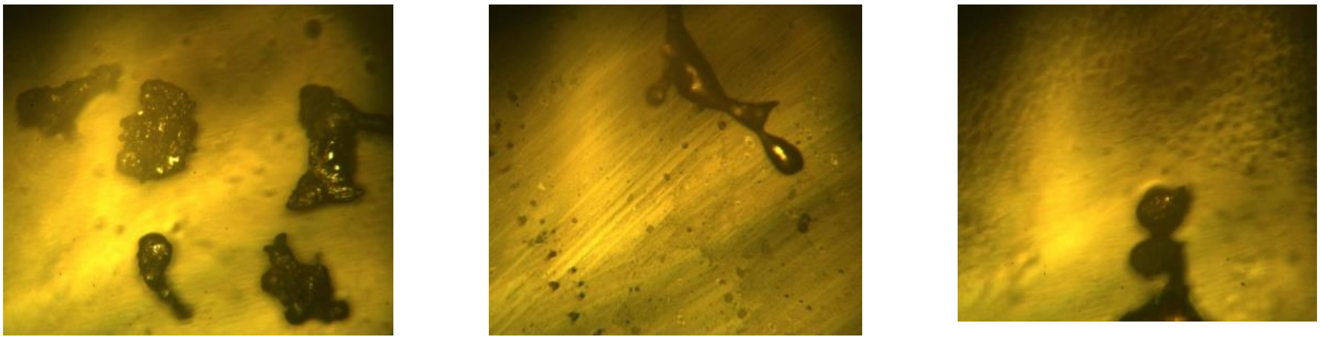

а б в

Рис. 2. Оптическая микроскопия частиц из цветных металлов:
а – частица из алюминиевой проволоки, б – частица из медной проволоки, в – частица из титановой проволоки

Выводы:

1. Отработаны режимы получения порошков микронного диапазона из сварочных проволок различного химического (из низкоуглеродистой, низколегированной стали; из стали аустенитного класса; из алюминия; из меди; из титана) состава и диаметра (0,8 мм, 1 мм, 1,2 мм).

2. Получены порошки из низкоуглеродистой, низколегированной стали и из стали аустенитного класса сферической формы и средним размером частиц 50–100 мкм.

3. Получены порошки из алюминиевой, титановой, медной проволок с формой, отличающейся от сферической, со средним размером частиц 100–500 мкм.

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IMPROVING THE ACCURACY OF MODELING SURFACE ROUGHNESS PROFILES WITH REGULAR MICRORELIEF

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Аннотация: В данной статье рассматриваются вопросы повышения точности моделирования профиля шероховатости поверхности при регулярном характере микрорельефа. В качестве исходных данных для рассмотрения взяты поверхности, обработанные чистовой токарной обработкой и алмазным заглаживанием с жесткой фиксацией индентора. Модель шероховатости поверхности основана на использовании методологического аппарата фрактальной геометрии.

Построение модели основано на использовании алгоритма случайного сложения. Исходными данными являются фрактальная размерность профиля и параметры закона распределения. Показано, что использование традиционных законов распределения случайных величин: нормального (Гаусса), Рэлея и Вейбуля не позволяет получить требуемую точность моделей.

Ключевые слова: шероховатость, моделирование, точность, закон распределения, критерии приемлемости.

Abstract: This article discusses the issues of improving the accuracy of surface roughness profile modeling in case of regular microrelief character. As initial data for consideration, surfaces treated with finishing turning and diamond smoothing with rigid fixation of the indenter are taken. The surface roughness model is based on the use of the methodological apparatus of fractal geometry.

The construction of the model is based on the use of a random addition algorithm. The source data is the fractal dimension of the profile and the distribution law parameters. It is shown that the use of traditional laws of distribution of random variables: normal (Gauss), Rayleigh and Weibul does not allow obtaining the required accuracy of models.

Keywords: roughness, modeling, accuracy, distribution law, acceptance criteria.

Introduction

Surface roughness is a normalized indicator and the most commonly used characteristic of surface quality. In most cases, the surface roughness in design and technological documents is required only to the height parameters of roughness: either the arithmetic mean deviation of the profile (Ra, microns), or the roughness of 10 points (Rz, microns). However, these values do not fully characterize the surface profile. In general, it should be said that the problem of describing the surface roughness has not been completely solved to date. Fundamentally, two approaches are used to solve this problem. The first approach can be called parametric [1]. He assumes that the description of the surface roughness is realized by using some system of numerical parameters. The second approach [2], in order to characterize the surface roughness profile, operates with such categories as the distribution of tangents of the angles of inclination of the sides of the profile, the height distribution function of the profile, the function that describes the reference curve, etc.

The most widely used in domestic practice is the assessment of surface roughness using parameters that are regulated by GOST 2789. This regulatory document assumes the use of both altitude parameters (Ra, Rz, Rmax), and step (S, Sm) and reference (tp). In addition, the standard provides for the possibility of specifying the features of the profile geometry (for example, the direction of irregularities). However, only a qualitative assessment of these aspects of the profile is possible.

The international standard ISO 4281/1–1984 expands the set of parameters for assessing surface roughness, prescribing not only scale factors, but also quantitative parameters of the shape and location of irregularities. For these purposes, the values of the arithmetic mean slope of the irregularities are used Δ_aи the root- mean -square slope of the irregularities Δ_q. These parameters are determined by the following calculated dependencies:

$$\Delta_q = \sqrt{\frac{1}{n} \times \sum_{i=1}^{n} \left(\frac{\Delta y_i}{\Delta x_i}\right)^2}$$

$$\Delta_a = \frac{1}{n} \times \sum_{i=1}^{n} \left|\frac{\Delta y_i}{\Delta x_i}\right|,$$

where *x*, *y* are, respectively, the abscissa and ordinate of points on the curve of the surface profilogram.

In general, we can say that today more than 50 parameters are used to characterize the surface roughness. A common disadvantage of the parametric approach to the description of surface roughness is that no parameter system provides an exhaustive description of the profile, and in addition, the parametric approach is not applicable to solving a number of design problems (for example, studies of tightness, contact interaction, etc.).

One of the first studies regarding the description of surface roughness by means of a nonparametric approach were carried out in the works of V.A. Zhuravlev and Greenwood [3]. At the same time, it was assumed that the altitude values of the microprofile have, obey the normal distribution law. This approach was further developed in the works of the scientific school under the leadership of Yu.R. Wittenberg [4], where correlation functions were used to characterize the surface roughness. In this case, the roughness parameters can be obtained from the relations of the form:

$$R_a = \sqrt{\frac{2}{\pi} \times K(0)}$$

$$R_q = \sqrt{K(0)},$$

where *K(0)* is the value of the autocorrelation function of the profile at the zero point.

The models shown above have the same disadvantages as the parametric approach. In the works of the scientific school of I.V. Kragelsky, N.B. Demkin, and others [5], surface roughness is considered as a set of geometric primitives. This approach made it possible to solve the problems of evaluating the study of the operational properties of surfaces. However, the disadvantage of the approach is that the profile curve is deterministic, and the structural properties of the profile are not taken into account. Recently, fractal geometry has become increasingly common in the modeling of geometric objects.

Studies have been devoted to the application of fractal theory in modeling profiles and surfaces of parts [6, 7]. The method of random additions gives very good results when modeling surface roughness [7]. However, in [7] it is shown that the use of the normal distribution in its pure form does not allow to provide the required accuracy.

Therefore, in [7], an adjustment of the algorithm was made, which actually consisted in fitting the law to real surface profiles. The disadvantage of such a solution is that it is not universal and requires an individual approach in relation to each specific case. For example, the results obtained in [7] are valid only for surfaces treated with finishing turning. Therefore, it is necessary to conduct research and choose a distribution law that obeys the roughness heights of surfaces with a regular profile, which are processed by different methods (turning and smoothing).

The purpose of the study improving the accuracy of modeling the roughness of surfaces with a regular profile by upgrading the algorithm for constructing a fractal curve.

Material and methods of research as initial data, the values of the heights of the roughness profiles of surfaces processed on a lathe by finishing turning and diamond smoothing were used. The roughness of the surfaces was measured using a profilometer-profilograph of the Abris PM-7 brand. An example of a profilogram of the treated surface is shown in Figure 1.

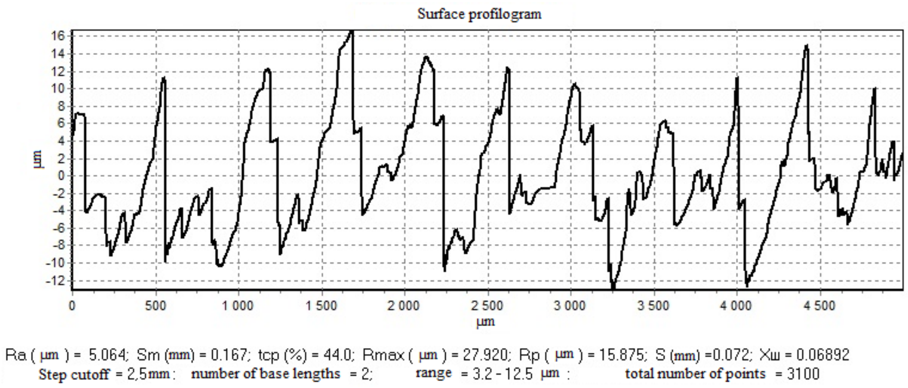

Fig. 1. Surface profilogram

The obtained values of the profile coordinates were used as initial data to test the hypothesis of compliance with the distribution law. The following laws were checked:

1. The normal distribution law, the parameters of which are determined by known dependencies [8]:

$$\phi(x, a, \sigma^2) = \frac{1}{\sqrt{2\pi\sigma}} e^{\left(-\frac{(x-a)^2}{2\sigma^2}\right)},$$

where a, σ are the parameters of the distribution law.

2. Weibull distribution law [8]:

$$\phi(x) = \frac{b}{a}\left(\frac{x}{a}\right)^{b-1} e^{-\left(\frac{x}{a}\right)^b},$$

where a, b are the parameters of the distribution law.

3. Rayleigh's distribution law [8]:

$$\phi(x) = \begin{cases} 0, x < 0 \\ \frac{x}{\sigma^2} exp\left(-\frac{x^2}{2\sigma^2}\right), x > 0 \end{cases}$$

4. Nakagami Distribution Law [8]:

$$\phi(x) = \frac{2}{\Gamma(m)}\left(\frac{m}{\Omega}\right)^m x^{2m-1}\, exp(-mx^2/\Omega),$$

where *Γ(m)* is the gamma function; *m*, Ω are the parameters of the distribution law.

In this case , the parameter m can be obtained from the following expression:

$$m = 1 + \gamma^4/(1+2\gamma^2) = 1 + (\alpha_P^2/2\sigma_B^2)^2/(1+\alpha_P^2/2\sigma_B^2),$$

where $\gamma^2 = {\alpha_P^2}/{2\sigma_B^2}$ – a parameter that reflects the ratio of the deterministic (σ_p) and stochastic ($\sigma_в$) components.

At the same time, the values σ_B and σ_P it can be obtained on the basis of correlation analysis of surface profilograms and determination of the implementation of the autocorrelation function $K_{XX}(t)$. Expressions for calculating the components of the correlation function have the form [7]:

$$K_\beta(\tau) \cong \frac{1}{2}\sum_{i=1}^{n} A_i^2 \cos \omega_i \tau$$

$$K_P(\tau) = \frac{1}{l-\tau}\int_0^{l-\tau} y_\gamma(t) y_\gamma(t+\tau)dt$$

Parameters σ_B and σ_P correspond to the values $K_\beta(0)$ and $K_p(0)$.

At the same time, it can be noted that the Nakagami distribution law has an important property: when the parameter *m* changes, it changes to normal.

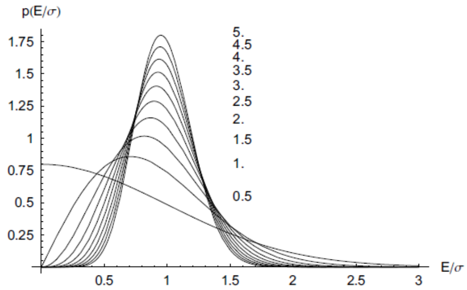

Fig. 2. Dependence of the shape of the curve of the Nakagami distribution law on the parameter m

Verification of compliance with the distribution law was carried out according to the Kolmogorov-Smirnov criterion [8].

The fractal model of surface roughness was constructed using the random addition method [7]. At the same time, the enlarged sequence of calculations looks like this:

1. As the initial values of the abscissa profile, the values are taken $x_i = 0;\ 0.5; 1;$
2. The initial ordinate values at these points are assumed to be zero;
3. Ordinate values are generated and added to the original ones. In this case, a generator with a Gaussian distribution is used by default.
4. The obtained ordinate values are averaged according to the dependence of the form:

$$y\left(x_{\frac{i+(i+1)}{2}}\right) = \frac{y(x_i)+y(x_{i+1})}{2},$$

5. The scattering parameters are adjusted:

$$\sigma_{i+1}^2 = \left(\frac{1}{2}\right)^{2H} \times \sigma_i^2,$$

where H is the empirical Hurst exponent.

In this case, the Hurst index is an estimate of the value of the fractal dimension D, since these values are interconnected by expressions of the form [7]:

– for flat objects: $D = 2 - H$;

– for three-dimensional objects: $D = 2 - H$.

6. New abscissa values are determined by averaging the previous values.

Research results and their discussion Figure 3 shows examples of calculations of the parameters of the distribution laws.

Similarly, distribution curves were constructed for other laws under consideration. Due to the absence of the Nakagami distribution law in standard statistical analysis packages, calculations were carried out in the author's computer program. As a result of statistical processing of more than 150 profilograms of surfaces, it was found that according to the Kolmogorov-Smirnov agreement criterion, the surface roughness corresponds to the Nakagami distribution law and does not correspond to the other three considered.

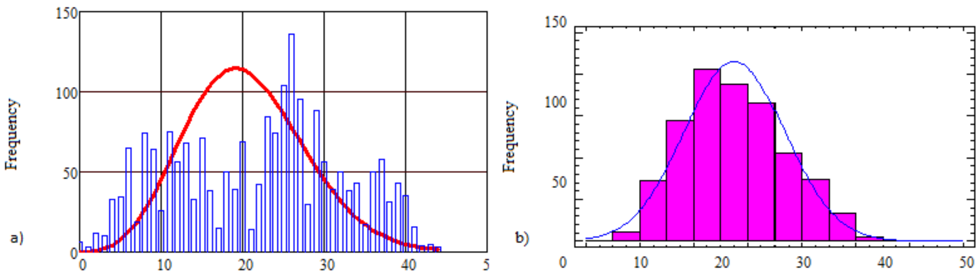

Fig. 3. Calculation results: a – normal distribution; b – Nakagami distribution

The ordinate generator of the fractal profile model based on the Nakagami distribution law was implemented. Figure 4 shows examples of a simulated two-dimensional profile and a three-dimensional rough surface.

To assess the accuracy of the results obtained, profiles were modeled with initial parameters that were determined from real objects (taken from real profilograms). Then, the obtained fractal curves were used to determine the surface roughness parameters in accordance with GOST 2789. Figure 5 shows an example of the results of determining parameters according to GOST 2789 for real profiles, models constructed using a profile ordinate generator based on the Gauss (normal) distribution law and Nakagami distribution law.

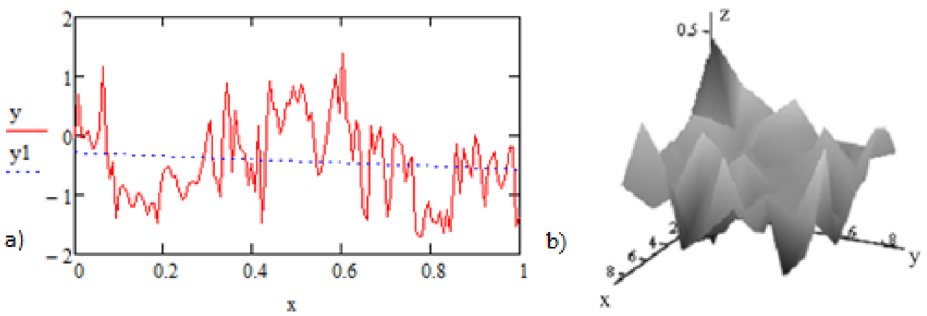

Fig. 4. Example of simulation results: a – fractal curve of the roughness profile;b – surface

As can be seen from Figure 5, the use of a profile ordinate generator based on the Gauss distribution law gives a significant error (more than 25 %). The ordinate generator based on the Nakagami distribution law allows us to obtain an error not exceeding 10 %, which is quite sufficient for solving both problems of describing surface roughness and solving applied problems related to the study of operational properties.

Conclusions or conclusion as a result of statistical analysis of profilograms of surfaces having a regular microprofile, it is proved that their ordinates obey the Nakagami distribution law. The implementation of the profile ordinate generator based on the use of the Nakagami distribution law makes it possible to obtain fractal models of surface roughness with an error that does not exceed 10 %.

An important advantage is the versatility of the generator in terms of modeling profiles and three-dimensional surfaces of parts that are processed by finishing turning and diamond smoothing with rigid fixing of the indenter without the use of smoothing windows [7].

The combined use of fractal geometry and the Nakagami distribution law allows us to take into account both the structural features of the profile texture (through the values of the fractal dimension) and the technological aspects of its formation (through the ratio of the deterministic and random component).

The application of the developed model is fundamentally possible when solving problems unrelated to those considered in this article. In particular, with the help of the developed tools, it is possible to model the microprofiles of roads [9–10] and other rough objects in different areas of modeling practice.

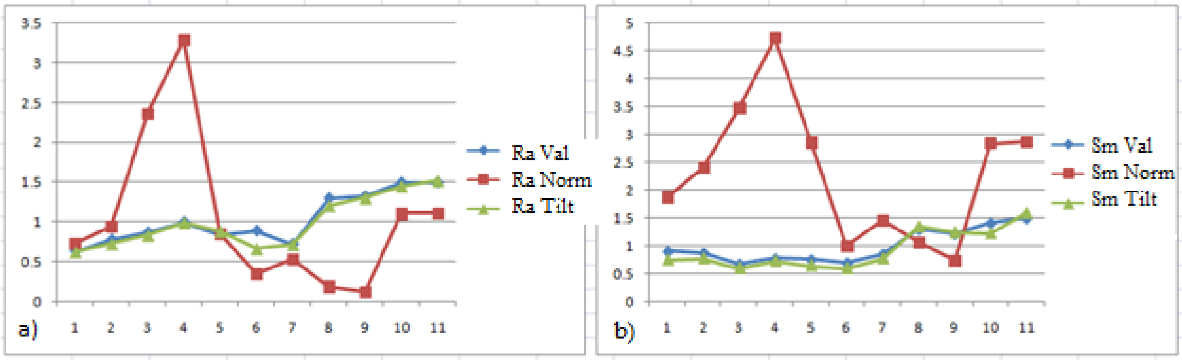

Fig. 5. Example of model accuracy: a – Ra values for real profiles and models; b – same for Sm

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