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Detecting systematic and random component of surface roughness signal

Abstract. The solution of the problem of separating the initial one-dimensional signal into two components – systematic and random – has an extremely wide practical application not only in the theory of information and communication (and related disciplines), but also in mechanical engineering disciplines. For example, mechanical engineering technology being a science discipline includes the teaching about the surface quality of the machined parts and researching the surface roughness after machining these parts by cutting and grinding. The paper shows that the theoretical and actual values of roughness parameters differ significantly (up to 20 times) due to the influence of a random component that is present in the roughness signal together with a systematic component. It is necessary to identify the share of each of these components in the specified surface quality parameters in accordance with the method proposed in the paper. This method allows detecting the systematic and random components of the signal and is based on the analysis of the signal autocorrelation function. Practical examples of this analysis are considered in detail for milled surface profilogram obtained experimentally. Both milling, which creates irregularities on the machined surface, and measurement of these irregularities are performed on modern CNC equipment: machining center 500V/5 and computer measuring station T8000, respectively. The developed and shown by examples signal separation technique is also applicable in other fields of science, technology and manufacturing. For example, when determining the signal to noise ratio in the theory of information and communication, in the field of telecommunications and telemetry, radio engineering, etc.

Keywords: roughness signal; systematic component; random component; surface roughness; surface waviness; profile shape deviation; correlation function

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1. Introduction

Experimental data processing is one of the most important directions in different fields of science, engineering and production because it influences on the validity of these data and, as a result, on the economic performance of enterprises. There are many problems in this direction, including “separating” (or “dividing”) of an initial signal into two components: a systematic component and a random one. The solution to this problem has an extremely wide practical application not only in the theory of information and communication (and related disciplines), but also in purely production areas, for example, in mechanical engineering technology, which being a science includes a combination of the following teachings: on machining accuracy, on quality surface and surface layer, on the performance and efficiency of technological processes. To one degree or another, all of these teachings are based on appropriate information support. It is known that the category of accuracy is a philosophical concept. Quantitatively, accuracy is characterized by so-called errors (mistakes), which are usually divided into two large groups, namely, systematic errors and random ones.

Systematic errors, as a rule, can be predicted and taken into account by the corresponding settings of technological equipment. The same cannot be said about random errors, which are unpredictable and, therefore, the most dangerous in terms of manufacturing defects and associated additional costs, since they lead to both an increase in the cost of production and a decrease in its competitiveness.

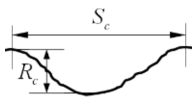
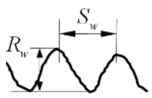
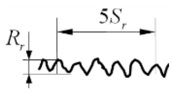
All this makes the task of detecting (identifying) a random component in the overall (total) information signal extremely relevant regardless of the field of science, engineering, and production.

2. Literature Review

The assignable law of the kinematic movement of the tool relative to the workpiece being machined guesses that the result will be the ideal shape of the machine part with traces of the cutting tool which can be determined using kinematic and geometric relationships [1]. For example, when turning a workpiece in its longitudinal section there should be a series of arcs which correspond to the cutter tip profile shape. The distance between adjacent repeating arcs should be equal to the feed of the cutter per workpiece revolution. In this case, such predefined irregularities would constitute a “theoretical roughness”. However, the presence of dynamic processes on the machine violates this predetermination and the real surface profile does not correspond to the ideal theoretical form built on the basis of geometric and kinematic calculations. For example, the irregularities height in the finish turning exceeds the theoretical height by 2 ... 5 times, and in the fine turning – by 20 times. In this regard, it seems appropriate to divide all factors acting on the surface texture during cutting into two categories: systematic (assignable) and random (unpredictable in advance) [1-2].

The conventional method to divide primary surface profile into the different components is presented in the form of criteria relations shown in Table 1 [3]. However, this method is among the visual ones and, therefore, is largely subjective, i.e. depends on the expert’s experience.

Table 1. Surface quality parameters segregation

Contour	Waviness	Roughness
 $\frac{S_c}{R_c} < 50$	 $\frac{S_w}{R_w} = 50...1000$	 $\frac{S_r}{R_r} < 50$

It was found in [4-7] that during machining with a cutting blade tool, the roughness of the machined surfaces can be divided into two categories: periodic and aperiodic (Fig. 1).

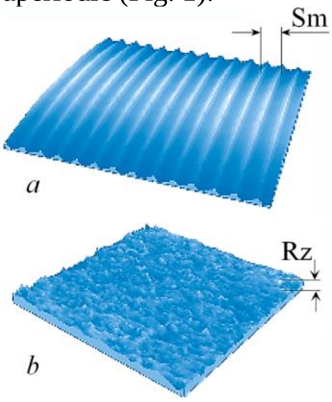


Fig. 1. Periodic (*a*) and aperiodic (*b*) profile of a machined surface [4]:
Sm and Rz are the step and height parameters of the profile, respectively

One of the reasons for the formation of periodic, i.e. a systematic component of irregularities, is the trace of the cutting blade on the machined surface. This trace can be found on the basis of “geometric considerations” and distinguished the concepts of “transverse roughness” (a roughness in the feed direction) and “longitudinal roughness” (in the direction of cutting speed vector) [8]. It is also noted there that “the geometric calculation does not take into account the plastic deformation influence, as well as a number of other factors, and in most cases leads to results that diverge greatly from experimental data”. In this case, the actual irregularities height is higher than the calculated height. However, the general nature of the dependence of the height on the feed for the actual and calculated irregularities is the same: with increasing the feed, the irregularities height increases rapidly [8].

When milling, it was obtained a formula for the “trochoidal” trajectory (in the trochoidal milling), which is a consequence of the relative working movement of the mill adjacent teeth cutting edges [9]. In a systematic form, calculations of the irregularities height as a deterministic component are performed in work [10] on a “kinematico-geometric basis” [1] for turning and milling.

Obviously, in the general case, the irregularities of a machined surface contain both periodic (deterministic) and aperiodic (random, non-deterministic) components, which together reflect on the surface topography. There is known the so-called theoretico-probabilistic approach, according to which the separation of the profile into deterministic (periodic) and random (aperiodic) components makes it possible mathematically to approach the solution of the problem of profile separating roughness, waviness, and contour which are in a superposition state, and take, e.g., the deterministic part of the profile as waviness, while its random part – as roughness [1].

The theoretical justification for theoretico-probabilistic approach is based on the presence (absence) hypothesis of a periodic component in the profilogram (more exactly as primary profilogram signal) characterizing the machined surface [11].

For the first time, the possibility of using correlation analysis apparatus (tool-kit) in the framework of the theoretico-probabilistic approach for the study of surfaces was proposed in [1]. It was proposed an idea to interpret the surface profilogram as a random stationary function realization that has a normal (or Gaussian or Gauss, or Laplace – Gauss) distribution. The capabilities of the correlation analysis method for assessing surface roughness and waviness were presented in [12-14].

However, the literature reviewed does not cover such provisions of correlation analysis as the influence of a limited observation interval on the correlation function type, there is no information about the need and techniques for centering the initial function subjected to both theoretico-probabilistic (statistical)

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and frequency analysis. There is no data on the agreement degree between theoretico-probabilistic and frequency approaches in the experimental data analysis.

Besides, there is not shown the universality of the frequency approach to a technological data system analysis especially for the different nature data, e.g., surface irregularities, mechanical vibration, etc.

The latter concerns, for example, the following areas:

– establishing the relationship between vibrations in the elastic system of a metal cutting machine and a profilogram of the surface machined on this machine;

– cutting system diagnosing the quality of the machined surface based on the analysis of the frequency spectrum of the vibration signal (vibro-acceleration, vibro-velocity, vibro-displacement) in the subsystem of the workpiece or/and cutting tool;

– restoring the gear grinding allowance stock distribution information based on the results of the stock selective measurements (when some of the gear teeth is missed in measuring).

The purpose of the paper's study is to develop a method for evaluating digitized experimental data based on the concept of dividing total measurement information, for example, information describing the micro- and macro-profile of the machined surface, into systematic and random components of this information, using the mathematical apparatus of correlation analysis.

3. Research Methodology

The general situation related to the classification of roughness and waviness parameters of the machined surface is shown in Fig. 2 [15]. As for the surface form deviation (it is not shown in Fig.2), this characteristic also has a corresponding wavelength, the value of which is more than the waviness width. All surface profile texture (roughness, waviness and contour) are given in Fig. 3 [16].

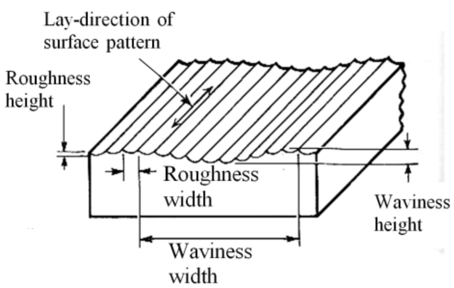

Fig. 2. Surface characteristics (roughness and waviness) excepting surface form deviation

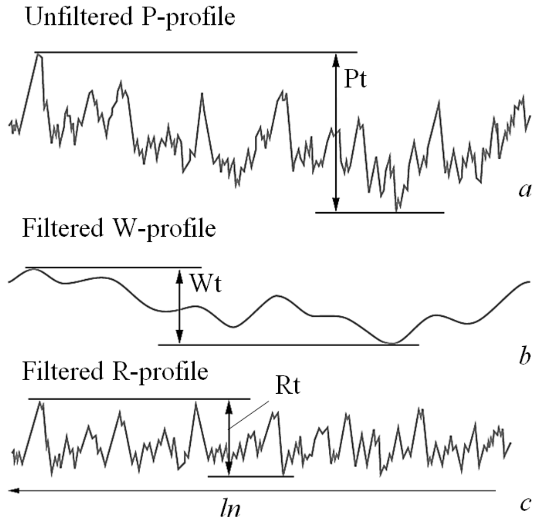

Fig. 3. Division of a surface primary profile (*a*) to separate the waviness (*b*) and roughness (*c*) signals

There are several information lengths to evaluate the standard surface quality parameters, namely: lr is the sampling length; ln is the evaluation length; lt is the traverse or trace length lt (Fig. 4). This classification of functional roughness intervals (by length) allows overcoming the shortcomings of existing domestic standards in this area, in particular, when determining the roughness parameter Rz.

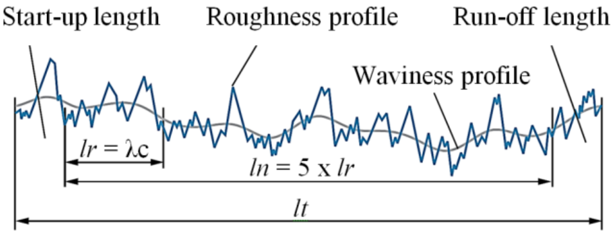

Fig. 4. Surface profile evaluation lengths with a cutoff of the step required [16]

For further analysis, we use the following general concepts which are unusual for the area under consideration. *First*, let's introduce the concept of a signal as a way of presenting the technological measurement information. As a result, we will discuss a mathematical description or mathematical model of an information signal containing two components: systematic (deterministic signal) and random (stochastic signal). Now we can discuss and analyze the frequency characteristics of deterministic and stochastic signals. *Secondly*, let's consider the signal random component as a certain evaluation of a random process which – accordingly cybernetics – is a mathematical abstraction of a real process that changes in time. *Thirdly*, let's present the same information in the time and frequency domain using the direct and inverse Fourier integral transforms including both the discrete and fast transforms. *Finally*, let's reduce the used mathematical models of time-limited or coordinate-limited signals to their "canonical" form adopted in computer signal processing technologies by "centering" the corresponding time functions, i.e. by removing from the systematic and random component of the signals a constant (or mean value) component and a mathematical expectation (expected value), respectively. In this case, the corresponding moments for the centered random variables will be called the central moments of the random signal component distribution density. *The first moment* of the distribution density is the mathematical expectation of the signal. *The second moment* of the distribution density is the dispersion of the signal or the standard deviation of its amplitude from the average value [17]. In statistics, dispersion is the extent to which a distribution is stretched or squeezed.

Based on these concepts, the method of signal separating (dividing, segregation), for example, a signal that characterizes a surface profilogram, in accordance with the theoretico-probabilistic and frequency approach is as follows.

1. The surface profilogram $y(x)$ is considered as the stationary random process realization (i.e., one of the possible realizations on the profilogram length l). This random process has a constant mathematical expectation equal to zero. To do this an auxiliary centered function is formed on the length l of the profilogram.

$$Y(x) = y(x) - m(x), \tag{1}$$

where $m(x)$ is the average arithmetic ordinate of the profilogram.

Taking into account the work [11], but for a discrete representation we get

$$m(x) = \frac{\sum_{i=0}^{n-1} y(i\Delta x)}{n}, \tag{2}$$

where n is the number of discrete samples of the profilogram continuous signal.

2. The real surface profile $Y(x)$ is the sum of two components: systematic (deterministic, periodic, regular) and random (non-deterministic, aperiodic, irregular). Moreover, the systematic component $Y_\beta(x)$, unlike the random component $Y_\gamma(x)$, is a poly-harmonic oscillation consisting of the sum of simple harmonics while the random component $Y_\gamma(x)$ is a random stationary function with zero mathematical expectation and dispersion $D_\gamma = \sigma_\gamma^2$.

Given the notation adopted in [1] and [10], the mathematical model, for example, of a profilogram signal has the form

$$Y(x) = Y_\beta(x) + Y_\gamma(x) = \\ = \sum_{j=1}^{m} (A_j \cos\omega_j x + B_j \sin\omega_j x) + Y_\gamma(x), \tag{3}$$

where: A_j, B_j are the Fourier series coefficients; $j = 1, 2, \ldots, n$ are the ordinary numbers of harmonics having an angular frequency ω_j in radian per second; $Y_\beta(x)$ and $Y_\gamma(x)$ are the systematic and random centered functions in μm.

It can be seen that the mathematical model (3) naturally contains the integral Fourier transform (the frequency approach according to R. V. Hamming) to describe the systematic (periodic and associated with the surface waviness) component of the signal. In turn, the random (aperiodic) component $Y_\gamma(x)$ can be studied by the random functions theory methods (the theoretico-probabilistic approach by A. P. Husu).

Let's note that the question of the model (3) probabilistic characteristics for the total signal $Y(x)$ first appeared in communication theory, where this model was called the "mixture of harmonic signal with noise" [11].

3. Bringing the signal of the profilogram profile being studied to the canonical form to determine the corresponding central moments of the distribution density of this signal. Now there is a possibility to apply the correlation analysis of the overall profilogram signal using the identification property of correlation function. On the one hand, this will allow revealing the latent (hidden) periodicity [18] and also, on the other hand, quantifying the relationship between the systematic and random component according to their share in the total signal dispersion [1; 17]. In this sense, the correlation function of the total signal $Y(x)$ is a tool for identifying its systematic $Y_\beta(x)$ and random $Y_\gamma(x)$ components.

The complexity of the identification problem lies in the choice of the trace length lt (and the corresponding base length lr when evaluating the surface quality), since any experimental data sequence has a finite length regardless of whether the length is in units of time or distance. *In the first case* (by time-dependent) it will be the signal with a limited spectrum which must not contain a constant compo-

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nent, because the frequency spectrum (in Hertz on the abscissa axis) for the constant component can be more complex than that of the variable part of polyharmonic signal (described by the discrete Fourier series). *In the second case* (by distance or coordinate-dependent), conditional frequencies are introduced, representing the ratio of the main step of the profile to the step of the k – th harmonic (in millimeters) [1]. As in the first case, it is necessary to remove from consideration the signal constant component.

Therefore, the first step in signal $y(x)$ mathematical processing should be removing the constant component of this signal. For the signal systematic component this allows removing from consideration a spectrum of a single pulse (e.g., with the length lr) which has a complex character of changing the spectral density of the signal, limited by a finite observation interval. For the random component of the signal $y(x)$, removing the constant component allows bringing the random process to its canonical form, which involves a centered random variable or the current deviation of the random process from its mathematical expectation.

Our research has shown that even at a limited trace length lt the mathematical expectation $m(x)$, which is the result of the signal filtering with a cut-off step equal to the roughness measurement base length lr , is a variable value (mean line in European DIN standards) and is an estimate of the waviness of the machined surface [19].

Both milling, which creates irregularities in the machined surface, and the measurement of these irregularities were performed on modern CNC equipment with carefully planned experiments, followed by an assessment of their error which is at least an order of magnitude smaller than the controlled irregularities of the milled surface. The studies were performed on CNC machining center 500V/5 where there was milling the special samples. Besides, there were measuring the quality parameters of the milled surface with the aid of computer measuring station T8000. It contains a motorized column of Wavelift type for vertical movement of the transverse crosshead by 400 mm, a rotary support of the drive, a drive of the feed mechanism of the Waveline type (to a length of 60 or 120 mm), a two-coordinate measuring table without an electric drive, a granite slab with a T-shaped groove. The GTR-4 type tool table has a niche with a printer and a passive vibration reduction system. There are two contact elements: an unsupported probe for measuring surface roughness and waviness (toolkit TKU 300/600) and the Wavecontour type sensor for measuring contour [20].

The software including TURBO ROUGHNESS, TURBO WAVE, TURBO CONTOUR and EVOVIS, is used to measure roughness, waviness, geometric parameters of the surface profile and topography, respectively, in accordance with DIN EN ISO 4287. Prefix “Turbo” allows to package applications and their dependencies into a lightweight, isolated virtual environment called a “container”. The “Turbo” simplifies development and eliminates bugs by deploying applications in a “known good” configuration with a fixed set of components and dependencies. Containers obviate the need for installers and prevent conflicts with natively installed software. Thus, the TURBO software is isolated from the host environment. Turbo containers are built on top of the Turbo Virtual Machine, an application virtualization engine that provides lightweight namespace isolation of core operating system objects such as the file system, registry, process, networking, and threading subsystems [21].

The digital filters make it possible to separate the long and short waves which are contained in the primary profile (Fig. 3a). To distinguish between types of irregularities, the following filters are used: RC discretely calculating (mm) according to DIN 4768; Gaussian (M1) digital filter (mm) according to DIN EN ISO 11562, part 1, (50 % Gauss); double Gauss (M2) for determining the relative reference length and Rk parameters according to DIN EN ISO 13565-1.

The maximum wavelength (cutoff step) for all filters (RC, Gauss M1 and M2) is: 0.025; 0.08; 0.25; 0.8; 2.5; 8 mm. The maximum length λs for ultra-short waves is selected by the steps of the ratio λc/λs, to wit: 30; 100; 300. The sampling length (base length) lr for the roughness (or cut-off step λc) is selected from the following row: 0.08; 0.25; 0.8; 2.5; 8 mm. Tracing speed: 0.05; 0.15; 0.5 mm/s. Tracing length lt may be the following: 0.48; 1.5; 4.8; 15; 48 mm or it may be variable from 0.1 to 200 mm. Evaluation length ln (Fig. 2) may be: 0.40; 1.25; 4.0; 12.5; 40 mm or it may be variable with cut-off of the maximum wavelength. The curvature radius of a probe in the mode of measuring roughness and waviness is 2 or 5 μm, while in the mode of the contour (surface form deviation) measuring: 22; 250; 500; 1000; 2000; 3000 μm.

4. Results

In accordance with the search algorithm for the autocorrelation function R_{xxi} in NI-DAQmx data acquisition system with NI-LabVIEW software, the calculation is performed using the formula

$$Y_j = \sum_{k=0}^{N-1} X_k \, X_{j+k} \,, \qquad (4)$$

where
$j = -(N-1), -(N-2), ..., -1, 0, 1, ..., (N-2), (N-1)$.

Determining the autocorrelation function performed on an interval of double trace length according to the algorithm

$$R_{xx\,i} = Y_{i-(N-1)} \,, \qquad (5)$$

where $i = 0, 1, 2, ..., 2(N-1)$.

This construction of the calculation algorithm can be explained graphically (Fig. 5), where the interrelation of the abscissa axes to the reference numbers i , j and k is seen.

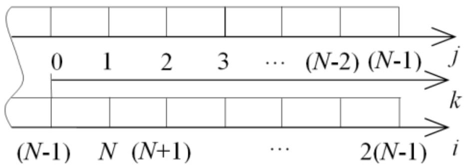

Fig. 5. The interrelation of the abscissa axes i , j and k for sequences of discrete samples when constructing an autocorrelation function

Table 2 shows examples of the relationship between the variable numbers of discrete samples to understand the algorithm for calculating the autocorrelation function of a signal containing systematic and random components.

Table 2. The interrelation between variable sample numbers for an autocorrelation function

Переменные номера отсчётов *i* и *j*		
i	$j = i - (N\text{-}1)$	j
$i = 0$	$j = 0 - (N\text{-}1)$	$j = -(N\text{-}1)$
$i = 1$	$j = 1 - (N\text{-}1)$	$j = N$
$i = 2$	$j = 2 - (N\text{-}1)$	$j = N\text{+}1$
$i = 3$	$j = 3 - (N\text{-}1)$	$j = N\text{+}2$
…	…	…
$i = N\text{-}1$	$j = (N\text{-}1) - (N\text{-}1)$	$j = 0$
$i = N$	$j = N - (N\text{-}1)$	$j = 1$
$i = N\text{+}1$	$j = (N\text{+}1) - (N\text{-}1)$	$j = 2$
…	…	…
$i = 2(N\text{-}1)$	$j = 2(N\text{-}1) - (N\text{-}1)$	$j = \text{N-1}$

For profilogram correlation analysis there selected two milled samples with a periodic surface profile (sample 5.1 in Fig. 6) and aperiodic one (sample 2.1 in Fig. 7). Each of them made of carbon steel with low carbon (less than 0.3 %), has overall dimensions 65x50x30 mm [22], and is obtained in milling with the following milling parameters. For sample 5.1: cutting depth 0.5 mm, feed per tooth 0.15 mm, mill rotary speed 3800 min^{-1}. For sample 2.1: cutting depth 0.5 mm, feed per tooth 0.15 mm, mill rotary speed 950 min^{-1}.

Let's analyze the obtained correlogram of signals characterizing the primary profilogram for samples 5.1 (Fig. 6) and 2.1 (Fig. 7).

1. The two correlogram (Fig. 8 and Fig. 9) are plotted at doubled traverse (trace) length of the samples (traverse length $lt = 15$ mm) and are symmetrical in the interval 0...30 mm relative to the reference interval $lt =$ 15 mm. This corresponds to the well-known parity property of the autocorrelation function $R_{xx\,i} = K(\tau)$.

2. Autocorrelation function at the abscissa $lt = 15$ mm (Fig. 8 and Fig. 9) takes its maximum value equal to the sum of two dispersions: $K_\beta(0)$ and $K_\gamma(0)$ for the systematic component of the total signal and the random component of the same signal respectively, as $K(0) = K_\beta(0) + K_\gamma(0)$. For samples 5.1 and 2.1, these equations have the form 3.5 = 2.5 + 1.0 (Fig. 8) and 32.2= 3.5 + 28.7 (Fig. 9), respectively. In the first case, the signal systematic component exceeds the signal random component by 2.5 times (sample 5.1, Fig. 8). In the second case (sample 2.1, Fig. 9), on the contrary, the random component of the profilogram signal exceeds its systematic component by 28.7/3.5 = 8.2 times.

3. The wave step (0.63 mm) of the initial total signal for sample No. 5.1 (Fig. 3) coincides with the wave step of the autocorrelation function for the same sample, i.e. $T_{\beta 1} = T_{\beta 2} = 0.63$ mm (Fig. 8). At the same time, for sample 2.1 (Fig. 9), the signal systematic component associated with its periodicity is not expressed, it is hidden and characterized by variable steps $T_{\beta 1} = 4.4$ mm and $T_{\beta 2} =$ 1.0 mm (Fig. 9).

The application of the developed method for other technological proposals – when analyzing the allowance stock for gear grinding, restoring the allowance stock from its sample measurements with an equal measurement step, modeling temperature fields during grinding, and others – is reflected in [23-26]. Thus, the ways to solve the problem considered are fully applicable in other areas of engineering, technology and production based on the theory of information and communication.

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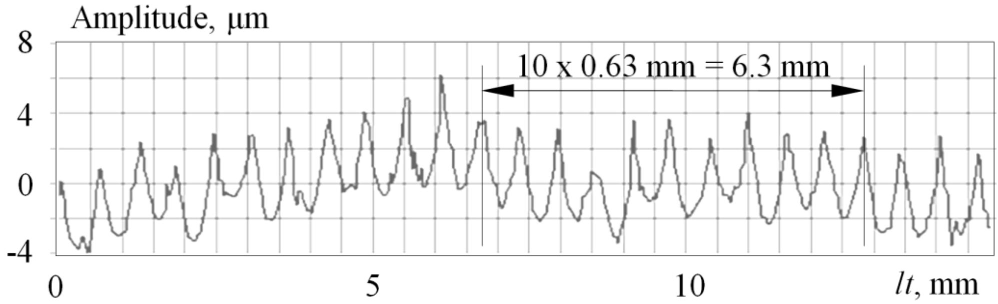

Fig. 6. Surface profilogram of the sample 5.1 after milling

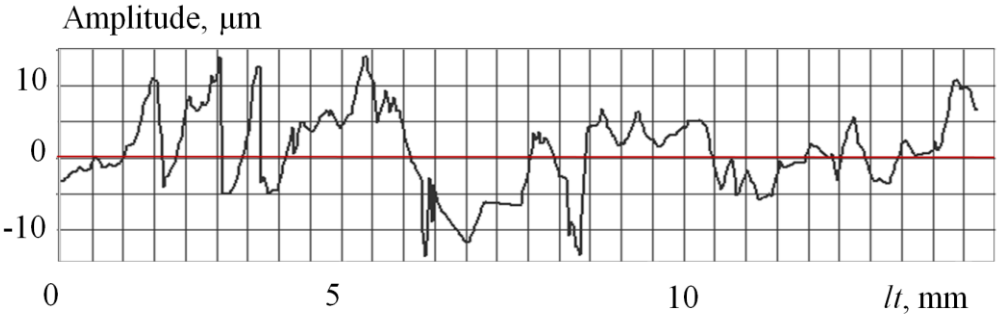

Fig. 7. Surface profilogram of the sample 2.1 after milling

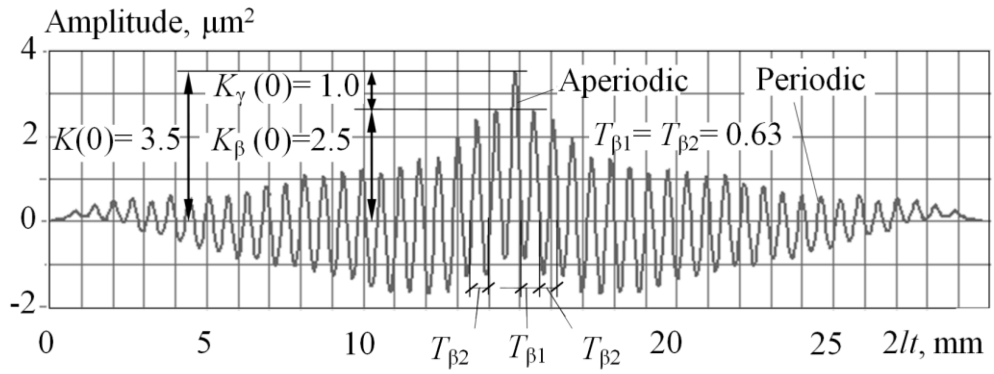

Fig. 8. Correlogram of sample 5.1

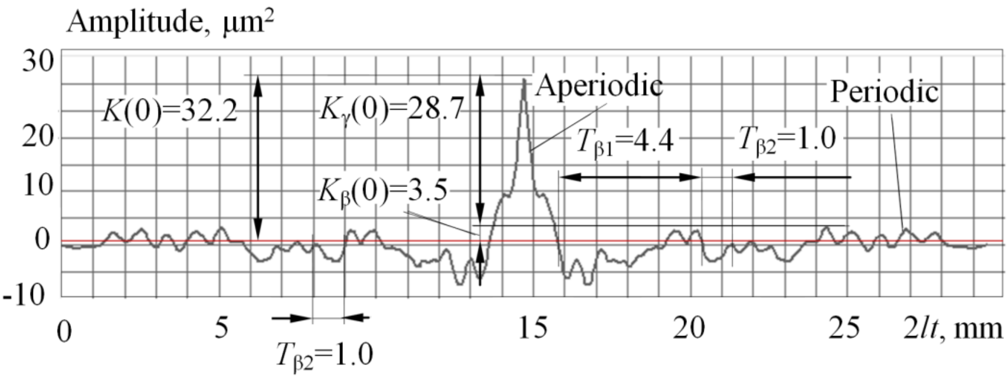

Fig. 9. Correlogram of sample 2.1

5. Conclusions

1. The method of detection and identification of the systematic and random component of the signal of the machined surface profile as well as other experimental data has been developed and tested on examples. It consists in reducing this signal (data) to a centered form by removing the constant component of this signal (data) from the initial total signal containing the technological information – the measurement result. Practical testing of this method was performed for the case when the above mentioned technological information was represented by a digitized profilogram of the milled surface.

2. It is shown that the first step in processing a sequence of experimental data is the "centering" the total signal by removing from it the constant component that is part of the systematic and random components of this signal. For the resulting centered total signal, it is possible to apply the frequency and theoretico-probabilistic approaches to process, respectively, the systematic and random components of the total signal.

3. The continuity (close agreement) between the frequency and theoretico-probabilistic approaches for processing the total measurement signal is shown, which consists in the possibility of determining the spectral density (continuous frequency spectrum) of the random component of the signal through its autocorrelation function. The spectral density of the random process corresponds to a direct Fourier transform of the correlation function of this random component. There is also a possibility for the corresponding inverse Fourier transform, which allows obtaining an autocorrelation function when the spectral density of the random component of the signal is available. This increases the possibilities of the frequency approach, since it expands the scope of its application to the study not only the systematic and random component of the total signal.

4. The universality of technological applications of frequency and theoretico-probabilistic approaches in modern computer technologies for processing experimental data is shown. The same mathematical apparatus of the frequency Fourier transform can be used in different technological applications for the analysis of systematic and random components of the total signal, for example, for the analysis of the following technological data: profilogram of the machine part machined surface profile; vibrations when forming the specified profile during machining (for example, milling); distribution of the allowance stock on the left and right sides of the gear teeth before gear grinding on a CNC machine; et cetera.

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ВИЯВЛЕННЯ СИСТЕМАТИЧНОЇ ТА ВИПАДКОВОЇ СКЛАДОВОЇ СИГНАЛУ ШОРСТКОСТІ ПОВЕРХНІ

Анотація. *Рішення завдання поділу вихідного одновимірного сигналу на дві складові - систематичну і випадкову - має надзвичайно широке практичне застосування не тільки в теорії інформації і зв'язку (і супутніх дисциплінах), але також в механіко-технологічних дисциплінах. Наприклад, технологія машинобудування як наука включає в себе вчення про якість поверхні оброблених деталей і дослідження шорсткості поверхні після обробки цих деталей різанням і шліфуванням. У статті показано, що теоретичні і фактичні значення параметрів шорсткості істотно (до 20 раз) розрізняються через вплив випадкової складової, яка присутня в сигналі шорсткості спільно з систематичної складової. Необхідно визначити частку кожної з цих складових в параметрах якості поверхні за методом, запропонованим в статті. Цей метод дозволяє виявляти систематичну і випадкову складові сигналу і заснований на аналізі автокореляційної функції сигналу. Практичні приклади такого аналізу розглянуті докладно для профілограм фрезерованої поверхні, отриманих експериментально. Як фрезерування, яке створює нерівності на оброблюваної поверхні, так і вимір цих нерівностей виконані на сучасному устаткуванні з ЧПУ: обробному центрі 500V/5 і комп'ютерної вимірювальної станції T8000, відповідно. Методика розподілу сигналу, яка розроблена і показана на прикладах, може бути застосована також в інших областях науки, техніки і виробництва. Наприклад, при визначенні відношення сигналу до шуму в теорії інформації і зв'язку, в області телекомунікації та телеметрії, радіотехніки і т.д.*

Ключові слова: *сигнал шорсткості; систематична компонента; випадкова компонента; шорсткість поверхні; хвилястість поверхні; відхилення форми; кореляційна функція*

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ОБНАРУЖЕНИЕ СИСТЕМАТИЧЕСКОЙ И СЛУЧАЙНОЙ СОСТАВЛЯЮЩЕЙ СИГНАЛА ШЕРОХОВАТОСТИ ПОВЕРХНОСТИ

Аннотация. *Решение задачи разделения исходного одномерного сигнала на две составляющие – систематическую и случайную – имеет чрезвычайно широкое практическое применение не только в теории информации и связи (и сопутствующих дисциплинах), но также в механико-технологических дисциплинах. Например, технология машиностроения как наука включает в себя учение о качестве поверхности обработанных деталей и исследование шероховатости поверхности после обработки этих деталей резанием и шлифованием. В статье показано, что теоретические и фактические значения параметров шероховатости существенно (до 20 раз) различаются из-за влияния случайной составляющей, которая присутствует в сигнале шероховатости совместно с систематической составляющей. Необходимо определить долю каждой из этих составляющих в параметрах качества поверхности по методу, предложенному в статье. Этот метод позволяет обнаруживать систематическую и случайную составляющие сигнала, и основан на анализе автокорреляционной функции сигнала. Практические примеры такого анализа рассмотрены подробно для профилограмм фрезерованной поверхности, полученных экспериментально. Как фрезерование, которое создает неровности на обрабатываемой поверхности, так и*

измерение этих неровностей выполнены на современном оборудовании с ЧПУ: обрабатывающем центре 500V/5 и компьютерной измерительной станции T8000, соответственно. Разработанная и показанная на примерах методика разделения сигнала применима также в других областях науки, техники и производства. Например, при определении отношения сигнала к шуму в теории информации и связи, в области телекоммуникации и телеметрии, радиотехники и т.д.

Ключевые слова: *сигнал шероховатости; систематическая компонента; случайная компонента; шероховатость поверхности; волнистость поверхности; отклонение формы; корреляционная функция*

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