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SPECIAL FEATURES IN THE APPLICATION OF FRACTAL ANALYSIS FOR EXAMINING THE SURFACE MICRORELIEF FORMED AT FACE MILLING

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Метод фрактального аналізу застосований для опису площі поверхні мікрорельєфу, що формується торцевим фрезеруванням при різних значеннях подачі. Розглядаються найбільш сприятливі умови отримання фотозображень поверхні зразків та аналізуються залежності фрактальних параметрів рельєфа поверхні від просторових масштабів його досліджень. Отримані кількісні взаємозв'язки між Хаусдорфовими розмірностями для площі поверхні мікрорельєфа пластин і подачами заготовки

Ключові слова: фрактальний аналіз, шорсткість поверхні, торцеве фрезерування, площа поверхневого рельєфа

Метод фрактального анализа применен для описания площади поверхности микрорельефа, формирующегося торцевым фрезерованием при различных значениях подачи. Рассматриваются наиболее благоприятные условия получения фотоизображений поверхности образцов и анализируются зависимости фрактальных параметров рельефа поверхности от пространственных масштабов его исследований. Получены количественные взаимосвязи между Хаусдорфовыми размерностями для площади поверхности микрорельефа пластин и подачами заготовки

Ключевые слова: фрактальный анализ, шероховатость поверхности, торцевое фрезерование, площадь поверхностного рельефа

1. Introduction

Providing the assigned level of roughness of the surfaces of parts at machining is an important direction of machine engineering. Surface roughness has an essential effect on the performance properties of parts. Given this, it becomes clear why significant attention is paid to studying the microrelief of the surface of samples both theoretically and practically. Among the theoretical directions in the studies of the surface microrelief state, of special interest are the series of articles that deal with the application of sufficiently new, nontrivial mathematical methods for analysis of the surface relief state [1–7]. They include papers on the application of fractal representations to the description of the self-similar states, which are formed either naturally, for example, due to the reflection by the surface of crystallographic properties of the volume of material of the base layer [8, 9], or due to the periodic action on the surface of machnining tool [10, 11].

Attempts at describing by simple mathematical expressions of complex geometric shapes, which are observed experimentally at the surface of the samples, prove to be futile, as a rule. At the same time, disregarding the influence of other emerging forms of symmetry, namely fractal, on the formation of ultimate operational properties of the parts' surface at the precision level of their studies is not justified.

The nontrivial methods of investigating the state of microrelief of the machine parts surface should also include those methods that use as their basis the theory of power series and representations of the fractal structure of samples' surface. Thus, we think it expedient to approach description of the surface microrelief based on the use of fractional dimensions. This may make it possible to subsequently establish interrelation with the fractional exponents in the power dependences for calculating the cutting modes in empirical formulas.

The previously mentioned allows us to assert that the use of fractal analysis and fractal geometry for describing the parameters of samples' surfaces after their machining by the cutting tools is relevant. Results of such study can be useful both in re-assessing the existing theoretical provisions and in practical sense in describing the observed surface reliefs. The existence of quantitative information of this kind will subsequently make it possible to optimize conditions for the machining of parts and to provide for the required level of parameters of surface microrelief. That is why present work should be considered as further development and practical application of approaches and results [1–7].

2. Literature review and problem statement

In the theory of cutting of materials, empirical mathematical expressions are widely used, obtained based on the processing of experimental results, which include fractional indicators in exponential functions. The latter, in its essence, reflects the emergence of fractal properties in the interacting technological machining system machine-device-tool-part. This situation stimulates attempts at employing fractal representations to describe the processes that take place at blade cutting of metals.

Some of the pioneer articles on the use of fractal analysis (FA), namely its multifractal generalization, in the metals science are considered to be studies [12, 13], in which FA was used for the quantitative description of the surface of metal destruction. This approach made it possible to calculate parameters of the fractal surface condition of metallic fracture. The latter, in its essence, indicated the realization of the so-called multifractal (MF) parametrization of the selected surface. Data obtained in this way allowd finding the interrelations between them and mechanical properties of samples. At the same time, MF-parametrization was performed relative only to the analysis of two-dimensional images of the structure surface and did not take into consideration the entire spatial picture of the relief. In this case, the real relief of surface was modeled by a series of zeros and unities. In the case when the relief, observed on the images, exceeded the assigned level, the input FA variable was assigned with a logical unity, otherwise its magnitude was taken equal to a logical zero. This simplified modeling of geometry of the real surface resulted in fractal parameters of the system that were difficult to interpret physically. The aforesaid, in the first place, relates to the magnitudes of Hausdorff dimension (or the Renyi numbers D_0 for multifractal analysis), which, when describing the area of a non-planar surface, rough at the micro level, occurred smaller than 2. We shall note that the area of a developed, non-planar surface must be of the magnitude exceeding two, according to the general geometric considerations.

At the same time, the approach, developed in [14–16], was applied for obtaining data on the fractal and even on the multifractal parameters for the surface reliefs, formed by different methods. Thus, in paper [14], mathematical provision for the multifractal analysis from [12, 13] was applied to the calculation of multifractal parameters that describe condition of the surface of aluminum alloys, treated by the electrohydroimpulse method. It is only natural that the obtained interrelations between the surface's fractal parameters and conditions for machining are useful data when selecting conditions for the execution of a technological process.

Article [15] addresses the estimation of parameters of structure and the totality of mechanical properties of structural and instrumental materials by the quantitative multifractal characteristics. It also operates by the mathematical apparatus [12, 13]. However, the original assumption accepted in [12, 13] on the possibility to model a surface relief by logical zeros and unities appears to be insufficiently accurate. The low accuracy of input information for the subsequent calculations within the framework of fractal analysis is reflected by low authenticity of the output fractal parameters of the system. The latter complicates further use of the obtained parameters both in the theoretical description of relief and when conducting a comparative analysis of the state of surface quality after machining under different technological conditions. We shall note that a similar approach with the introduction into examinations of threshold magnitudes to describe the surface relief has been used until now [17].

In a generalizing article [16], fractal analysis was applied to describe the surface condition of machine parts after the electrophysical and electrochemical methods of treatment. The interrelations between the fractal parameters of surface and the conditions for its obtaining, received in this case, are quite sufficient and informative for the orientation in selecting the regimes for obtaining a surface with the assigned parameters of relief. At the same time, fractal analysis was applied to calculate the Hausdorff dimensions of length of the lines, drawn through the points of surface relief of the sample. The informativeness of obtained data on such a selected parameter of the system is beyond a doubt. However, its direct application in the subsequent calculations and modeling of the processes that occur when obtaining the surfaces with the assigned relief is difficult because this parameter is practically not employed in the analysis.

Furthermore, during thorough analysis of the scientific sources we did not discover sufficiently fundamental scientific articles, devoted to the application of fractal analysis for examining the impact of cutting modes on the microrelief parameters of machined surfaces. Therefore, the questions specified have not been sufficiently explored up to now and are thus of significant interest.

Such a situation stimulates conducting additional studies, at least, in the following directions. An improvement in the authenticity of results of fractal analysis implies the fulfillment of further theoretical, computational developments in the preparation of initial data for the implementation of methods of fractal analysis. In turn, an improvement in the authenticity of calculation data will lead to the possibility of their use in practical recommendations for selecting the cutting modes, as well as in the future, when creating systems of adaptive control over the machining process of the non-contact type.

3. The aim and tasks of the study

The aim of present studies is to obtain quantitative data on the structure of surface microrelief of machine parts and its description by the methods of fractal analysis depending on the machining conditions for face milling.

To achieve the set aim, the following tasks had to be solved:

– the search for conditions of obtaining the photographic images of machine parts surface with the assigned resolution;

– the adaptation of methods of fractal analysis to the calculations of fractal parameters of the surface after face milling.

4. Materials and methods of research

4. 1. Realization of fractal analysis

A principal moment in the application of FA to the description of surface condition of a plate after face milling is the selection of a particular physical parameter that most fully characterizes it and is subject to fractal parametrization. Among possible geometric parameters of spatial shapes, which form at the surface of a plate, we chose a surface area, since finding it matches the purpose in the prediction of many parameters of technological process. Specifically, this parameter of the system formed the base set of measure in the implementation of FA in the present work.

The realization of FA method was carried out in accordance with the procedure standard for it [1, 2, 12, 13]. Input information for FA of the plate surface area was received from microphotographs. In this case, the surface area of real samples was calculated by the interpolation method based on the data about chromaticity of different pixels in a photographic image. In this case, coordinates of the points of surface relief, information about which is contained in each pixel of the photograph, were used to calculate the surface area between adjacent pixels in accordance with the method of triangulation. The appropriate software was developed, tested and applied in [8, 9] for the realization of multifractal parametrization of the surface area of semiconductor film structures. In the present work, to describe the surface condition of samples, we used fractal analysis, not the MF as in [8, 9]. This was achieved by the simplification of developed software, assuming the magnifying number q in a MF analysis constant and equal to unity. It is necessary to note that the software from [8, 9] in the description of fractal properties of the surface area yields the same quantitative magnitudes as the known computational package «Gwyddion» [18].

A generation of measure of each space cell was carried out by splitting the measure of space that covers the base set into N cells. As the measure of cell v_i, we adopted a relative magnitude of the surface area, which was included into a given cell of partition:

$$v_i = S_i / S, \tag{1}$$

where S_i is the area of the small, selected «elementary» area; $S = \sum_{i=1}^{N} S_i$ is the area of the entire analyzed surface, found by the data of its spatial image.

A calculation of fractal dimensions for the specified parameter of the system was performed by the rough partition method by a standard procedure [8, 9, 11, 12]. In this case, for a cell of the assigned size, a statistical sum was formed:

$$Z(K) = \sum_{i=1}^{K} v_i, \tag{2}$$

where l_k is the standardized current length of the cube edge, utilized at the current step in the rough partition method.

A change in the scales of cells in the calculations (enlarging the dimension of cubes) was conducted by dependence $l_{k+1} = l_k \cdot 2$ (k = 1, 2, 3, ...).

In case there is a fractal symmetry in the analyzed physical system, then dependence $\ln Z(q,l_k)$ on $\ln l_k$ is the totality of points, which are grouped along the straight line. A calculation of the parameters of linear regression between the indicated parameters of the system was performed by the method of least squares. All the operations indicated were carried out by numerical methods.

4. 2. Samples and peculiarities of obtaining the images of a surface

Samples for present research were obtained during face milling at the machine of model 6R12. As a cutting tool, we used a face milling cutter with diameter 40 mm with mechanical fastening of four pentahedral plates made of hard alloy (T15K6 and VK8 coated by titanium nitride). The machined samples were the plates of thickness 20 mm (50×300 mm) made of steel 35 and alloy D16T. Materials selected for research are widespread and frequently used in machine building; which is why they were used to prove effectiveness of the FA application to describe a condition of the machined surface.

We chose as a constant parameter when obtaining the examined surfaces the cutter rotation frequency – 125 r/min. In this case, the magnitude of cutting speed was 130 m/min. The feed of workpiece S served as the varied parameter for the surface machining process.

Digital camera Sunny P5v04a Raspberry Pi Model B+ (5 MP) for capturing the images of the surface was mounted directly on the microscope XS-2610 MICROmed. Image taking of the surface was conducted under reflected light. The uniformity of illumination of the sample surface was ensured by using a set of the light-emitting diodes, which were evenly arranged on the annular holder around the sample. Such a design of illuminator provided for a minimum volume of possible shadow formation from the relief peaks and distortion in the true picture of the surface. The conditions for obtaining an image of the surface relief were selected so that the entire spread of the surface relief was captured in the focus of a photograph and so that each part was photographed at the same magnification in the microscope. The measures indicated allowed us to reduce to a minimum possible distortion in the color shades when obtaining a photographic image of the surface (Fig. 1, 2). The latter, in turn, made it possible to compare fractal parameters for the surfaces, formed under different cutting modes.

5. Results of examining the fractal structure of a surface

Fig. 1, 2 show original photographs of the surface microstructure of samples made of steel 35 and alloy D16T, obtained for the different magnitudes of S feed. Images of such particular type were processed by FA methods using the specified software for the purpose of quantitative description of the surface relief and search for the interrelations between parameters of surface condition and the conditions under which it was obtained.

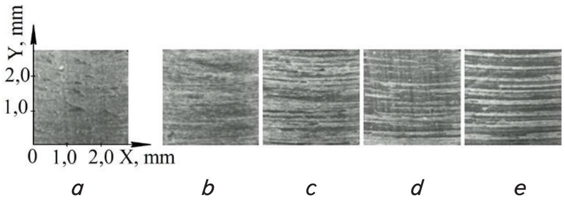

Fig. 1. Microphotographs of the surface of plates made of steel 35 after face milling (n=125 r/min, t=1 mm) at different values of S feed: *a* – 25 mm/min; *b* – 50 mm/min; *c* – 100 mm/min; *d* – 200 mm/min; *e* – 400 mm/min

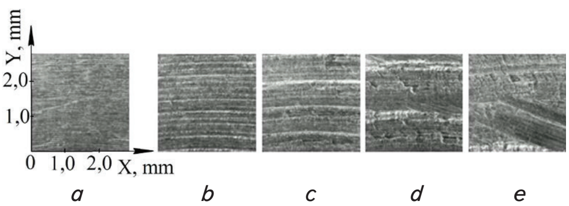

Fig. 2. Microphotographs of the surface of plates made of alloy D16T after face milling (n=125 r/min, t=1 mm) at different values of S feed: *a* – 25 mm/min; *b* – 50 mm/min; *c* – 100 mm/min; *d* – 200 mm/min; *e* – 400 mm/min

Distinct observation on the photographic images of the machined surface (especially at significant magnitudes of the feed in Fig. 1, 2) of bands (traces) from the cutter tooth passage allowed us to find for the photographing conditions a linear scale for the coordinate axes that lie in the area of milling surface. A known formula that connects the distance between bands and conditions of the work of face milling cutter was used during this procedure: $l=S/(4\cdot n)$, where n is the cutter rotation frequency (r/min) while factor «4» considers the existence of four cutting blades on the face-milling cutter used during work. The linear scales obtained in this way are denoted on the sides of squares in the images of Fig. 1, 2.

Photographic images of the surface, obtained in the work, contain information about the surface relief of the workpieces. A typical form of these data is represented in Fig. 3, 4.

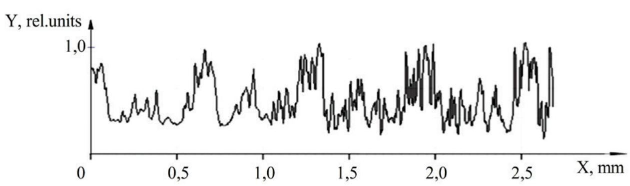

Fig. 3. Typical form of the surface profile of plate after face milling (machined material – steel 35, S=400 mm/min, t=1 mm, n=125 r/min)

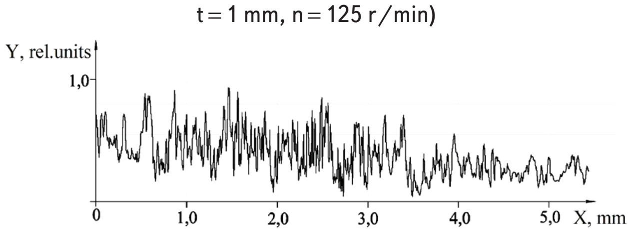

Fig. 4. Typical form of the surface profile of plate after face milling (machined material – steel 35, S=25 mm/min, t=1 mm, n=125 r/min)

An analysis of the surface profile will make it possible to subsequently substantiate approach to the realization of fractal analysis for the surface area of such a complex, self-similar structure.

6. Discussion of the results of examining the fractal structure of a surface

Before discussing the results obtained, it is necessary to point to the features of the relief of the received surfaces.

Fig. 3 vividly shows that at high values of the feed, a relief of the surface is a superposition of at least two oscillating processes. One of them is related to the strictly periodic motions of cutting edges of the cutter and manifests itself in the rectangular pulse fluctuations of surface relief. This picture of cutting is superimposed with stochastic fluctuations, caused by oscillations of both the process of cutting itself and natural fluctuations of the interconnected technological machining system. It is natural that under different conditions of cutting, the influence of each of the indicated predominating factors on shaping the resulting surface relief proves to be different. Actually, if at high magnitudes in the feed of S, flat microsegments at the surface profile manifest themselves sufficiently vividly (Fig. 3), then at small feeds these sections practically cannot be isolated because they appear to be depressed by the intensive natural oscillations of the technological system (Fig. 4).

It directly follows from the represented observation that there is the following approach to studying such a complex periodic structure. Thus, if the volume of the space is exposed to analysis, where, mainly, the rapidly changing and sufficiently high-frequency natural oscillations of the technological system are manifested, then the results of running a fractal analysis must be connected precisely to the description of this self-similar, periodic process. In the situation when calculated areas include a sufficient number of flat sections, connected to the passage (trace) of tool cutting edges, and they are sufficiently large, then the result of analysis should be linked to the periodic nature of the very process of cutting.

Therefore, a focus in the performed fractal analysis of the surface parameters was shifted towards a separate study of patterns that govern a change in the Hausdorff dimensions for a surface of small size and the size, which includes the entire complex of traces from the passage of cutter tooth.

It is also necessary to indicate that the consequence of changing a statistical basis of fractal analysis at any of the approaches indicated is the need to employ a significant volume of experimental data on the condition of surface area. This is required for the successful realization of the method of least squares when searching for Hausdorff dimension, that is, the basic unknown parameter of the system. In practice, this indicates the existence of the smallest possible size of the surface area under investigation. Otherwise, it is not possible to consider the application of statistical methods of analysis substantiated due to the absence of the required set of initial data. These considerations set the limitations on a minimum quantity of pixels, which must remain when creating an image of minimal size. In present work, it was assumed that such a minimal size corresponds to the quantity of pixels at the level of 200 per each side of the square of the processed image. At this selection, an amount of initial data for subsequent calculation of the areas of those microscopic sections, which approximate the entire area of surface relief, appears to be fully sufficient for the stable realization of statistical component of the fractal analysis [2, 8, 9, 12].

The minimum linear size of a surface image for the experiments in this work contains about 200 pixels, which corresponds to the size of real surface of about 1 mm. Thus, the expressed considerations make it possible to assert that the Hausdorff dimensions, calculated for the images of surfaces should be related to the oscillating processes in the technological system. At the same time, estimated values of Hausdorff dimensions, found at processing images with a significant quantity of traces of the cutter tooth passage, that is, about 6...7 mm (1500 pixels), should, in the first place, be related to the description of conditions for the very method of surface machining.

The approach described above allowed us to carry out calculations of the Hausdorff dimensions for the images of surface, which are shown in Fig. 1, 2. The main results of applying the software for fractal analysis to these images are shown in Fig. 5–7. Thus, Fig. 5 shows, as an example, the dependences of statistical totals $Z(l_k)$ on the reduced length of the edge of cell in the rough partition method, which were obtained during the computation of images in Fig. 1.

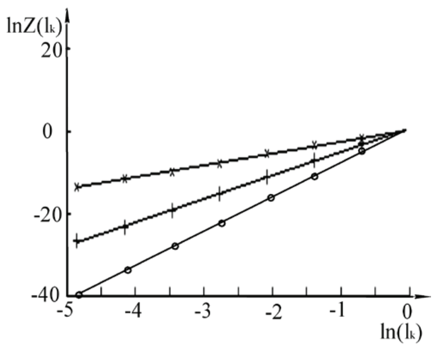

Fig. 5. Dependence of statistical total $Z(l_k)$ for the relief surface area on the normalized length of the edge of cube l_k in the rough partition method at calculating the Hausdorff number for the surfaces shown in Fig. 1, *c* (×), Fig. 1, *d* (+), and Fig. 1, *e* (○)

It follows from Fig. 5 that the experimental data are distinctly grouped along the straight lines. A typical value of correlation coefficients in the method of least squares in the implementation of the rough partition method, as a rule, exceeded 0.93, changing, naturally, from one sample to the next one. Sufficiently high values of correlation coefficients allow us to argue about the presence of self-similar structures in the surface relief and, obviously, the existence of fractal symmetry for the elemental areas at the surfaces obtained as a result of milling.

Fig. 6 shows data on the Hausdorff dimensions of the samples' surface area dependent on the linear size of the side of the image square, used in the analysis, for the case of different magnitudes in the cutter feeds when machining the steel 35 and alloy D16T. Lines were drawn by the method of least squares with the use of third power polynomials. It is obvious that the application of polynomials of higher power would provide for a substantial improvement in accuracy in the description of experimental data. However, an increase in the powers of the approximating polynomials could lead to the occurrence of oscillations in the required polynomial functions, characteristic of the polynomials of high power. Specifically, these considerations limited the power of the employed polynomials only by third power.

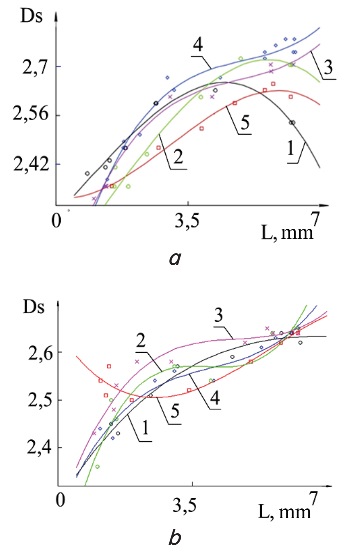

Fig. 6. Dependence of the Hausdorff dimensions of the surface area on the linear size of side of the square of the analyzed image at different values of feeds for the machined materials: *a* — steel 35, *b* — alloy D16T (t = 1 mm, n = 125 r/min): 1 — S = 25 mm/min; 2 — S = 50 mm/min; 3 — S = 100 mm/min; 4 — S = 220 mm/min; 5 — S = 400 mm/min

It follows from Fig. 6 that there is an essential dependence of the Hausdorff dimension for the area of surface relief on the surface area, along which a fractal averaging takes place. In this case, the tendencies in the compared dependences for the materials, which differ considerably in their physical-mechanical characteristics, prove to be similar. This situation is not unexpected. Actually, according to the considerations expressed earlier, a change in the size of analyzed surfaces will unavoidably be reflected in the magnitude of contribution from each of the above-discussed periodic processes into an overall magnitude of the Hausdorff dimension.

Fig. 6 also shows the analyzed dependences in the Hausdorff dimensions for the surfaces, which were obtained at different magnitudes of the feed of workpiece S. It was generally expected that an increase in the magnitude of feed had to lead to the shift of the examined curves towards the increase in dimensionality of the surface area. Actually, an increase in the magnitude of feed of a workpiece unavoidably stimulates an energy increase, added to the technological system at cutting. The latter must find its reflection in shaping the rougher, more developed surface, which will specifically affect an increase in the Hausdorff dimension. However, calculations revealed that this simplified understanding is not always applicable. It follows from Fig. 6 that the discussed dependences take place in parallel to each other not in all the sections of surface, but sometimes they even intersect. Such a motion may be related to the competitive influence of at least two oscillating processes, which were discussed earlier, and whose contribution into an overall magnitude of fractal dimensionality for the area depending on the magnitude of feed can be different.

The overall tendency in the considered dependence somehow does not cover data on the Hausdorff dimensions for the magnitude of S feed at 400 mm/min. This change in dimensionality at large feed can be treated as a consequence of the emergence at the surface of a new periodic structure, when sufficiently high-frequency oscillations of the technological system are distinctly modulated by the low-frequency, rectangular fluctuations, created by the milling cutter teeth passage.

Data of Fig. 6 allowed us to obtain dependences of the Hausdorff dimensions on the magnitude of feed for different dimensions of the analyzed area both for steel and alloy D16T. These results are shown in Fig. 7. Straight lines in Fig. 7 are drawn by the method of least squares, applied for the appropriate set of experimental results.

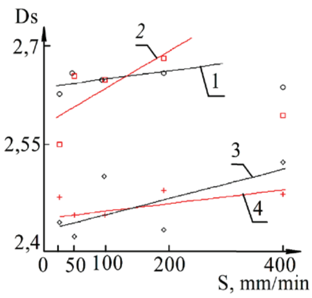

Fig. 7. Dependence of the Hausdorff dimension of the surface area on the magnitude of workpiece feed for different values of length of the side of the square of the analyzed image L: 1, 2 — L = 6 mm; 3, 4 — L = 1.5 mm (machined material: 1, 3 — steel 35; 2, 4 — alloy D16T)

A consideration stated above is confirmed by data on the surface microrelief in Fig. 4 where the rectangular strictly periodic oscillations of relief are distinctly visible, created by the passage of milling cutter tooth. At the same time, at low magnitude of feed, such bands are lost in a general picture of the oscillations, related to the fluctuations of the entire technological system (Fig. 4).

It directly follows from the previously mentioned that it is important to select the dimensions of space, which will be processed in accordance with the methods of fractal analysis. Actually, if the methods of fractal analysis are applied to the region of space, in which the rapidly changing natural fluctuations of technological system are observed, then the output parameters of such analysis should be linked to such a self-similar process. At the same time, if the dimensions of the region being investigated include an entire set of periodic traces from the passage of tool teeth, then such fractal parameters of the system, first of all, should be related to a periodic progress of the process of shaping the surface by face milling. It is only natural that for the intermediate sizes of the investigated surface regions, the fractal parameters of relief will reflect the impact of each of the factors indicated to a considerable degree.

It follows from Fig. 7 that with an increase in the feed, the dimensionalities of surface areas for both materials grow. This corresponds to a common, and known in practice, tendency to provide for the rougher, non-planar surfaces at the more rigid, energy consuming conditions of cutting, which include the machining mode at large feed. At the same time, generalizing data in Fig. 7 illustrate the presence of a different magnitude in the «sensitivity» of fractal parameters of relief to a change in the magnitude of feed for different materials. This assertion is a consequence of the different magnitudes in the slopes of the indicated straight lines. In this case, according to the data obtained, for a less strong material, D16T, roughness of the surface relief grows less intensively with an increase in feed than that for steel. This tendency is in good agreement with known provisions in material processing [19].

7. Conclusions

1. Based on the optical system of microscope XS-2610 MICROmed, we created an installation and defined its parameters for efficient operation to obtain photographic images of the articles' surface with resolution at the level of 0.05 mm. Photographs of the surface of plates made of steel 35 and alloy D16T were taken after their face milling at variable feed values from 25 mm/min to 400 mm/min.

2. A fractal analysis is adapted for computing the Hausdorff dimension for the surface area of the plates' microrelief after face milling and it is used to analyze the fractal parameters of surface at dimensions of the averaged space of 1×1 mm^2 and 5×5 mm^2. We obtained dependences on the magnitudes of fractal parameters for the surface area with the rate of feed for workpieces made of steel 35 and alloy D16T. It is shown that an increase in feed from 25 mm/min to 400 mm/min leads to an increase in the values of Hausdorff dimensions for the surface relief area at dimensions of its analyzed surface 5×5 mm^2 from 2.55 to 2.68, and with dimensions 1×1 mm^2 – from 2.43 to 2.51.

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MODELING OF THE CORROSION PROCESS IN STEEL OIL PIPELINES IN ORDER TO IMPROVE ENVIRONMENTAL SAFETY

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Розглянуто фактори, що впливають на екологічну безпеку експлуатації нафтопроводів. Розв'язана задача моделювання електрохімічної корозії трубопроводу в тріщині ізоляційного покриття при дії агресивного по відношенню до металу трубопроводу електролітичного середовища, котра зводиться до визначення стаціонарного електричного поля, що виникає при роботі гальванопари. Перевагою даної моделі є можливість прогнозування розвитку корозії сталі за часом, що є важливим при визначенні залишкового ресурсу трубопроводу

Ключові слова: сталевий нафтопровід, електрохімічна корозія, гальванічний елемент, модель корозії, швидкість корозії, екологічна безпека

Рассмотрены факторы, влияющие на экологическую безопасность эксплуатации нефтепроводов. Решена задача моделирования электрохимической коррозии трубопровода в трещине изоляционного покрытия при воздействии агрессивной по отношению к металлу трубопровода электролитической среды, которая сводится к определению стационарного электрического поля, возникающего при работе гальванопары. Преимуществом данной модели является возможность прогнозирования развития коррозии стали со временем, что является важным при определении остаточного ресурса трубопровода

Ключевые слова: стальной нефтепровод, электрохимическая коррозия, гальванический элемент, модель коррозии, скорость коррозии, экологическая безопасность

1. Introduction

Ukraine as a whole and Poltava region in particular has a well-developed network of oil pipelines, oil-product pipelines and gas pipelines whose average operation period exceeds 30 years while the first built oil pipelines have been in operation for more than 48 years [1, 2]. Prolonged interaction between pipe metal and the environment leads to the