UDC 621.92:621.9.015

[0000-0002-9374-2550] **L. Ya. Ropyak,** *Doctor of Technical Sciences, Associate Professor,*
e-mail: L_ropjak@ukr.net
[0000-0002-5302-3623] **M. V. Shovkoplias,**
[0000-0003-3682-1612] **V. S. Vytvytskyi,** *Ph. D.*
Ivano-Frankivsk National Technical University of Oil and Gas
Karpatska st. 15, Ivano-Frankivsk, 76019, Ukraine

DETERMINATION OF MACHINING ALLOWANCE FOR PARTS WITH CHROME COATINGS

The analysis of methods of determination of allowances for machining of coatings is carried out. The surface roughness after diamond round grinding of electrochemical chrome coatings applied in quiet and flowing electrolytes is investigated. It is established that the thickness of the defective layer depends on the method of applying the electrochemical chrome coating. Chrome coating of steel parts in a flowing electrolyte provides a smaller thickness of the defective layer compared to chrome coating in a quiet electrolyte. It is also established that the minimum allowance for obtaining surfaces with minimum roughness after diamond grinding of electrochemical chrome coating depends on the total thickness of the coating and increases with its growth. The scientific novelty of the obtained research results lays in the specification of dependence of the thickness of defective surface layer on the operational layer of chrome electrochemical coatings applied in quiet and flowing electrolytes on cylindrical steel parts to provide obtaining the processed surface with the minimum roughness after diamond round grinding. The practical value lies in the fact that an engineering method for calculating allowances for machining (diamond grinding operation) of cylindrical steel parts with chrome electrochemical coatings has been developed.

Keywords: *chrome electrochemical coating, surface roughness, machining allowance, diamond grinding, rod, piston pump.*

Introduction. Functionally oriented technologies for the manufacture of machines and mechanisms involve strengthening the operational surfaces of parts by composite [1-5], oxide [6, 7] and polymer coatings [8], at the same time it is necessary to pay attention to preparation of a surface before coating [9] and to study their stressed state [10] for establishment of admissible levels of stresses in the parts with coverings.The application of wear-resistant and corrosion-resistant coatings on the operational surfaces of pump parts, such as plungers, rods, bushings, etc. allows to rationally combine the properties of coating material and the base material, while ensuring high performance [11]. In modern mechanical engineering there are increased requirements for the quality of the operational surfaces of machine parts [12, 13]. In particular, such indicators as: hardness, wear resistance, roughness, accuracy of dimensions, shape and relative position of surfaces, conicity, roundness, beating, misalignment, etc. are regulated. Moreover, the hardness of the surface is provided by a rational choice of coating material, technological modes of its application and heat processing at the stage of parts construction. And the parameters of quality and accuracy of the operational surfaces of these parts, for example, the parameters of surface roughness, are achieved by rational choice of technological modes of coatings machining by removing the allowance to remove the defective surface layer of the reinforced part, which is especially true for hard-to-process materials, such as chrome coatings. To ensure the operability of machines and mechanisms during the product life cycle, an important place also belongs to the operational methods that help to preserve the topology of the operational surfaces of machine parts.

Analysis of the latest sources of research and publications. Many researchers [14-16] paid considerable attention to the study of machining processes of coatings, in particular [17], to ensuring of the accuracy of reinforced cylindrical parts by turning. The works [18-20] studied the force interaction of coatings with an indenter to simulate turning and the work [21] studied this interaction with an abrasive to simulate grinding.

It is proposed in [22] to determine the allowance for machining of parts with sprayed

DOI: 10.24025/2306-4412.2.2021.242339

coating depending on their thickness and strength conditions. This method of determining the allowance removes a layer of coating of considerable thickness.

There is also a method of determining the allowance for processing of parts with gas-thermal coatings [23], which includes layered machining of the sample with the same step and taking into account the presence of a defective layer, which is based on the determination of microhardness.

In [24] it is proposed to determine the allowance for machining of the sprayed coating, which is based on the establishment of the pattern of change in roughness during layered machining. The allowance is determined by the thickness of the removed layer at which the minimum roughness of the processed surface is achieved.

The works [25-27] studied the roughness parameters of smooth, threaded and involute surfaces, respectively, processed by grinding.

In the article [28] the analysis of methods of mechanical processing of microarc oxide coatings is carried out and the results of research of the process of grinding of the parts strengthened by oxide coverings from aluminium alloys by circles on the basis of green silicon carbide are presented. The modes of grinding of the oxide layer of parts, at which the surface roughness R_a = 0.40 … 0.63 μm is achieved and the microhardness of the reinforced layer is not reduced, are proposed.

The works [29, 30] show empirical dependences for definition of roughness of the processed surface of the sprayed ceramic coverings on technological modes of cutting for grinding of the sprayed ceramic coverings.

The analysis of the results of [22-30] shows that they relate to the assignment of allowances for machining of wear-resistant sprayed coatings, i.e. the hard top layer of the coating is removed by machining by cutting and turned into chips, which leads to irrational costs for hardening and machining of work surfaces with coatings. In the monograph [31] it is recommended to assign the values of allowances for machining of galvanic chrome coatings, which are applied in a quiet electrolyte on the part, depending on the thickness of chrome coating. But nothing is indicated about the magnitude of the roughness of the processed surface of chrome coating on the part.

However, in the normative literature there is also virtually no information on the selection or calculation of allowances for machining by diamond grinding of electrochemical chrome coatings.

The purpose and objectives of the study. The work aims at the development of an engineering method for determining the allowances for machining of steel parts with chrome electrochemical coatings applied in a quiet and a flowing electrolyte, respectively, to ensure the required accuracy and roughness of outer cylindrical surfaces by diamond grinding.

Statement of the task. To achieve this goal it is necessary to solve the following tasks:

- to establish the dependence of the thickness of the defective surface layer on the thickness of the operational layer for chrome electrochemical coatings, applied in quiet and flowing electrolytes, on cylindrical steel parts;
- to determine the minimum allowance for machining, which ensures the minimum roughness of the processed surface of chrome coating by diamond grinding.

Presentation of the main material.

Research methodology. The coating was applied to steel in quiet and flowing electrolytes on an upgraded device with an automated control system of technological parameters of the process of electrochemical chrome coating according to the technology described in [32]. The surface roughness of cylindrical specimens with chrome coatings after round grinding with diamond wheels on a 3A151 machine was investigated. Geometric dimensions of a rod of the drilling piston pump were selected from the catalog [33]. A profilometer-profilograph was used to measure the roughness of the processed surfaces.

Approximating polynomials were used to construct analytical dependences of the roughness of the processed surface on the depth of the cut layer by diamond grinding for single-layer electrochemical chrome coatings of different thickness applied in quiet and flowing electrolytes.

Statistical estimates of $\alpha_0,...,\alpha_m$ coefficients of approximating polynomials were obtained by the method of the least squares. The significance of the obtained coefficients was evaluated on the basis of Student's t-test (95 % confidence level) and the number of degrees of

DOI: 10.24025/2306-4412.2.2021.242339

freedom: $n - k - 1$, where n is the number of observations, k is the number of coefficients in the regression equation. The adequacy of the approximation dependence was checked by the Fisher's test. Correlation coefficients were also determined by the known formula for R^2.

Research results. To ensure the accuracy and quality of manufacturing parts of hydraulic part of drilling piston pumps, the operational surfaces of which are coated with chrome, there is a need for the final machining – diamond grinding.

This is due to the fact that during the manufacture of new parts or restoration of worn ones, the layer of coating reaches a significant thickness – 0.3 mm per side or more, which leads to changes in the accuracy of size, shape and roughness of the resulting surface.

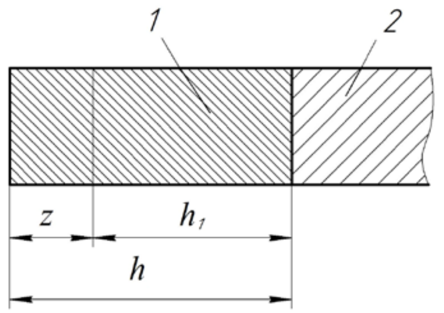
To ensure the operability of piston pump parts (piston rods and cylinder liners) that work in conjunction with rubber parts of the seal in conditions of abrasive flushing fluid, and in order to reduce running time and wear, it is necessary to provide metal elements of friction pairs with chrome coatings by surface roughness within R_a = 0.25… 0.32 μm [33].

The total thickness h (μm) of electrochemical chromium coating applied in the electrolyte (Figure 1) is determined by the formula:

$$h = h_1 + z, \quad (1)$$

where h_1 is the thickness of operational layer of electrochemical chrome coating, μm;

z is the value of the allowance for diamond grinding of electrochemical chrome coating, which provides a processed surface with a given minimum roughness, μm.



1 – the layer of the chrome coating, 2 – steel base

Figure 1 – Scheme of single-layer electrochemical chrome coating

Due to the lack of reference data for electrochemical chrome coatings applied in both quiet and flowing electrolytes, the thickness of operational layer of electrochemical chrome coating is difficult to calculate analytically by formulas. Therefore, it can be determined experimentally depending on the required service life of parts of coated drill piston pumps or calculated by formula (2), pre-setting the wear rate of chrome coatings according to the results of laboratory tests on the stand, in conditions similar to operational ones:

$$h_1 = I_v \cdot t, \quad (2)$$

where I_v is the wear rate, μm/hour;

t is the pre-specified resource of work of a part with a chrome covering, hour.

The minimum allowance for diameter during machining of external and internal surfaces of rotation bodies is calculated by the known formula [34]:

$$2z_{i\,min} = 2(Rz_{i-1} + Rt_{i-1} + \sqrt{\rho_{i-1}^2 + \varepsilon_{yi}^2}), \quad (3)$$

where Rz_{i-1} is the height of profile micro-irregularities (Rz is surface roughness parameter, μm) at the previous machining ($i-1$);

Rt_{i-1} is the depth of the defective surface layer at the previous machining ($i-1$), μm;

ρ_{i-1} is the total value of spatial deviations for the calculated surface at the previous machining ($i-1$), μm;

ε_{yi} is the installation error when performing the i-th machining, μm.

The maximum allowance for machining is

$$2z_{i\,\max} = 2z_{i\,\min} + T_{i-1} - T_i, \quad (4)$$

where T_{i-1} and T_i are dimensional tolerances at the previous machining ($i-1$) and the machining performed (i), respectively, μm.

In the reference and normative literature there is almost no information about the assignment of allowances for machining of electrochemical chromium coatings applied in quiet and flowing electrolytes to achieve a given roughness, so the dependence of the processed surface roughness on the cut layer depth for coatings of different thicknesses was investigated (Figure 2).

The studies were performed on cylindrical steel specimens, on the outer cylindrical surface of which chrome coatings of different thickness h ranged from 0.077 mm to 0.37 mm were applied. After completion of the process of applying electrochemical chrome coatings on the specimens, we carried out machining of the coating for every layer with the constant step of 0.05 mm (depth of cut) by a diamond wheel on a grinder 3A151 and determined the roughness R_a of the processed surfaces by a profilometer-profilograph.

DOI: 10.24025/2306-4412.2.2021.242339

Figure 2 shows the measurement results. The marked points display experimental values of the roughness R_a according to the thickness of the removed layer for each of the above coating thicknesses. Square markers (Figure 2, *a*) refer to the roughness of *h* = 0.08 mm, triangular markers – *h* = 0.3 mm, and rhombic markers (Figure 2, *b*) refer to the roughness of *h* = 0.37 mm; square markers – *h* = 0.08 mm.

Figure 2 shows that the size of the defective surface layer for grinding decreases with decreasing the total thickness of electrochemical chrome coating. For electrochemical chrome coatings applied in a quiet electrolyte with the thickness of *h* = 0.08 mm and *h* = 0.3 mm, the defective surface layer is 12 % and 27 %, respectively, of their total thickness, and when applying coatings in a flowing electrolyte with the thickness of *h* = 0.077 mm and *h* = 0.37 mm it is 10 % and 15 %, respectively. With a further increase in the depth of the cut layer, the roughness of the processed surface of chrome coatings remains virtually unchanged.

For applied electrochemical chrome coatings, acceptable data were obtained during the approximation of the measurement results of the surface roughness parameter by polynomials of the fourth (thin coating) and fifth (thick coating) degrees, respectively (Figure 2).

The correlation coefficients R^2, respectively, were: 0.986; 0.995 (Figure 2, *a*) and 0.929; 0.928 (Figure 2, *b*) for thin and thick coatings, respectively.

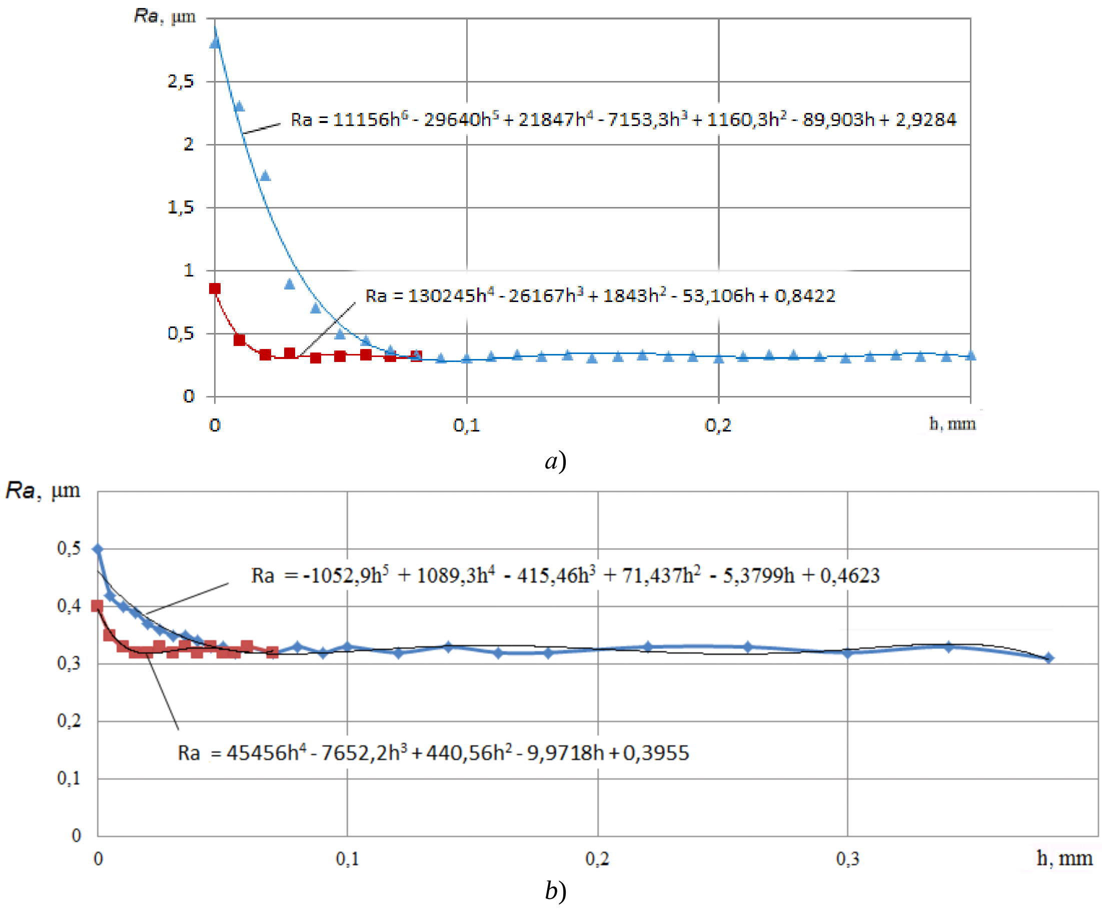


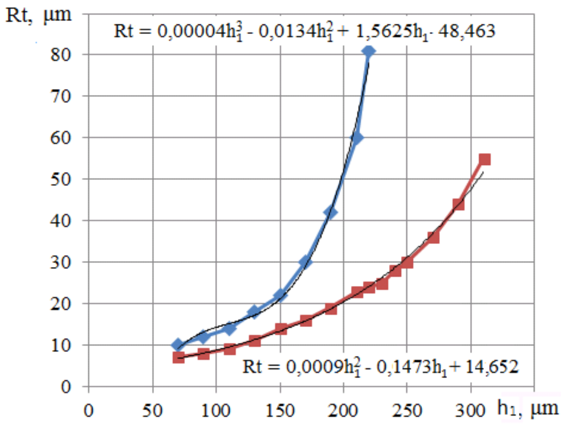
Figure 2 – Dependence of the processed surface roughness on the layer cut depth for single-layer electrochemical chrome coatings of different thickness, applied in quiet and flowing electrolytes

The analysis of graphical dependences (Figure 2) has shown that the roughness of electrochemical chrome coating decreases with increasing the thickness of its removed layer. This indicates the removal of the defective surface layer formed during the application of electrochemical chrome coating. After its removal by diamond grinding the stabilization of roughness of the processed surface of a part is provided, i.e. the qualitative operational layer of electrochemi-

DOI: 10.24025/2306-4412.2.2021.242339

cal chrome covering remains. Since the thickness of the operational layer is an important performance characteristic of the part's coating, we established its effect on the size of the defective surface layer (Figure 3).

Figure 3 shows that with increasing the thickness of the operational layer of electrochemical chrome coating, the depth of the defective surface layer increases, and this growth occurs more rapidly for coatings applied in a quiet electrolyte compared to coatings applied in a flowing electrolyte. This difference in the depth of the defective surface layer can be explained by different conditions of electrolysis and gas removal from the surface of the part during the application of electrochemical chrome coating.



Rhombic markers – the coating is applied in a quiet electrolyte, square markers – the coating is applied in a flowing electrolyte

Figure 3 – Dependence of the depth of the defective surface layer on the thickness of the operational layer of electrochemical chromium coating

After mathematical processing of experimental data we obtained regression equations, presented in Figure 3, which allow to determine the depth of the defective surface layer depending on the thickness of the operational layer to ensure the minimum roughness of the processed surface during diamond grinding of electrochemical chrome coating applied in a quiet electrolyte and in a flowing electrolyte, respectively.

Let's consider an example of calculating the allowance for diamond grinding in the centres of the outer cylindrical surface of the piston rod $\varnothing 70e8(^{-60}_{-106})$ of the drilling piston pump UNB-600. Given the service life of the piston rod t = 300 hour and using the results of our laboratory studies of the wear rate I_{v1} = 0.7 µm/hour for the chrome coating applied in a flowing electrolyte; I_{v2} = 1.2 µm/hour for the chrome coating applied in a quiet electrolyte; according to formula (2) we calculated the required thickness of the operational layer of electrochemical chrome coating applied in a flowing electrolyte h_1 = 0.7·300 =210 µm. To ensure the same service life, a greater thickness of electrochemical chrome coating applied in a quiet electrolyte h_1 = 1.2·300 = 360 µm is required. In order to compare the values of the allowance for diamond grinding, the calculations were performed for the same thickness of the operational layer of chrome coatings h_1 = 210 µm. According to the formulas presented in Figure 3 we determined the depth of the defective surface layer for chrome coating in a quiet electrolyte Rt = 59 µm and in a flowing electrolyte Rt = 22 µm, respectively. The results of calculations of allowances are presented in Table 1.

The analysis of the results of the calculation of allowances given in Table 1 has shown that the allowance for machining of workpieces with chrome-coated parts applied in a quiet electrolyte is greater than the coating obtained in a flowing electrolyte in 2.5 times. This is due to the fact that during the application of electrochemical chrome coating in a quiet electrolyte there is a greater surface roughness, a large conicity is formed, and the depth of the defective surface layer increases at the expense of uneven coating because of the difficulty of gas removal from the coating surface in the process of electrolysis compared with electrolysis in a flowing electrolyte. These disadvantages of chrome coating in a quiet electrolyte are eliminated when coating the parts in a flowing electrolyte, as evidenced, for example, by reducing the cone-like coatings obtained by this method by about 1.7 times and the depth of the defective surface layer by 2.6 times compared to these characteristics obtained for coatings applied in a quiet electrolyte.

The test calculation for parts with chrome coatings was performed according to formula (4). Calculation results for coatings are the following:

– in a quiet electrolyte 272 – 198 = = 120 – 46 = 74 µm;

– in a flowing electrolyte 105 – 77 = = 74 – 46 = 28 µm.

The diameters of the coated workpiece are the following:

– in a quiet electrolyte d_w = 70.152 ± ± 0.06 mm;

– in a flowing electrolyte d_w = 70.008 ± ± 0.037 mm.

DOI: 10.24025/2306-4412.2.2021.242339

Table 1 – **The results of the calculation of the allowance for diamond grinding of the outer cylindrical surface of the piston rod with chrome coatings applied in quiet and flowing electrolytes** $\varnothing 70e8(^{-60}_{-106})$

The route of surface processing with a diameter $\varnothing 70e8(^{-60}_{-106})$	Allowance elements, μm				Estimated values		Tolerance by size *Td*, μm	Limit sizes, mm		Limit values of allowances, μm	
	Rz	*Rt*	ρ	ε_{yi}	allowance $2\,z_{\min}$, μm	min diameter, mm		min	max	$2\,z_{\min}$	$2\,z_{\max}$
Chrome coating is applied in a quiet electrolyte											
Coated workpiece	16	59	24	0	–	70.092	120	70.092	70.212	–	–
Grinding	1.6	–	–	–	198	69.894	46	69.894	69.940	198	272
Chrome coating is applied in a flowing electrolyte											
Coated workpiece	2.5	23	14	0	–	69.971	74	69.971	70.045	–	–
Grinding	1.6	–	–	–	77	69.894	46	69.894	69.940	77	105

With the same thickness of the operational layer, the total thickness of electrochemical chrome coating applied in a quiet electrolyte is $h = 210 + 59 = 269$ μm, and for the coating applied in a flowing electrolyte: $h = 210 + 22 = 232$ μm, which reduces the allowance for mechanical processing and, accordingly, the cost of machining and, besides, increases the service life of chrome-coated rods of double-acting drilling piston pumps.

Discussion. Determination of rational allowances for machining of parts with coatings is an important technical and economic task of mechanical engineering. As underestimated values of allowances lead to the fact that not all the thickness of the defective layer is removed on the processed surfaces, therefore the accuracy of dimensions and the corresponding roughness of the operational surface of the parts are not guaranteed. This reduces the service life of the products. Inflated values of allowances increase the cost of machining: increase the cost of energy, cutting tools, reduce the utilization of metal, which, in turn, leads to increased costs for the production of machine parts and reduce in the competitiveness of products.

Determination of the thickness of the defective coating layer based on the results of measuring the microhardness [23] requires the use of witness samples with coatings and the manufacture of transverse micro-loops and does not take into account the roughness of the processed surface, which is important for parts of machines in friction pairs, especially from polymeric materials.

The dependences obtained in [23, 24] for determining the allowance for machining of a sprayed coating are based on the established regularities of the change in roughness during layer-by-layer machining of this coating. The allowance is determined by the thickness of the removed layer at which the minimum roughness of the processed surface of the sprayed coating is achieved. Since conditions of formation and thickness of sprayed and electrochemical coatings are different, it is incorrect to apply the known dependences for electrochemical chrome coatings. Determining the roughness of the processed surface of the coating by empirical formulas [29, 30] does not take into account the presence of the defective coating layer.

The use of our method for determining the allowances for machining of parts with electrochemical chrome coatings, which is based on the calculation of the thickness of the defective coating layer, that provides the processed surface of chrome coating with minimal stable roughness allows to reduce the running time of elements of reversible friction pair, to improve operating conditions of chrome-coated piston rods, which work in contact with rubber rings sealed in the medium-higher flushing fluid and to increase the service life of double-acting drilling piston pumps.

Conclusions. On the basis of the conducted research it is established that:

- the thickness of the defective layer depends on the thickness of chrome coating and the method of applying electrochemical chrome coating, while chrome coating in a flowing electrolyte provides a smaller thickness of the defective layer compared to chrome coating in a quiet electrolyte of cylindrical parts;
- the minimum allowance for obtaining after round diamond grinding the surfaces with the minimum roughness of electrochemical chrome covering depends on the general thickness of a covering and increases with its

DOI: 10.24025/2306-4412.2.2021.242339

growth, the further processing does not lead to improvement of quality of the operational surface, thus the size of the allowance for processing cylindrical parts that are chrome-coated in a quiet electrolyte is 2.5 times greater than those chrome-coated in a flowing electrolyte.

The scientific novelty of the obtained research results lays in specification of dependence of the thickness of the defective surface layer on the thickness of the operational layer for chrome electrochemical coatings applied in quiet and flowing electrolytes on cylindrical steel parts to provide obtaining the processed surface with the minimum roughness after diamond round grinding.

Practical value – the engineering technique of calculation of allowances for machining (diamond grinding operation) of cylindrical steel parts with chrome electrochemical coverings is developed.

In further research it is planned to study the influence of technological parameters of the process of electrochemical chrome coating on the roughness of the processed coating surfaces and the size of the defective surface layer.

Acknowledgement. The research was carried out within the project funded by the Ministry of Education and Science of Ukraine at the expense of the general fund of the state budget: "Development of environmentally friendly chrome coating technology in a flowing electrolyte of long parts with complex surface topology", D 8-21-P (RK 0121U109591, 2021 – 2022.

References

[1] I. Koval, L. Bodrova, H. Kramar, S. Marynenko, Ya. Kovalchuk, and N. Kondzelko, "Wear resistant hard alloys for agricultural machines elements", *Scientific Journal of TNTU (Tern.)*, vol. 98, no. 2, pp. 33-39, 2020.

[2] V. M. Holubets, M. I. Pashechko, J. Borc, O. V. Tisov, and Y. S. Shpuliar, "Wear resistance of electrospark-deposited coatings in dry sliding friction conditions", *Powder Metallurgy and Metal Ceramics*, vol. 60, no. 1-2, pp. 90-96, 2021.

[3] Y. M. Kuskov, V. A. Zhdanov, I. O. Ryabtsev, M. M. Student, and H. H. Veselivska, "Methods for increasing the corrosion resistance of coatings deposited under a flux layer from high-chromium powder wires", *Materials Science*, vol. 55, no. 5, pp. 710-715, 2020.

[4] V. Gurey, and I. Hurey, "Influence of surface hardened nanocrystalline layers on the resistance of contact fatigue destruction", *Lecture Notes in Mechanical Engineering*, pp. 483-491, 2020.

[5] V. Kovbashyn, and I. Bochar, "Research of properties of protective coating applied to the surface of reaction-sintered ceramic materials", *Scientific Journal of TNTU (Tern.)*, vol. 101, no. 1, pp. 22-27, 2021.

[6] V. M. Posuvailo, V. V. Kulyk, Z. A. Duriagina, I. V. Koval'chuck, M. M. Student, and B. D. Vasyliv, "The effect of electrolyte composition on the plasma electrolyte oxidation and phase composition of oxide ceramic coatings formed on 2024 aluminium alloy", *Archives of Materials Science and Engineering*, vol. 105, no. 2, pp. 49-55, 2020.

[7] I. M. Zin', R. S. Mardarevych, L. M. Bilyi, S. A. Kornii, and Z. A. Duryagina, "Influence of the surface chemical treatment of D16T alloy on the protective properties of alkyd coatings", *Materials Science*, vol. 55, no. 2, pp. 278-284, 2019.

[8] I. V. Smirnov, V. K. Furman, A. V. Chornyi, N. A. Dolgov, and A. Y. Andreytsev, "Nanostructured PVD film-coated alumina powders for thermal spraying technologies", in *Proc. IEEE 7th Int. Conf. on Nanomaterials: Applications and Properties, NAP 2017*, art. no. 01FNC04, 2017.

[9] J. Viňáš, D. Draganovská, Y. Nykyforchyn, and I. Okipnyi, "The influence of surface pretreatment on the quality of plasma coatings", *Scientific Journal of TNTU (Tern.)*, vol. 90, no. 2, pp. 5-11, 2018.

[10] O. Hasiy, and I. Horbachevsky, "Determination of stresses in materials with evaporated coatings", *Scientific Journal of TNTU (Tern.)*, vol. 92, no. 4, pp. 24-33, 2018.

[11] T. A. Shihab, L. S. Shlapak, N. S. Namer, P. M. Prysyazhnyuk, O. O. Ivanov, and M. J. Burda, "Increasing of durability of mechanical seals of oil and gas centrifugal pumps using tungsten-free cermet with Cu-Ni-Mn binder", *Journal of Physics: Conference Series*, vol. 1741, no. 1, art. no. 012031, 2021.

[12] R. M. Kreyda, S. M. Matsepa, V. I. Gordienko, and M. V. Golub, "Features of man-

DOI: 10.24025/2306-4412.2.2021.242339

ufacturing a rotor for a float gyroscope in production conditions", *Visnyk Cherkaskogo derzhavnogo tekhnolohichnogo universytetu*, no. 2, pp. 143-149, 2020 [in Ukrainian].

[13] V. Borovets, O. Lanets, V. Korendiy, and P. Dmyterko, "Volumetric vibration treatment of machine parts fixed in rotary devices", in *Lecture Notes in Mechanical Engineering*, pp. 373-383, 2021.

[14] L. G. Polonskyi, "Mechanical processing of gas-thermal coatings and its influence on the development of the spraying technic", *NTU KPI bulletin:* coll. of research papers, Kharkiv, pp. 132-145, 2011.

[15] S. A. Klimenko, *Turning of wear-resistant protective coatings*, Kyiv, Ukraine: Tehnika, 1997 [in Russian].

[16] O. M. Pylypenko, *Vibration treatment of gas-thermal coatings*, Cherkasy, Ukraine: Siyach, 2000 [in Ukrainian].

[17] V. V. Kustov, "Precision analysis of outer cylindrical sleeve surface turning", *Bulletin of Mykhailo Ostrohradskyi KrNU*, Kremenchug, KrNU, no. 1, part 1 (90), pp. 86-93, 2015.

[18] I. P. Shatskyi, L. Y. Ropyak, and M. V. Makoviichuk, "Strength optimization of a two-layer coating for the particular local loading conditions", *Strength of Materials*, vol. 48, no. 5, pp. 726-730, 2016.

[19] L. Ya. Ropyak, I. P. Shatskyi, and M. V. Makoviichuk, "Influence of the oxide-layer thickness on the ceramic-aluminium coating resistance to indentation", *Metallofizika i Noveishie Tekhnologii*, vol. 39, no. 4, pp. 517-524, 2017.

[20] L. Ya. Ropyak, I. P. Shatskyi, and M. V. Makoviichuk, "Analysis of interaction of thin coating with an abrasive using one-dimensional model", *Metallofizika i Noveishie Tekhnologii*, vol. 41, no. 5, pp. 647-654, 2019.

[21] I. P. Shatskyi, V. V. Perepichka, and L. Y. Ropyak, "On the influence of facing on strength of solids with surface defects", *Metallofizika i Noveishie Tekhnologii*, vol. 42, no. 1, pp. 69-76, 2020.

[22] Zh. A. Mroczek, *Processing of wear-resistant coatings*, Minsk, Belarus: Design PRO, 1997 [in Russian].

[23] M. P. Kravchenko, L. G. Polonskyi, V. M. Nochvay, V. O. Loshenkov, and O. A. Stepchyn, "Method for determining the allowance for machining of products with gas-thermal coatings", *Patent 100332 Ukraine, / patentee and patent owner is ZSTU, no. a201111957*, appl. 11.10.11, publ. 10.12.12, Bul. no. 23.

[24] M. P. Kravchenko, V. M. Nochvay, L. G. Polonskyi, A. J. Shchehorskyi, and Yu. E. Ryzhov, "Determination of allowance for machining of products with gas-thermal coating PG-12N-01 of 0.6-2.4 mm thick according to roughness criterion", *Bulletin of ZSTU. The processes of machining in mechanical engineering*, no. 10, pp. 178-191, 2011.

[25] S. A. Klimenko, V. V. Burykin, L. G. Polonskyi, and V. G. Snitsar, *Repair and restoration technology (Diamond abrasive finishing with elastic tools in repair production)*, Zhytomyr, Ukraine: ZSTU, 2014 [in Ukrainian].

[26] L. Ya. Ropyak, V. S. Vytvytskyi, A. S. Velychkovych, T. O. Pryhorovska, and M. V. Shovkoplias, "Study on grinding mode effect on external conical thread quality", *IOP Conference Series: Materials Science and Engineering*, vol. 1018, no. 1, art. no. 012014, 2021.

[27] N. Lishchenko, "Theoretical-probabilistic model for defining the gear grinding stock allowance", *Scientific Journal of TNTU (Tern.)*, vol. 89, no. 1, pp. 89-99, 2018.

[28] Yu. A. Kuznetsov, and N. V. Mityureva, "Features of machining of parts made of aluminum alloys, hardened by micro-arc oxidation", *Uprochnyayushchiye tekhnologii i pokrytiya*, no. 9, pp. 29-31, 2006 [in Russian].

[29] Z. Lipa, J. Peterka, P. Pokorný, Š. Václav, and I. Buranský, "Contribution to the investigation of surface roughness models of grinded plasma-jet sprayed ceramic coatings", *Research papers Faculty of Materials Science and Technology in Trnava Slovak University of Technology Bratislava*, Bratislava, no. 28, pp. 27-37, 2010.

[30] T. Kubohori, Y. Inui, and T. Ikuta, "Evaluation of grinding characteristics of thermal spraying ceramics film", *Materials Transactions*, vol. 48, no. 5, pp. 1050-1054, 2007.

[31] A. A. Mikhailov, *Processing of parts with electroplated coatings*, Moscow, Russia: Mashinostroyeniye, 1981 [in Russian].

[32] L. Ropyak, and V. Ostapovych, "Optimization of process parameters of chrome plating for providing quality indicators of recipro-

DOI: 10.24025/2306-4412.2.2021.242339

cating pumps parts", *Eastern-European Journal of Enterprise Technologies*, vol. 2, no. 5, pp. 50-62, 2016.
[33] V. G. Zyikov, A. D. Kochetova, I. S. Kochetova, I. S. Shnyirova, and L. N. Goronovich, *Drilling pump UNB-600: Catalog of spare parts for oil equipment*, Ministry of Oil and Gas Industry of the USSR, PO "Soyuz-nefteburmashremont". Moscow, Russia: Nedra, 1989 [in Russian].
[34] A. G. Kosilova, and R. K. Mescheryakov, *Handbook of a technologist-mechanical engineer*, in 2 vol. Vol. 2, 4th ed., revised and add. Moscow, Russia: Mashinostroenie, 1986 [in Russian].

Список використаних джерел

[1] I. Koval, L. Bodrova, H. Kramar, S. Marynenko, Ya. Kovalchuk, and N. Kondzelko, "Wear resistant hard alloys for agricultural machines elements", *Scientific Journal of TNTU (Tern.)*, vol. 98, no. 2, pp. 33-39, 2020.
[2] V. M. Holubets, M. I. Pashechko, J. Borc, O. V. Tisov, and Y. S. Shpuliar, "Wear resistance of electrospark-deposited coatings in dry sliding friction conditions", *Powder Metallurgy and Metal Ceramics*, vol. 60, no. 1-2, pp. 90-96, 2021.
[3] Y. M. Kuskov, V. A. Zhdanov, I. O. Ryabtsev, M. M. Student, and H. H. Veselivska, "Methods for increasing the corrosion resistance of coatings deposited under a flux layer from high-chromium powder wires", *Materials Science*, vol. 55, no. 5, pp. 710-715, 2020.
[4] V. Gurey, and I. Hurey, "Influence of surface hardened nanocrystalline layers on the resistance of contact fatigue destruction", *Lecture Notes in Mechanical Engineering*, pp. 483-491, 2020.
[5] V. Kovbashyn, and I. Bochar, "Research of properties of protective coating applied to the surface of reaction-sintered ceramic materials", *Scientific Journal of TNTU (Tern.)*, vol. 101, no. 1, pp. 22-27, 2021.
[6] V. M. Posuvailo, V. V. Kulyk, Z. A. Duriagina, I. V. Koval’chuck, M. M. Student, and B. D. Vasyliv, "The effect of electrolyte composition on the plasma electrolyte oxidation and phase composition of oxide ceramic coatings formed on 2024 aluminium alloy", *Archives of Materials Science and Engineering*, vol. 105, no. 2, pp. 49-55, 2020.
[7] I. M. Zin’, R. S. Mardarevych, L. M. Bilyi, S. A. Kornii, and Z. A. Duryagina, "Influence of the surface chemical treatment of D16T alloy on the protective properties of alkyd coatings", *Materials Science*, vol. 55, no. 2, pp. 278-284, 2019.
[8] I. V. Smirnov, V. K. Furman, A. V. Chornyi, N. A. Dolgov, and A. Y. Andreytsev, "Nanostructured PVD film-coated alumina powders for thermal spraying technologies", in *Proc. IEEE 7th Int. Conf. on Nanomaterials: Applications and Properties, NAP 2017*, art. no. 01FNC04, 2017.
[9] J. Viňáš, D. Draganovská, Y. Nykyforchyn, and I. Okipnyi, "The influence of surface pretreatment on the quality of plasma coatings", *Scientific Journal of TNTU (Tern.)*, vol. 90, no. 2, pp. 5-11, 2018.
[10] O. Hasiy, and I. Horbachevsky, "Determination of stresses in materials with evaporated coatings", *Scientific Journal of TNTU (Tern.)*, vol. 92, no. 4, pp. 24-33, 2018.
[11] T. A. Shihab, L. S. Shlapak, N. S. Namer, P. M. Prysyazhnyuk, O. O. Ivanov, and M. J. Burda, "Increasing of durability of mechanical seals of oil and gas centrifugal pumps using tungsten-free cermet with Cu-Ni-Mn binder", *Journal of Physics: Conference Series*, vol. 1741, no. 1, art. no. 012031, 2021.
[12] Р. М. Крейда, С. М. Мацепа, В. І. Гордієнко, та М. В. Голуб, "Особливості виготовлення ротора для поплавкового гіроскопа в умовах виробництва", *Вісник Черкаського державного технологічного університету*, № 2, с. 143-149, 2020.
[13] V. Borovets, O. Lanets, V. Korendiy, and P. Dmyterko, "Volumetric vibration treatment of machine parts fixed in rotary devices", in *Lecture Notes in Mechanical Engineering*, pp. 373-383, 2021.
[14] L. G. Polonskyi, "Mechanical processing of gas-thermal coatings and its influence on the development of the spraying technic", *NTU KPI bulletin:* coll. of research papers, Kharkiv, pp. 132-145, 2011.
[15] С. А. Клименко, *Точение износостойких защитных покрытий*, Київ, Україна: Техніка, 1997.

DOI: 10.24025/2306-4412.2.2021.242339

[16] О. М. Пилипенко, *Вібраційна обробка газотермічних покриттів*, Черкаси, Україна: Сіяч, 2000.
[17] V. V. Kustov, "Precision analysis of outer cylindrical sleeve surface turning", *Bulletin of Mykhailo Ostrohradskyi KrNU*, Kremenchug, KrNU, no. 1, part 1 (90), pp. 86-93, 2015.
[18] I. P. Shatskyi, L. Y. Ropyak, and M. V. Makoviichuk, "Strength optimization of a two-layer coating for the particular local loading conditions", *Strength of Materials*, vol. 48, no. 5, pp. 726-730, 2016.
[19] L. Ya. Ropyak, I. P. Shatskyi, and M. V. Makoviichuk, "Influence of the oxide-layer thickness on the ceramic-aluminium coating resistance to indentation", *Metallofizika i Noveishie Tekhnologii*, vol. 39, no. 4, pp. 517-524, 2017.
[20] L. Ya. Ropyak, I. P. Shatskyi, and M. V. Makoviichuk, "Analysis of interaction of thin coating with an abrasive using one-dimensional model", *Metallofizika i Noveishie Tekhnologii*, vol. 41, no. 5, pp. 647-654, 2019.
[21] I. P. Shatskyi, V. V. Perepichka, and L. Y. Ropyak, "On the influence of facing on strength of solids with surface defects", *Metallofizika i Noveishie Tekhnologii*, vol. 42, no. 1, pp. 69-76, 2020.
[22] Ж. А. Мрочек, *Обработка износостойких покрытий*, Минск, Беларусь: Дезайн ПРО, 1997.
[23] M. P. Kravchenko, L. G. Polonskyi, V. M. Nochvay, V. O. Loshenkov, and O. A. Stepchyn, "Method for determining the allowance for machining of products with gas-thermal coatings", *Patent 100332 Ukraine, / patentee and patent owner is ZSTU, no. a201111957*, appl. 11.10.11, publ. 10.12.12, Bul. no. 23.
[24] M. P. Kravchenko, V. M. Nochvay, L. G. Polonskyi, A. J. Shchehorskyi, and Yu. E. Ryzhov, "Determination of allowance for machining of products with gas-thermal coating PG-12N-01 of 0.6-2.4 mm thick according to roughness criterion", *Bulletin of ZSTU. The processes of machining in mechanical engineering*, no. 10, pp. 178-191, 2011.
[25] С. А. Клименко, В. В. Бурикін, Л. Г. Полонський, та В. Г. Сніцар, *Технологія ремонту та відновлення (Фінішна алмазно-абразивна обробка еластичними інструментами в ремонтному виробництві)*. Житомир, Україна: ЖСТУ, 2014.
[26] L. Ya. Ropyak, V. S. Vytvytskyi, A. S. Velychkovych, T. O. Pryhorovska, and M. V. Shovkoplias, "Study on grinding mode effect on external conical thread quality", *IOP Conference Series: Materials Science and Engineering*, vol. 1018, no. 1, art. no. 012014, 2021.
[27] N. Lishchenko, "Theoretical-probabilistic model for defining the gear grinding stock allowance", *Scientific Journal of TNTU (Tern.)*, vol. 89, no. 1, pp. 89-99, 2018.
[28] Ю. А. Кузнецов, и Н. В. Митюрева, "Особенности механической обработки деталей из алюминиевых сплавов, упрочненных микродуговым оксидированием", *Упрочняющие технологии и покрытия*, № 9, с. 29-31, 2006.
[29] Z. Lipa, J. Peterka, P. Pokorný, Š. Václav, and I. Buranský, "Contribution to the investigation of surface roughness models of grinded plasma-jet sprayed ceramic coatings", *Research papers Faculty of Materials Science and Technology in Trnava Slovak University of Technology Bratislava*, Bratislava, no. 28, pp. 27-37, 2010.
[30] T. Kubohori, Y. Inui, and T. Ikuta, "Evaluation of grinding characteristics of thermal spraying ceramics film", *Materials Transactions*, vol. 48, no. 5, pp. 1050-1054, 2007.
[31] А. А. Михайлов, *Обработка деталей с гальваническими покрытиями*. Москва, Россия: Машиностроение, 1981.
[32] L. Ropyak, and V. Ostapovych, "Optimization of process parameters of chrome plating for providing quality indicators of reciprocating pumps parts", *Eastern-European Journal of Enterprise Technologies*, vol. 2, no. 5, pp. 50-62, 2016.
[33] В. Г. Зыков, А. Д. Кочетова, И. С. Кочетова, И. С. Шнырова, и Л. Н. Горонович, "Насос буровой УНБ-600: каталог запасных частей к нефтяному оборудованию", М-во нефт. и газ. пром-сти СССР, ПО "Союзнефтебурмашремонт". Москва, Россия: Недра, 1989.
[34] А. Г. Косилова, и Р. К. Мещеряков, *Справочник технолога-машиностроителя*: в 2 т. Т. 2, 4-е изд., перераб. и доп. Москва, Россия: Машиностроение, 1986.

DOI: 10.24025/2306-4412.2.2021.242339

[0000-0002-9374-2550] **Л. Я. Роп'як,** *д-р техн. наук, доцент,*
e-mail: L_ropjak@ukr.net
[0000-0002-5302-3623] **М. В. Шовкопляс,**
[0000-0003-3682-1612] **В. С. Витвицький,** *канд. техн. наук*
Івано-Франківський національний технічний університет нафти і газу,
вул. Карпатська, 15, Івано-Франківськ, 76019, Україна

ВИЗНАЧЕННЯ ПРИПУСКІВ НА МЕХАНІЧНУ ОБРОБКУ ДЕТАЛЕЙ З ХРОМОВИМИ ПОКРИТТЯМИ

Проведено аналіз методів визначення припусків на механічну обробку металевих, оксидних та керамічних покриттів, які базуються на міцності покриттів, зміні мікротвердості, забезпеченні одержання мінімальної шорсткості обробленої поверхні. Визначення раціональних припусків на механічну обробку деталей з електрохімічними хромовими покриттями є важливою техніко-економічною задачею машинобудування, оскільки занижені значення припусків не гарантують досягнення необхідної точності розмірів та відповідної шорсткості робочої поверхні деталей, призводять до зниження ресурсу роботи виробів, а завищені значення припусків призводять до зростання витрат на механічну обробку. Мета – розроблення інженерної методики визначення припусків на механічну обробку сталевих деталей з хромовими електрохімічними покриттями для забезпечення необхідної точності та шорсткості зовнішніх циліндричних поверхонь. Покриття наносили на циліндричні сталеві зразки у спокійному та проточному електроліті на установці, спорядженій автоматизованою системою контролю технологічних параметрів процесу електрохімічного хромування. Досліджено шорсткість поверхонь після алмазного круглого шліфування електрохімічних хромових покриттів, нанесених у спокійному та в проточному електролітах. Встановлено, що товщина дефектного шару залежить від способу нанесення електрохімічного хромового покриття. Хромування сталевих деталей у проточному електроліті забезпечує одержання меншої товщини дефектного шару порівняно з хромуванням у спокійному електроліті. Також встановлено, що мінімальний припуск для одержання поверхонь із мінімальною шорсткістю після алмазного шліфування електрохімічного хромового покриття залежить від загальної товщини покриття та збільшується з її зростанням. Аналіз результатів розрахунку припусків показав, що припуск на механічну обробку заготовок деталей з хромовим покриттям, нанесеним у спокійному електроліті, є більшим порівняно з покриттям, отриманим у проточному електроліті, в 2,5 разу. Це обумовлено нерівномірним нанесенням електрохімічного хромового покриття у спокійному електроліті внаслідок ускладнення газовідведення з поверхні покриття у процесі електролізу порівняно з електролізом у проточному електроліті. Зазначені недоліки хромування в спокійному електроліті усуваються під час нанесення покриття на циліндричні деталі в проточному електроліті, про що свідчить також зменшення конусоподібності деталей з покриттями приблизно в 1,7 разу та глибини дефектного поверхневого шару – 2,6 разу відповідно. Наукова новизна одержаних результатів досліджень полягає у встановленні залежності товщини дефектного поверхневого шару від товщини робочого шару для хромових електрохімічних покриттів, нанесених у спокійному та в проточному електроліті, на циліндричні сталеві деталі, після зняття якого алмазним круглим шліфуванням забезпечується отримання обробленої поверхні з мінімальною шорсткістю. Практична цінність полягає в тому, що розроблено інженерну методику розрахунку припусків на механічну обробку (операцію алмазного шліфування) циліндричних сталевих деталей з хромовими електрохімічними покриттями.

Ключові слова: *хромове електрохімічне покриття, шорсткість поверхні, припуск на механічну обробку, алмазне шліфування, шток, поршневий насос.*

Стаття надійшла 21.05.2021
Прийнято 16.06.2021

DOI: 10.24025/2306-4412.2.2021.242339