Environment. Technology. Resources. Rezekne, Latvia
Proceedings of the 14th International Scientific and Practical Conference. Volume 3, 159-163

Solving Functional-Technological Problems Using a Non-Parametric Approach for Control of Microgeometry of the Surfaces of Details

Dimilyan Leonov
Department of Mechanical Engineering Equipment and Technologies
Technical University of Gabrovo
Gabrovo, Bulgaria
dimilqn@gmail.com

Hristo Metev
Department of Mechanical Engineering Equipment and Technologies
Technical University of Gabrovo
Gabrovo, Bulgaria
hmetev@abv.bg

Kalin Krumov
Department of Mechanical Engineering Equipment and Technologies
Technical University of Gabrovo
Gabrovo, Bulgaria
kalin_krasimirov_krumov@abv.bg

Angel Lengerov
Department of Mechanical Engineering Equipment and Technologies
Technical University Sofia, Branch Plovdiv
Plovdiv, Bulgaria
anlengerov@abv.bg

Abstract. **In the article considers the effect of surface roughness on the functioning of a specific mechanism. In case of proven dependence of the studied functional property of surface microgeometry, a process of optimization of the sought parameter is carried out, in which the methods of mathematical analysis and theoretic foundations of technology of appliance and mechanical engineering are used for the basis of the theoretical studies. As control parameters of the specified optimal microgeometry, deciding the given task, the so-called non-parametric criteria are used, namely graphical of certain surface-profile functions.**

Keywords: surface roughness, non-parametric method, graphic images, theory of experimental planning.

I. INTRODUCTION

Increasing the quality of the manufacturing output is the most important task of the industry [1] – [4]. The task is especially topical for mechanical and instrumental engineering, where multiple technological problems, related to the functioning of the manufactured products need to be solved. The role of the state of the surface layer of the details in the given process is generally recognized, though the problems, related to optimization of the surface microgeometry remain the least researched.

It has been established so far that the roughness of the surfaces affects about 20 of their functional properties (adhesion, corrosion resistance, force of friction etc.). However, the task to optimize the surface microgeometry cannot be reliably solved by using the standardized parameters (ISO 4287), since they often do not reflect the real nature of the surface relief. By setting a specific value to the roughness parameter in the technical documentation, and trying to comply with it, we can process a surface and obtain one of the numerous possible micro-reliefs, which will provide different functional properties - to give an example, two mirror-like profiles, describing totally different microreliefs, have the same parameters [5], [6].

Most surface treatment methods produce a random roughness profile. Therefore, the theory of random functions can be used to model the surface roughness, which actually means that the profile of a real surface can be regarded as a realization of a random variable.

On this basis Prof. Valetov proposed a fundamentally new approach to surface roughness evaluation and

Print ISSN 1691-5402
Online ISSN 2256-070X
https://doi.org/10.17770/etr2023vol3.7230

control – a method, using non-parametric criteria, in the role of which the graphs of various functions are taken [7] – [11]. Considering the random component in the process of forming the surface microrelief and based on the theory of random functions, it is clear that the biggest amount of information about the profile as a random variable is contained in the distribution functions and distribution density of its ordinates, as well as in the distribution functions and distribution density of the tangents of the slope angles of the profile. Thence, the conclusion about the expediency of using these functions as criteria for evaluating and controlling the roughness of the surfaces follows.

II. MATERIALS AND METHODS

A special pneumatic mechanism, shown in Fig. 1, was used in this case as an object of study. The basis of its functioning is the outflow of air through the gap between the cylindrical surfaces (pos. Δ) of the sleeve (pos. 1) and the obturator (pos. 2) during the movement of the latter under the action of a spring with certain parameters (pos.3).

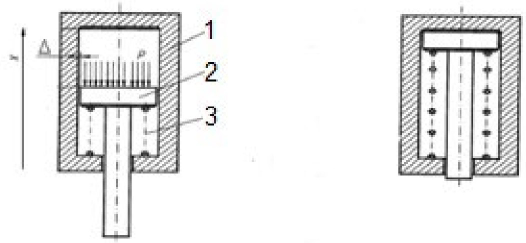


Fig. 1. Pneumatic mechanism.

The process is described by the following system of equations (1):

$$\begin{cases} m\frac{d^2x}{dt^2} = -R_{as} + cx(t) + P(t)S_{п} \\ \frac{dM(t)}{dt} = -Q(t) \\ M(t) = \rho(t)x(t)S \end{cases} \quad (1),$$

where *m* is the mass of the obturator, R_{as} – the spring tension in the composition of the assembly, *c* – the spring hardness, *S* – the area, through which the air goes out, *Q(t)* – amount of air per second, *M(t)* – air mass consumption, S_n – area of the functional surface of the obturator, *P(t)* и *ρ(t)* – air pressure and density, *x(t)* – movement of the obturator in the sleeve.

Modeling the process and solving the system of equations (1) in “Matlab” software environment allows for obtaining limiting values of the movement time in the range: 104 ms $\geq t \geq$ 37 ms. The given values match the conditions of friction between the parts (with possible intersection of the axes of the two functional details) and the conditions of absence of friction (pure gas-dynamic process).

The results, obtained when solving the mathematical model, are difficult to reproduce experimentally, due to the impossibility to model accurately the intersection of the axes of the functional details in the mechanism. Therefore, to prove the validity of the performed calculations, a representative sample from a general set of mechanisms of the given type was considered, with fixing the time of the obturator movement in the sleeve [12]. It showed that for a batch of 12000 mechanisms a sample of 1200 pcs. is required to claim with a probability of 0,95 that the true value of the average movement time during the operation of the mechanisms will be in the range 78,86 – 81,25 ms.

In addition, the influence of the surface roughness of the nodes in the pneumatic mechanism on the movement time was also studied in the indicated range.

To construct and compare the non-parametric evaluation criteria, the Lemming software product, developed by the Department of Instrumentation Technology at the St. Petersburg National Research University for Information Technologies, Mechanics and Optics (ITMO University) was used [13] – [15].

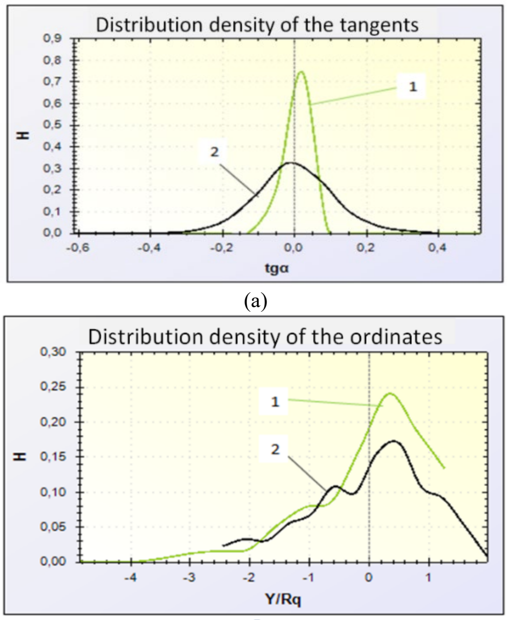
With the help of this program, the obtained profile data were processed in the following sequence:

- Construction of the profile of the studied surface;
- Profile filtration using a straight and inverse Fourier transformation - the filtration was carried out on the basis of the given functional property of the surfaces by comparing the amplitude spectra of the profiles of the studied surfaces before and after the moment of functional impact on them.
- Calculation of the standardized roughness parameters according to ISO 4287;
- Calculation and construction of the non-parametric criteria for evaluating the profile of the surfaces.

Prior to functional property verification, roughness data were taken from the surface of each sample. After processing the obtained profile data, graphs of the non-parametric criteria for these surfaces were drawn (Fig.2).

From the graphs in Fig.2. it follows that the technologies of machining sleeves and obturators allow for providing the same standardized criteria for their surface roughness. However, the more informative non-parametric criteria indicate, that these microreliefs are different.

Another important conclusion drawn up from the conducted research is the effect of the surface roughness of the two details (sleeve and obturator) on the movement time of the obturator in the sleeve, which defines the operation of the specified mechanism. This effect justifies the necessity of carrying out a process of optimization of the respective microgeometries.



(a)

(b)

Fig. 2. Distribution densities of the tangents of the slope angles of the profiles (a) and distribution densities of the ordinates of the profiles (b) (H-frequency of repetition of the corresponding value of the tangent (a); H- frequency of repetition of the corresponding values of the dimensionless amplitude (b); 1 – sleeve surface roughness corresponding to $R_a = 0.32$ µm, 2 – obturator surface roughness corresponding to $R_a = 0.30$ µm).

At the second stage of the research, possibly the most appropriate for specific manufacturing conditions surface roughness of sleeves and obturators, ensuring the optimal value of the functional property, were defined. With the aim of organizing the process of optimization of the microgeometry of the surfaces, the theory of experimental design was used.

The optimization, based on the theory of experimental design and the use of non-parametric criteria for evaluating the roughness of the surfaces, includes the following main stages [16], [17]:

- selecting/choosing the optimization parameter;
- determining the factors of the technological process and their changes;
- designing the experiment plan or the planning matrix;
- obtaining information about the surface roughness of each sample;
- processing of the profiles and constructing the non-parametric criteria for evaluation of the microgeometry;
- conducting the experiments according to the plan for their implementation;
- performing a statistical analysis in order to derive a regression equation, expressing the relationship between the parameter and the optimization factors;
- assessing the adequacy of the obtained mathematical model.

III. RESULTS AND DISCUSSION

Microgeometry optimization should be understood as choosing the most suitable, possibly the best microgeometry for particular production conditions. In the given task, when justifying the parameter and the optimization factors, it is necessary to analyze the specific solutions.

The movement time (t) of the obturator in the sleeve within the mechanism assembly was taken as an optimization parameter. The additional calculations and the experimental studies show that the optimal value of the movement time during the operation of this type of mechanisms is 80 ms with a possible tolerance of ± 10 ms.

The technological process of machining sleeves includes drilling, countersinking/chamfering, reaming, honing, zinc coating and polishing. The technological process of obturator processing includes rough turning, finish turning and grinding. The modes of finish machining of both parts were chosen as optimization factors. Based on the capabilities of the technological equipment and on the results of preliminary studies (part of their graphs are shown in Fig. 2), the ranges of their changes were selected (Table 1):

TABLE 1

Factor	Coding notation	Range of changes	Levels of factor values		
			Low (–1)	Base (0)	High (+1)
Feed rate for polishing $V_{f,\ pol}$	X_1	±0,4 m/min	0,1	0,5	0,9
Polishing speed $V_{c,pol}$	X_2	±15 m/s	20	35	50
Circular feed when grinding $V_{f,\ gr}$	X_3	±1,5 m/min	5	6,5	8
Grinding wheel speed $V_{c,gr}$	X_4	±10 m/s	20	30	40

Since the factors in the optimization process are non-uniform and have different measuring units, and the values, expressing their magnitudes are of different orders, they are reduced to a single system of calculations by a transition from the actual values of the factors to coded ones (2):

$$\widetilde{X_\iota} = \frac{X_i - X_{ibas}}{\Delta x_i} \qquad (2),$$

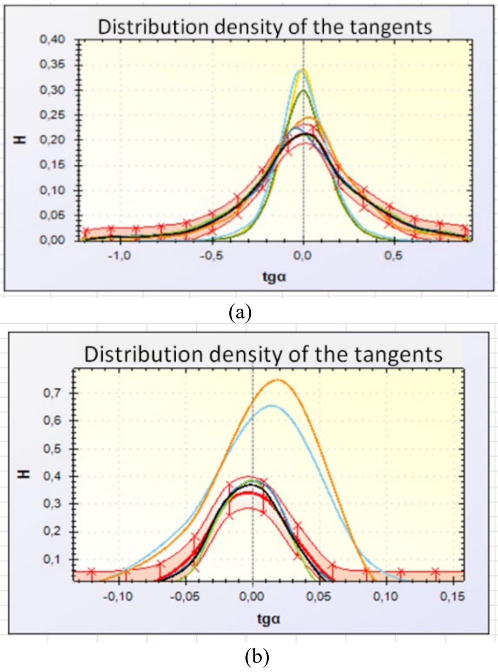
where – $\tilde{X}_i$ is the coded value of the factor; X_i –actual values of the factor; X_{ibas} – value of the factor at the basic level; ΔX_i – current factor variation interval; i – number of the factor.

In result from a subsequent statistical analysis in accordance with the theory of experimental design [18], an adequate to Fisher's criterion mathematical model of the studied process was obtained in the form of a regression equation, pointing at the relationship between the movement time of the nodes in the mechanism and the technological processes of machining the contact surfaces of the two details (sleeve and obturator) (3):

$$t = 74{,}25 + 17{,}5V_{f,pol} - 6{,}5V_{pol} - 5{,}25V_{f,gr} - 2V_{gr} - 2V_{pol}V_{f,gr} \qquad (3)$$

The sign of the coefficients of the variable factors in the regression equation defines the nature of the influence of each of them on the parameter under optimization. The values of the coefficients point at the degree of influence of each of the factors on the movement time during the operation of the studied mechanism. Consequently, when controlling the process, much attention should be paid to the modes of sleeve polishing, although the obturator grinding modes, as well as the mutual interference of the polishing speed and grinding feed rate also have certain influence.

Following the described methodology in the optimization process, when controlling the roughness of the specific surfaces of the sleeves and obturators, it is proposed to use the graphs of the functions of the distribution density of the tangents of the slope angles and the dimensionless ordinates of the profiles. As an example, reference graphs are given, titled “Density of distribution of the tangents of the slope angles of the profile” and tolerances are set for possible deviations in performing control in series production of sleeves and obturators (Fig. 3). The figures present graphs, satisfying the required movement time values, which fall within the tolerance field, on the one hand, and graphs, which are outside the tolerance field because of not meeting the requirements, on the other hand.



(a)

(b)

Fig. 3 - Reference graph "Density of distribution of the tangents of the slope angles of the profile" with a tolerance for possible deviations: (a) for the sleeves, (b) for the obturators.

The tolerance value in Fig.3 was chosen to be 30%, due to the scattering, resulting from superimposing of the graphs of all surfaces at an allowable value of the functional property. The given graph illustrates once again the informativeness of the non-parametric criteria for roughness control of the surfaces, while the efficiency and expedience in their use for solving tasks, related to optimization of the microgeometry, is also proved in a number of similar studies [19] – [25].

In conclusion of the study the determination of the most appropriate (reference) microrelief from the possible ones for the specific functional property of the surfaces, allows for obtaining also the technological methods of reproducing the given microrelief: $V_{f,pol}$ =0,572 m/min; $V_{c,pol}$ =34 m/s; $V_{f,gr}$ = 49,2 m/min; $V_{c,gr}$= 29,8 m/s.

IV. CONCLUSION

The proposed methodology for optimization of the surface microgeometry can be applied in the analysis of any functional property in any type of production conditions. Moreover, the research allows for creating a database with determination of optimal technological treatment modes for specific properties of the surfaces, which can be used by other production enterprises, possessing the same type of technological equipment. The non-parametric approach, used as a basis for analysis, evaluation and control, allows to unambiguously determine the optimal microgeometry, to reproduce the technological process for achieving it, and to quickly perform quality control under the conditions of serial production by comparing with the reference. The fulfillment of these conditions allows to increase the quality of the issued production for the specific enterprise.

REFERENCES

[1] V.M. Musalimov, V.A. Valetov. Dynamics of frictional interactions: Monograph: in 2 parts. - St. Petersburg: PIMash Publishing House (State St. Petersburg Institute of Mechanical Engineering LMZ-VTUZ)), 2006., p. 191 (in Russian).

[2] H. Metev, K. Krumov, A. Lengerov. Determination of inoccoracies in the reporting by turning the phenomenon of heredity technology. Journal of the Technical University - Sofia, Plovdiv branch, Bulgaria « International Scientific Conference on Engineering, Technologies and Systems TECHSYS 2018». –P. 227–232.

[3] V.A. Valetov. Additive technologies (state and prospects). Tutorial. - St. Petersburg: ITMO University, 2015, p.63.

[4] Chirag Patel, Mangal Bhatt. Investigation of Phy-sical Characteristics and Machining Parameters of Impro-ved Al-SiC MMC Using Dry EDM Process for Aerospace Industries. JoEAM. 2018. P. 15–32.

[5] A.Y. Ivanov, D.B. Leonov. Methodology for optimization, evaluation and control of products surface roughness // Journal of the Technical University - Sofia, Plovdiv branch, Bulgaria «Fundamental Sciences and Applications». – 2012, Volume 17, pp. 19–23 (in Russian).

[6] E. Filimonova. Automation of the control of microgeometry of machine parts and devices’ surfaces using topography, IX All-Russian Mechanic University Conference of Young Scientists. 5th session of the scientific school "Problems of mechanics and accuracy in instrumentation". - St. Petersburg, 2012. - Issue. 1. - pp. 132 - 136. - 152 (in Russian).

[7] V.A. Valetov. Feasibility of changing the standard for surface roughness of parts. Intercollegiate collection No. 6. St. Petersburg, Northwestern State Polytechnic University, 1997, pp. 118-121 (in Russian).

[8] I.N. Gibadullin, V.A. Valetov. Image of the surface profile as a graphic criterion of its roughness. Journal of Instrument Engineering. 2019. Vol. 62, N 1. P. 86—92 (in Russian).

[9] V.A. Valetov, I.N. Gibadullin. Surface roughness of parts and quality of functional properties of products //Journal of Metalworking, Politechnika Publishing House, 2017. V. 101, No. 5. pp. 38-43.

[10] I.N. Gibadullin, V.A. Valetov. Automated control of the microgeometry of surfaces of parts using graphic images of profiles. Journal of Instrument Engineering (Izvestiya vysshikh uchebnykh zavedeniy. Priborostroenie), 2017. V. 60, No. 3. pp. 287-289.

[11] V.A. Valetov. Problems of optimization of workpiece surface microgeometry to ensure specific functional properties. Journal of Instrument Engineering, 2015, vol. 58, no. 4, pp. 250–267 (in Russian).

[12] D.B. Leonov. Technological methods for controlling the roughness of the product surfaces // Collection of scientific papers from the 2012 scientific session at Vasil Levski National University, Part 1., Shumen, 2012, pp. 77–81 (in Bilgarian).

[13] V.A. Valetov, E.A. Filimonova, Program for automated control of surface microgeometries using non-parametric criteria, Metalworking, No. 5, 2011, pp. 44-47 (in Russian).

[14] V.A. Valetov, E.A. Filimonova, Automation of surface microgeometry control using non-parametric criteria, Materials of the 14th International Scientific and Practical Conference, Saint Petersburg, 2012 (in Russian).

[15] E.A. Filimonova. Development of Methodology and Software for Automated Control of Instruments Surface Microgeometry using Graphical Criteria and their Application in Technological Research. Eng. Sci. Dis. Thesis. St. Petersburg, 2014, 24 p (in Russian).

[16] A.Y. Ivanov, D.B. Leonov. Assessment of the influence of surface roughness on the corrosion resistance of machine-made products // Scientific and technical journal of information technologies, mechanics and optics. – 2013, Issue 6(88), pp. 144–147 (in Russian).

[17] D.B. Leonov, I.L. Lilov. Metodology for optimizing the influence of surface roughness of the functional properties of details in mechanical engineering // Machines, Technologies, Materials. – 2015. - Issue 5. – P. 46–47.

[18] Guidelines 109-77. Methodology of selection and optimization of controllable parameters of technological processes. Intr.01.07.1978, M, Standards Publishing House, 1978, 48 p (in Russian).

[19] Yu.S. Andreev, N.A Demkovich, R.M. Isaev, A.A. Tselishchev, S.D. Vasilkov. Determination of the microgeometry of the functional surface of a part that provides the required performance of an aviation vibration sensor // Scientific and technical bulletin of information technologies, mechanics and optics. 2016. V. 16. No. 6. pp. 1103–1110. D.

[20] V.V. Maksarov, R.V. Vyushin, A.E. Efimov. Technological support of surface layer roughness based on transient modeling // Journal of Metalworking, Politechnika Publishing House, 2017. No. 2 (98). pp. 39–46.

[21] S.D. Tretyakov, O.S. Yulmetova. On the problems of optimizing the microgeometry of the surface layer of instrument parts. Journal of Instrument Engineering (Izvestiya vysshikh uchebnykh zavedeniy. Priborostroenie), 2010. V. 53, No. 8. pp. 12-15.

[22] Yu.S. Andreev, V.V. Medunetsky. Research of surface microrelief changes during their sliding friction. Journal of Instrument Engineering (Izvestiya vysshikh uchebnykh zavedeniy. Priborostroenie), 2012. V. 55, No. 9. pp. 30-34.

[23] V.A. Krasny, V.V. Maksarov. Tribotechnical characteristics of mining machine parts with regular surface microgeometry, Journal of Metalworking, Politechnika Publishing House, 2016. No. 1 (91). pp. 29–36.

[24] O.S. Yulmetova, M.S. Tutova, R.F. Yulmetova. Chemical analysis of thin-film's colour generation during surface laser oxidation of TiN-coating. Journal of Physics: Conference Series. 2018. Vol. 1124. No. 8. pp. 081010. [Тип: Статья, Год: 2018]

[25] T.O. Tolstykh, L.A. Gamidullaeva, E.V. Shkarupeta. Key factors in the development of industrial enterprises in the conditions of industry 4.0 // Russian journal of industrial economics, 2018. V. 11, No. 1. pp. 11-19.