sampling pick up a little more traverses slopes resulting in smaller values of SΔq. Another effect of different way of attacking slopes is a certain flattening of peaks observed in spiral sampling.

A cause of possible difference is also converting points from spiral to rectangular grid for calculations. This is due to interpolation procedure applied after measurement. Different algorithms cause - which seems to be understandable - different results, and the bigger is distance between convolutions of a spiral, the bigger are these differences.

Yet, all these differences - using proper sampling density and interpolation algorithm - can be minimized to a level smaller than 10 - 15% (depending on type of machining and magnitude of asperities), what is not a significant value bearing in mind, that traditional measurements in various areas on the same surface can give much higher discrepancies. A topographical image obtained by means of spiral sampling for a milled surface was shown on figure 8.

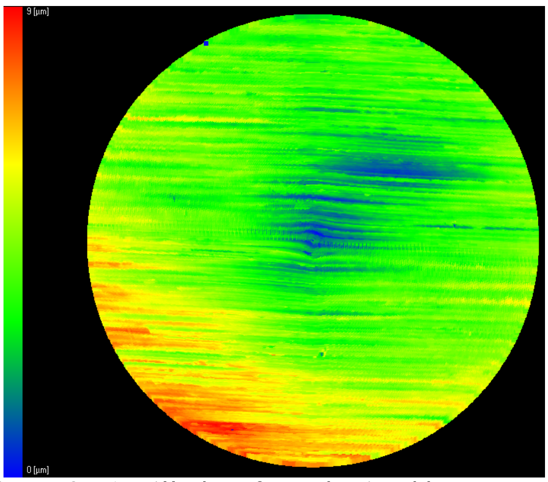

Figure 8 - A milled surface obtained by means of spiral sampling

On this figure one more problem appearing while using spiral sampling is visible. It is a small area of instability around a starting point. There, linear velocity of pick up is relatively small and main force component comes from rotation. Assuming, that at a starting point a pick up tip is on the slope (probability of that is close to 1) all backlashes and imperfections in mechanics may cause big interferences.

CONCLUSIONS

Basing on the above mentioned research a number of conclusions can be drawn:

- *Application of spiral sampling for surface topography measurements can be a good solution to a time consuming measuring process.*
- *A measuring method with all the algorithms and construction of a stand was worked out.*
- *With a spiral sampling the whole measuring process is fluent and is performed with no pauses.*
- *The considerations show a possibility of a further time reduction by means of angular speed corrections.*
- *Before the measurement it is necessary to aligned center of rotation with the spiral pole, using a special master.*
- *Spiral sampling is very interesting from theoretical considerations and proved to be successful in practical applications.*

REFERENCES

[1.] Mathia T. G., Pawlus P., Wieczorowski M., Recent trends in surface metrology, Wear, 2011, 271, 3-4, 494-508

[2.] Dong P. W., Sullivan P.J., Stout K.J.: The significance of surface features in characterising 2-D and 3-D surface topography, Engineered Surfaces, ASME, PED-62, 1992, pp. 1-15.

[3.] Stout K. J. et al.: The Development of Methods for the Characterisation of Roughness in Three Dimensions, published on behalf of the Commission of the European Communities, Brussels, 1993.

[4.] Wieczorowski M., Cellary A., Chajda J.: Parameters for three dimensional surface texture character analysis. Proceedings of the Third International Symposium on Measurement Technology and Intelligent Instruments ISMTII'96. Hayama, Japan 1996, pp. 209-216.

[5.] Damir M.: Error in measurement due to stylus kinematics, Wear, 26, 1973, pp. 219-227.

[6.] McCool J. I.: Assessing the effect of stylus tip radius and flight on surface topography measurements, Transactions of the ASME: Journal of Tribology, 106, 1984, pp. 202-210.

[7.] Song J. F., Vorburger T.V.: Stylus flight in surface profiling. Manufacturing Science and Engineering, ASME, PED-68-1, 1994, pp. 161-174.

[8.] Cellary A., Wieczorowski M.: Sampling grids in topography measurements, Proceedings of a National Metrology Congress, Gdansk, 1998, vol. 4, pp. 71-76. (in Polish).

[9.] Li M., Philips M. J., Whitehouse D. J.: Extension of two-dimensional sampling theory, Journal of Physics A: Mathematical and General, 22, 1989, pp. 5053-5063.

[10.] Hennig J.: K-space sampling strategies, European Radiology, 1999, 9, 1020-1031.

[11.] Yudilevich E., Stark H.: Spiral sampling: theory and an application to magnetic resonance imaging, Journal Optical Society of America A, 1988, 5, 542-553.

[12.] Irarrazabal P., Nishimura D. G.: Fast three dimensional magnetic resonance imaging, Magnetic Resonance in Medicine, 1995, 33, 656-662.
[13.] Ahn C. B. et al., High-speed spiral-scan echo planar NMR imaging - part I, IEEE Transactions on Medical Imaging, 1986, MI-5, 2-7.
[14.] Wieczorowski M., Theoretical assumptions of spiral sampling application in surface topography measurement, Archives of Machine Technology and Automation, 2001, 21, 121-129.
[15.] Majchrowski R., Wieczorowski M. i in., The high-speed measurement of surface topography - spiral sampling, in: Legutko S., Development of mechanical engineering as a tool for enterprise logistics progress, Poznan University of Technology, 2006, 297-304.
[16.] Mollenhauer C.: Surface topology measurement techniques, Proceedings of International Conference on Surface Technology, Pittsburgh, 1973, 173-186.
[17.] Nelle G., Ein Verfahren zur raumlichen Ermittlung geometrischer Oberflachenmessgroessen, PhD thesis, TU Braunschweig, 1970.
[18.] Wieczorowski M.: Spiral sampling as a fast way of data acquisition in surface topography, International Journal of Machine Tools and Manufacture, 2001, 41, 2017-2022.

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