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Investigation of technological parameters effect on metal removal during centrifugal rotary machining

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Introduction. The study results on the single interaction under the centrifugal rotary part machining in the abrasive discrete medium are presented. Simultaneously with the numerical simulation, experiments were carried out on a centrifugal-rotary unit, and the maximum depth of penetration into the surface of the part, the single-track sizes, metal removal in one blow of an abrasive granule, were investigated. The removal of metal from workpieces was investigated depending on the processing modes, characteristics of the abrasive particle and the processed material.
Materials and Methods. The dependences for determining the metal removal from workpieces (steels 45, copper Cu-OF, and aluminum alloy D16T) are taken into account depending on the grain size (Nз) of abrasive particles. The process of a single interaction of an abrasive particle and the workpiece surface is considered within the framework of the dynamic contact problem of the elasticity theory. The authors have carried out finite element modeling of the considered structures in CAE ANSYS package.
Results. The results of theoretical and experimental studies on the metal removal from workpieces depending on the grain size of abrasive particles are presented. The technique of their implementation, the tool and equipment used are described. The results of theoretical and experimental studies are compared. Their fine precision is established. Abrasive tools and processing modes are selected.
Discussion and Conclusions. The dependences constructed in the work provide determining the rational values of the technological parameters of the centrifugal rotary machining (CRM) process. They can be used under designing the CRM processes. Therefore, time and financial resources can be saved to achieve the desired surface quality.

Keywords: metal removal from the workpiece surface, penetration depth, single interaction, metal removal analysis, centrifugal rotary machining.

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Introduction. In mechanical engineering, grinding technology always provides high surface accuracy, which is the last step in surface treatment of parts. Materials with high temperature resistance, hardness, and high strength can be processed using grinding technology [1]. To increase the efficiency of the centrifugal rotary machining (CRM) process, it is required to optimize the model of friction interaction between abrasive particles and the workpiece surface.

Machining in a free abrasive environment enables to process parts of various shapes, sizes and materials using simple and reliable equipment. Temperature in the processing zone is much lower than under grinding, and the machining is accompanied by the supply of process fluid. In [2, 3], the thermal texture analysis and workpiece wear forecast were performed using the finite element method and the Gaussian process. The studies presented in [4, 5] have shown that when a particle of aluminum oxide is sliding, the workpiece surface is destroyed, and the metal is removed from the part. This paper deals with the process of a single interaction of a workpiece and an abrasive medium under CRM. Simultaneously with numerical modeling, experiments were conducted to study the depth of penetration of the abrasive granule into the surface of the part. The effect of the grit size on the metal removal from the processed parts is studied.

The research to determine the impact of technological parameters of CRM processing on quality and productivity is not deep. This hinders a widespread introduction of CRM technology into production. To solve this problem, it is required to obtain a theoretical model of the CRM process that provides predicting the results of processing at the design stage.

Installation Description. The CRM operation principle (Fig. 1) is as follows: the workpiece (4) and abrasive particles are loaded into the working chamber (1); abrasive particles and the workpiece move in a spiral orbit; the rotating bottom (rotor) (2) is connected to the engine; the inner surface of the bottom is covered with a wear-resistant material to reduce friction.

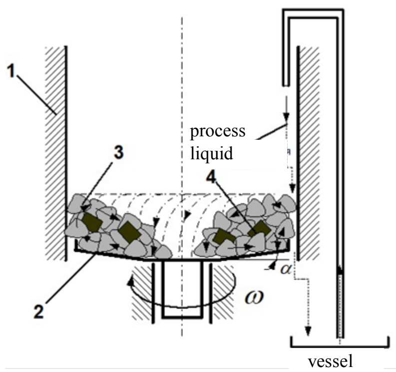


Fig. 1. Centrifugal rotary machining flowchart: 1—cylindrical shell; 2 — rotor;
3 — abrasive media; 4 — workpieces

Fig. 2 shows a three-dimensional model of the interaction of an abrasive particle and a workpiece.

In [6], the process of a single interaction of an abrasive granule and a part was studied. The features of this process are presented in [7–10]. It is known from [11] that the temperature in the processing zone is low and does not change the structure of the surface layer of the workpiece. This paper studies the contact interaction of an abrasive particle and the workpiece surface; the abrasive moves at a speed of v_0, the angle of contact with the processed workpiece surface is α = 15°–25° (Fig. 2).

Investigation of single interaction process. Solving the problem of theoretical modeling of a single interaction will allow us to study the effect of technological parameters on the CRM. To create a mathematical model of metal removal from the surface of a part, it is required to describe impact of the factors on the shape and size of traces of interaction between the granule and the surface.

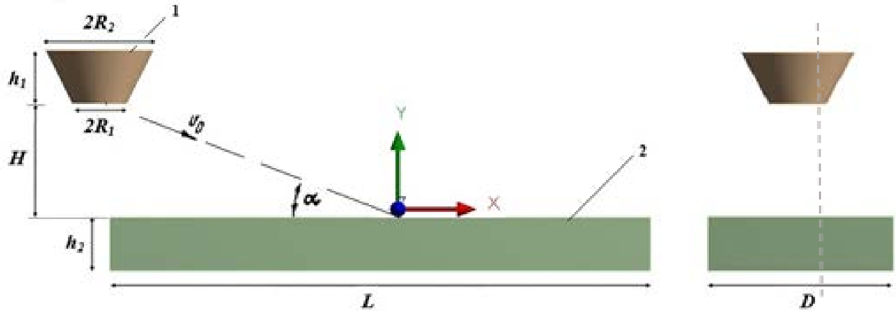


Fig. 2. Model of the abrasive particles and the workpiece:
1 — abrasive particle; 2 — workpiece

Many papers were devoted to the process of single interaction [12, 14, 15]. Analysis of the works [12–14] shows that the interaction of an abrasive particle and the workpiece surface occurs as follows: when a moving particle collides with the surface of the workpiece at a certain angle α, the abrasive particle is affected by resistance force P, which consists of tangent P_τ and normal P_N.

The problem is reduced to the movement of a circular cone at a constant speed $v > 0$. In [5, 6], the maximum depth of penetration under a single interaction is determined.

$$h_{\max} = 2V_{эф} R \sin\alpha \sqrt{\frac{\rho_ш}{3\kappa_s c \sigma_s}} \tag{1}$$

where $\rho_ш$ — material density; k_s — coefficient considering the effect of the workpiece surface roughness on the true contact area; c — coefficient of bearing capacity of the contact surface; σ_s — yield strength of the part material; R — radius of the abrasive particle; α — angle of contact of the abrasive particle with the workpiece surface; $V_{эф}$ — effective velocity of the moving abrasive particle determined from the formula:

$$V_{эф} = \kappa_{эф}\omega R_{эф}, \quad (2)$$

where $R_{эф}$ — effective rotor radius; ω — rotor rotational rate; $\kappa_{эф}$ — generalized coefficient of effective velocity.

Based on the work [4], when an abrasive particle collides with a workpiece with the formation of an elliptical processing trace, the values of the semi-axes *a, b* are found from the formula:

$$b = \sqrt{R^2 - (R - h_{\max})^2}.$$

$$a = \frac{\pi}{2}(ctg\alpha - f)h_{\max} + b, \quad (3)$$

where f — particle workpiece surface friction coefficient.

The destruction of the surface layer occurs due to microcutting. Therefore, when calculating the removal of metal, it is sufficient to take into account the number of interactions N_P, that lead to microcutting [16]:

$$Q = N_p q,$$

where Q — metal removal from the workpiece surface.

Substituting value N_p from the dependencies above, we get:

$$Q = P_1 P_2 \omega t q \frac{S_{дет}}{4R^2} \text{ при } S_{дет} \succ 4R^2 \quad (4)$$

$$Q' = P_1' P_2 \omega t q \text{ при } S_{дет} \prec 4R^2 \quad (5)$$

Finite element models of abrasive particles and parts were built in the ANSYS program to explore the maximum penetration depth under a single interaction based on the parameters of the CRM technology.

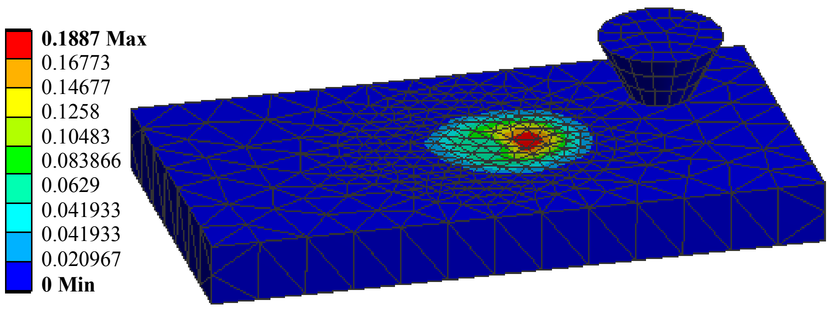


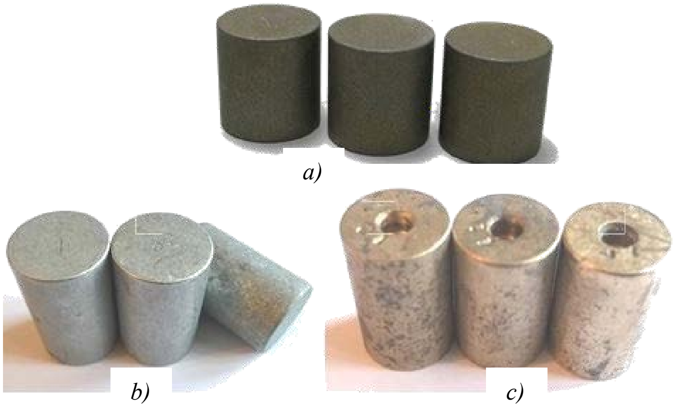
Fig. 3. Maximum penetration depth under a single interaction

Fig. 3 shows the distribution of vertical displacement during impact and sliding of an abrasive particle fragment on the workpiece surface calculated in ANSYS with account for the plasticity of the part material (bilinear model).

Experimental Research Methods. The study of the process of removing metal from the workpiece surface was carried out on cylindrical samples made of various materials: steel 45, aluminum alloy D16T, copper Cu-OF, 12 pieces per sample (Fig. 4). The hardness (HB) was measured on the Brinell hardness tester. The hardness (HB) and yield strength of the sample materials are shown in Table 1.

The following were selected as abrasive media: white prisms PT 15×15 conditionally equated to 25 grit (Fig. 5 a); porcelain balls 10 mm in diameter conditionally equated to M60 grit (Fig. 5 b); PT 25×25 conditionally equated to 12 grit (Fig. 5 d); abrasive white-green cone with 8 grit, d=30 mm, h=30 mm (Fig. 5 d).

Abrasive granules and blanks are loaded into the working chamber of the CRM. Processing is performed at the rotation speed of ω=12 rev/s. Every 30 minutes, the treatment is stopped, the samples are removed from the chamber, thoroughly washed and dried. Ad 200 scales were used to determine the removal. To avoid corrosion, a 0.2% solution of soda ash was used.



a) b) c)

Fig. 4. Samples for determining metal removal from the workpiece surface:
a) steel 45; *b*) copper Cu-OF, *c*) aluminum alloy D16T

Table 1

Dimensions and mechanical properties of sample materials

Sample materials	Sample dimensions, mm	Hardness, HB	Yield stress $\sigma_т$, MPa
Steel 45	∅ 20x20	190–200	340
Aluminum alloy D16T	∅ 30x50	80–82	240
Copper Cu-OF	∅ 15x20	56–59	180

a) b) c) d)

Fig. 5. Abrasive particles used in CRM: *a*) white prisms PT; *b*) porcelain balls;
c) PT 25×25; *d*) white-green abrasive cone

Experimental Results. The dependence of the metal removal process on the abrasive grit size (N_3) is studied. For a comprehensive test of the theoretical model, the comparison based on the results of processing 12 samples of each grade was made. The theoretical calculation results using dependencies (4) and (5) were compared to the experimental results. Based on the results of experimental and theoretical studies, graphs are constructed.

Fig. 6–8 show the dependences of metal removal from the surface of the part on the grain size of abrasive particles M60; 8; 12; 25; part materials are steel 45; aluminum alloy D16T, copper Cu-OF; the processing mode — the rotor speed is ω=12 rev/s.

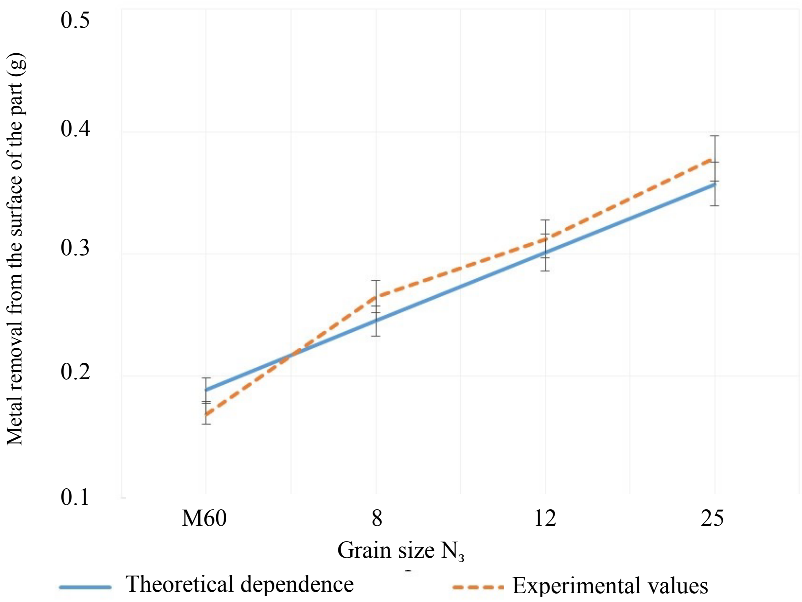


Fig. 6. The dependence of metal removal on N_3, the workpiece materials steel 45

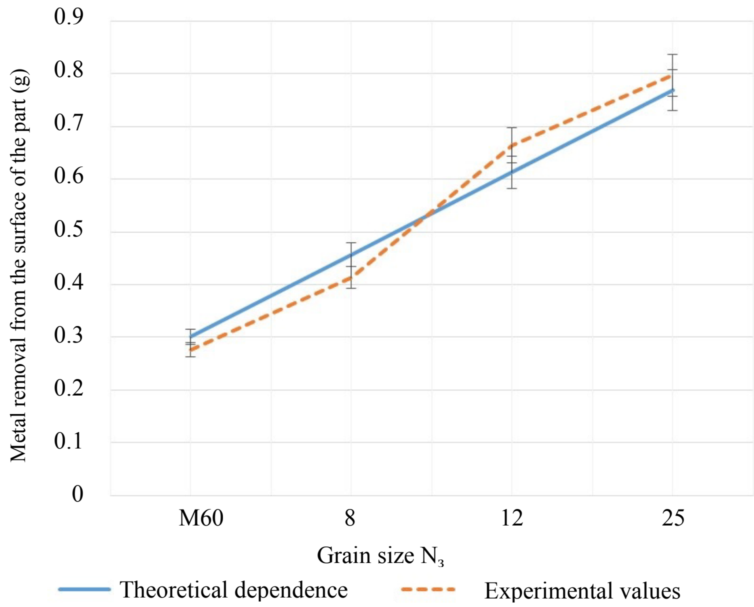


Fig. 7. The dependence of metal removal on N_3, the workpiece material is D16T

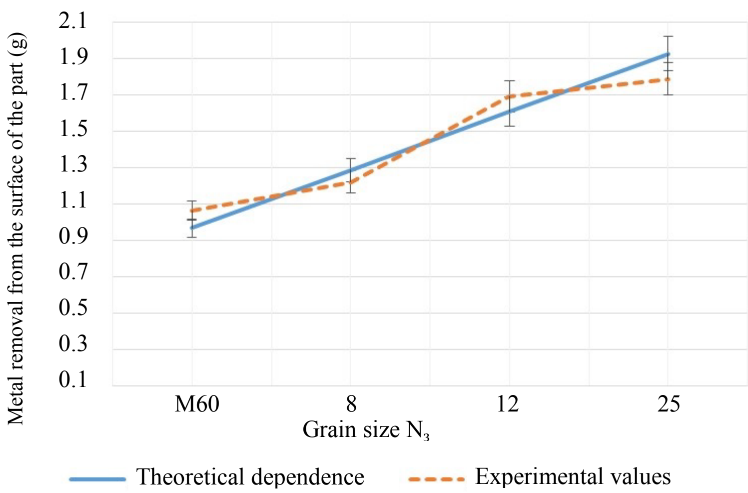


Fig. 8. The dependence of metal removal on N_3, the workpiece material is Cu-OF

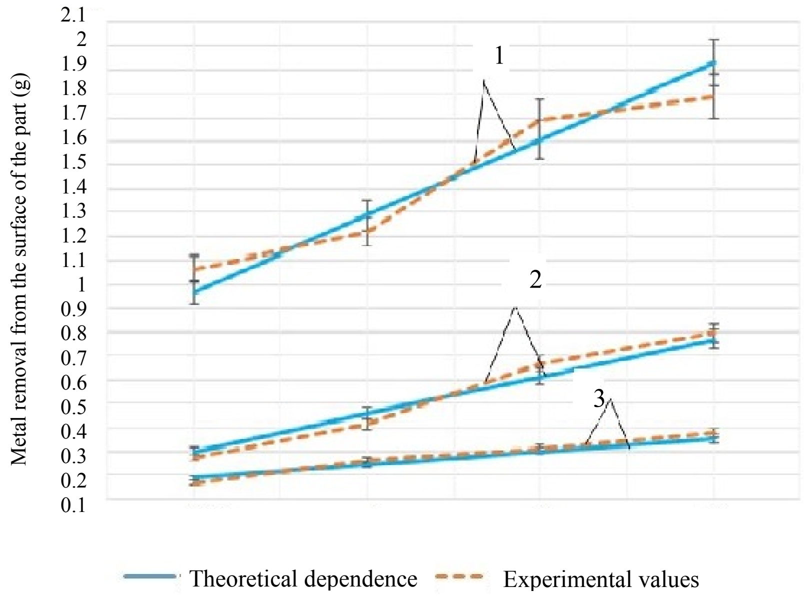


Fig. 9. Comparison of theoretical and experimental dependences of metal removal on N_3: 1 — copper Cu-OF; 2 — aluminum alloy D16T; 3 — steel 45

Discussion and Conclusions. Based on the results of theoretical and experimental studies, the dependences presented in Fig. 6–9 were found. After analyzing the research results, the following conclusions can be drawn:

1. The metal removal Q is proportional to the increase in the grit size of abrasive particles. When processing at ω=12 rev/s, for steel 45 at N_3=M60, Q=0.169g, at N_3=25 Q=0.37g; for aluminum alloy D16T at N_3=M60 Q=0.267g, at N_3=25 Q=0.797g; for copper Cu-OF at N_3=M60 Q=1.065g, at N_3=25 Q=1.789g.

2. The effect of the abrasive medium grain size, the mechanical properties of the material and the processing mode, reflects correctly the theoretical model of a single interaction.

3. When comparing the results of experimental studies and theoretical data, the difference is less than 20 % (with account for the metal removal on the grain size of abrasive particles N_3).

4. The introduction of research results into production enabled to increase the processing productivity by 1.5–2 times with the required quality of the treated surface and reduction of the working media wear.

The results obtained can be used to improve the efficiency of process design of the CRM and to expand technological capabilities.

References

1. Rowe WB. Principles of Modern Grinding Technology. William Andrew; 2014. 480 p.

2. Li Xin, Peng Gaoliang, Li Zhe. Prediction of seal wear with thermal-structural coupled finite element method. Finite Elements in Analysis and Design. 2014;83:10–21. DOI: 10.1016/j.finel.2014.01.001

3. Anh Tran, Furlan JM, Krishnan V, et al. A computationally efficient machine learning framework for local erosive wear predictions via nodal Gaussian processes. Wear. 2019;422-423:9–26. DOI: org/10.1016/j.wear.2018.12.081

4. Gee M, Nunn J. Real time measurement of wear and surface damage in the sliding wear of alumina. Wear. 2017;376—377:1866–1876.

5. Tamarkin MA, Tishchenko EE, Druppov VV. Issledovanie udaleniya metalla pri tsentrobezhno-rotornoi obrabotke v abrazivnoi srede [Investigation of metal removal during centrifugal rotary processing in abrasive medium]. Vestnik of P.A. Solovyov Rybinsk State Aviation Technical University. 2007;11(1):169–186. (In Russ.)

6. Tamarkin MA, Tishchenko EE, Korol'kov YuV, et al. Povyshenie ehffektivnosti tsentrobezhno-rotatsionnoi obrabotki v srede abraziva [Improving the efficiency of centrifugal rotary processing in abrasive medium]. STIN. 2009;2:26–30. (In Russ.)

7. Tamarkin MA, Rozhnenko OA, Tishchenko EE, et al. Teoreticheskie i ehksperimental'nye issledovaniya protsessov obrabotki fasonnykh poverkhnostei detalei svobodnym abrazivom [Theoretical and experimental study of

process of shaped parts surfaces by loose abrasive]. Strengthening Technologies and Coatings. 2011;11:27–31. (In Russ.)

8. Tamarkin MA, Glazman BS, Korol'kov YuV, et al. Reducing abrasive wear in centrifugal-rotary machining. Russian Engineering Research. 2014;34(1):60–64.

9. Soloviev AN, Tamarkin MA, Nguyen Van Tho, et al. Computer Modeling and Experimental Research of Component Processing Procedure in the Centrifugal-Rotary Equipment. Advanced Materials. 2020;6:513–528.

10. Nguyen Van Tho, Soloviev AN, Tamarkin MA, et al. Finite Element Modeling Method of Centrifugally Rotary Processing. Applied Mechanics and Materials. 2019;889:140–147.

11. Soloviev AN, Tamarkin MA, Nguyen Van Tho. Konechno-ehlementnoe modelirovanie termouprugogo kontaktnogo vzaimodeistviya v abrazivnoi obrabotke poverkhnosti detalei mashin [Finite element modeling of thermoelastic contact interaction in the abrasive surface treatment of machine components]. Ecological Bulletin of Research Centers of the Black Sea economic cooperation. 2019;16(1):51–58. DOI: 10.31429/vestnik-16-1-51-58 (In Russ.)

12. Nepomnyashchy EF. Trenie i iznos pod vozdeistviem strui tverdykh sfericheskikh chastits [Friction and wear caused by a jet of solid spherical particles]. In: Contact interaction of solids and calculation of friction and wear forces. Moscow: Nauka; 1971. P. 190–200. (In Russ.)

13. Mikhin NM. Vneshnee trenie tverdykh tel [External friction of solids]. Moscow: Nauka; 2002. 222 p. (In Russ.)

14. Babichev AP, Babichev IA. Osnovy vibratsionnoi tekhnologii [Fundamentals of vibration technology]. Rostov-on-Don: DSTU Publ. Centre; 1998. 624 p. (In Russ.)

15. Tamarkin MA, Tishchenko EE, Druppov VV. Formirovanie parametrov kachestva poverkhnosti dlya tsentrobezhno-rotornoi obrabotki v abrazivnoi srede [Formation of parameters of quality of surface at centrifugal-rotational processing in the environment of the abrasive]. Strengthening Technologies and Coatings. 2007;10:19–24. (In Russ.)

16. Yushchenko AV, Flek MB. Issledovanie protsessa s"ema metalla pri abrazivnoi galtovke [Study on metal removal process under abrasive rumbling]. Vestnik of DSTU. 2013;13(3–4):125–133. (In Russ.)

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Claimed contributorship

Nguyen Van Tho: basic concept formulation; research objectives and tasks setting; conducting experiments; development of the program in ANSYS package and computational analysis; analysis of the research results; text preparation. E. E. Tishchenko: conducting experiments; analysis of the research results. I. A. Panfilov: development of the program the package. A. A. Mordovtsev: analysis of the research results and correction of the conclusions.

All authors have read and approved the final manuscript.