Improving the Quality of Hole Processing with a Combined Tool

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ABSTRACT

This article focused on improving the quality of hole machining using a new design of a metal-cutting tool, referred as reamer-broach. Before conducting experimental studies, fixtures were designed, a turning and screw-cutting machine was tested for geometric accuracy, and methods for evaluating the quality of the processed surface were developed. A full-factorial experiment of the 2^2 type was conducted to determine the influence of technological factors (rotation speed, supply) on hole accuracy, roughness, and shape deviations when machining with both a machine reamer and a reamer-broach. Additionally, an analysis of the microstructure of hole surface was performed, to prove the machinability of the material. The results indicated that an increase in feed led to an increase in the radial forces, a stabilized tool position, and a decrease in hole breakdown. An increase in rotation frequency resulted in the rise of hole breakdown as well as in an increase in surface roughness. These findings demonstrated an increase in accuracy by 1-2 quality grades compared to machine reamer and a decrease in surface roughness by 1-2 grades when processing holes using a reamer-broach.

Keywords-reamer; broach; reamer-broach; hole; accuracy; roughness; quality

I. INTRODUCTION

One of the most important factors in ensuring the quality of machine part processing and labor productivity is the metal-cutting tool. This tool works by cutting off the material in relatively thin layers giving the desired shape and size. Its performance significantly impacts the economic efficiency of the production process. The hole machining with axial tools is the most common and economical method of obtaining holes, occupying a special place in the technological process of manufacturing machine parts. However, this approach deals with a number of difficulties due to the tool's reduced rigidity [1]. As the tool moves through the hole, a bending moment is created, causing deflection in the tool axis. This effect becomes more intense as the tool diameter decreases, reducing its rigidity and leading to hole breakdown and axis removal. These circumstances necessitate a reduction in cutting modes, as well as the introduction of additional operations into the technological process.

Tool life is typically estimated by predicting the time required to reach the threshold flank wear width. As a crucial component in any machining process, the cutting tool's failure affects the manufacturing process adversely. The prediction of tool life by considering several factors that affect it is essential for managing quality, cost, availability, and waste in machining processes. The cutting process involves elastic and plastic deformations [2-3], material destruction [4], friction [5-6], tool wear [7], and vibrations of individual parts and units as well as of the technological system (machine, fixture, tool, and workpiece) [8]. Understanding the patterns of these phenomena allows the selection of optimal conditions enhancing productivity and high-quality part processing [9].

In serial and mass engineering production, reaming [10] and broaching [11] are the preferred methods for finishing holes, based on the principle that the initial cylindrical surface of the cutting tool, with some deviations, is transferred to the processed surface of the hole [12-13]. The analysis of methods and techniques for processing holes, parameters of the cut layer during cutting, and geometry and designs of existing metal-cutting tools (reamers, broaches, combined tools) led to the development of a new metal-cutting tool, referred as a reamer-broach [14].

The reamer-broach is structurally designed according to the following principle: in the axial section, it contains design elements typical of a broach including a front shank, a neck, front and rear guides, as well as cutting and calibrating parts. In the cross section, it exhibits features of a reamer, such as the shape and number of teeth and the geometry of the cutting part, as can be seen in Figure 1. The new design of the cutting tool utilizes the advantages of broaching: relatively low cutting speed, quality of processing (size accuracy, roughness), and reduced abrasion.

This study aims to review the literature on the prediction of cutting tool life. Additionally, the goal is to enhance the hole processing quality by developing a new processing method and a redesigned metal-cutting tool.

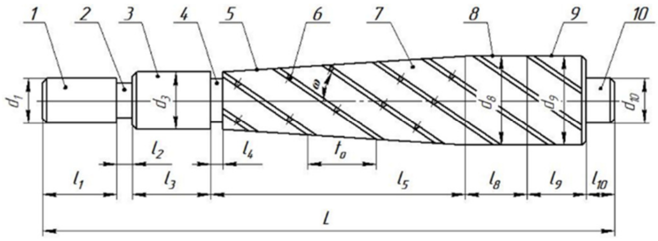

Fig. 1. Construction of the reamer-broach: 1. front shank, 2. a neck, 3. front guide, 4. the annular groove, 5. cutting part, 6. shaving separator groove, 7. shaving groove, 8. calibrating part, 9. rear guide, 10. a rear shank, d_1: diameter of front shank, d_3: diameter of front guide, d_8: diameter of calibrating part, d_9: diameter of rear guide, d_{10}: diameter of rear shank, ℓ_1: front shank length, ℓ_2: neck length, ℓ_3, ℓ_9: front and rear guide length, ℓ_4: length of the annular groove, ℓ_5: length of the cutting part, ℓ_8: calibrating part length, ℓ_{10}: rear shank length, L: reamer-broach length, ω: helical flute angle, t_o: axial pitch of the reamer-broach..

II. THEORETICAL RESEARCH

A. Research of the Cutting Process using a Reamer-Broach

The magnitude and components of the cutting force during processing, in the general case, as illustrated in Figure 2, are determined by:

$$R = \sqrt{N^2 + F^2} = \sqrt{P_x^2 + P_z^2} \tag{1}$$

where N is the normal force, F is the friction force, P_x is the axial force, and P_z is the tangential force.

To improve the quality of hole processing, a method for machining cylindrical holes using a new reamer-broach design was developed. As the metal-cutting tool is being introduced for the first time, it is necessary to conduct a theoretical study of the process and derive empirical relationships $R = f(V, S)$. Values P_x and P_z are determined by:

$$\begin{aligned} P_x &= C_x \times V^n \times S^m \\ P_z &= C_z \times V^p \times S^q \end{aligned} \tag{2}$$

where V is the cutting speed, S is the supply, C_x is the coefficient that considers specific processing conditions for calculating axial cutting force, C_z is the coefficient that considers specific processing conditions for calculating tangential cutting force, n is the exponent that considers the characteristics of the material being processed to calculate the axial cutting force, m is the exponent considering the characteristics of the material of the cutting part of the tool for calculating the axial cutting force, p is the exponent that considers the characteristics of the material being processed to calculate the tangential cutting force, and q is the exponent that considers the characteristics of the material of the cutting part of the tool to calculate the tangential cutting force.

The main features of determining cutting force characteristics, considering the sliding motion of the cutting edge [15], in relation to the proposed metal-cutting tool designs, are based on the following assumptions:

Consider a diagram illustrating the acting cutting forces – both physical and technological- at point (A) of the Main

Cutting Edge of a Metal-Cutting Tool (MCEMCT) during machining, as displayed in Figure 2.

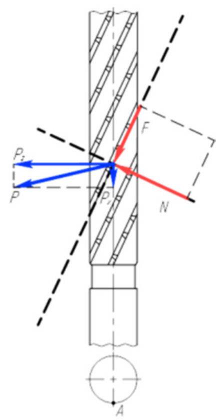

Fig. 2. Cutting forces during machining.

The technological force components acting at point (A) of the MCEMCT are depicted in Figure 3. The elastic pressing force P_y is balanced by the forces acting on other cutting edges.

By analyzing the technological components of the cutting force P_z and P_x, as well as the movement components V_x and V_z, generated by the working parts of the equipment, the total work in the cutting process is expressed by:

$$A_{eq} = A_x + A_z = P_x \times V_x + P_z \times V_z \quad (3)$$

where A_{eq} is the work expended in the cutting process, A_x is the work spent on the cutting process along the axis X, and A_z is the work spent on the cutting process along the axis Z.

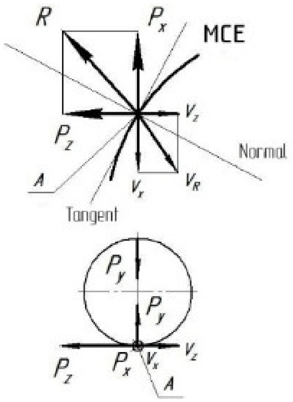

Fig. 3. Technological cutting forces and velocities during machining.

Considering the system of forces and velocities of movements presented in Figure 4, the cutting process work can also be expressed as:

$$A_{eq} = P_p \times V_p + P_c \times V_c \quad (4)$$

where V_c is the sliding speed of the point (A) of the MCEMCT, along the tangent to the cutting edge, V_p is the cutting speed of point (A), perpendicular to the cutting edge, and P_p, P_c are the components of the cutting force R, in the same directions.

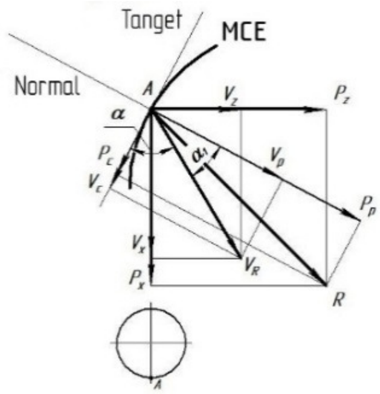

Fig. 4. Forces and velocities during machining.

The principles of the cutting process outlined above form the basis for analyzing the cutting process with sliding motion along a tangential line to the Main Cutting Edge (MCE). Assuming $V_c \perp V_p$ and $P_c \perp P_p$, the total work is given by:

$$A_{eq} = A_c + A_p = P_p \times V_p + P_c \times V_c \quad (5)$$

The accumulated practical experience in mechanical cutting indicated that when sliding occurs along the MCE, where $V_c \perp 0$, the cutting process becomes less energy-consuming. This can be estimated using the coefficient K:

$$K = A_p / A_{eq} \quad (6)$$

If $V_c = 0$, then $A_{eq} = A_p, = P_p \times V_p$ and $K = 1$.

If $V_c \to \infty$,then $A_c \to \infty$, and $A_{eq} \to \infty$, resulting in $K \to 0$.

Thus, the coefficient K belongs to the interval 0–1:

$$0 \le K \le 1 \quad (7)$$

Based on the above, the main provisions for determining the cutting force [16] for a reamer-broach $P_{r\text{-}b}$, considering sliding, are:

- The traction force for broaching a traditional structure is determined as $P_{t.s}$.
- The efficiency of sliding cutting is given by:

$$K_{ef} = P_{zc} / P_z \quad (8)$$

where P_{zc} is the circumferential cutting force with sliding, ($S_n = 0$), P_z is the circumferential cutting force in conventional cutting ($S_n = 0$).

- The cutting force of the reamer-broach is then calculated as:

$$P_{r-b} = P_{t.s} \times K_{ef} \quad (9)$$

where $P_{t.s}$ is the cutting force of a standard design.

Thus, the combination of the straight-line movement of the tool with an additional rotation of the workpiece from the derived formulas reduces the cutting force when machining holes with a new tool design.

B. Method of Processing Cylindrical Holes with a Reamer-Broach

In the developed reamer-broach design, the shank is positioned at the front, and the tool is inserted through the hole, eliminating the breaking hole during machining, as illustrated in Figure 5.

Acting Forces:

- $P_{a/z}$: axial force per cog.
- $P_{rad/z}$: radial force per cog.
- P_z: resultant force per cog.

This design ensures a clear centering of the reamer-broach improving the quality of hole processing. Based on these facts, a new method was developed for processing cylindrical holes.

(a)

(b)

(c)

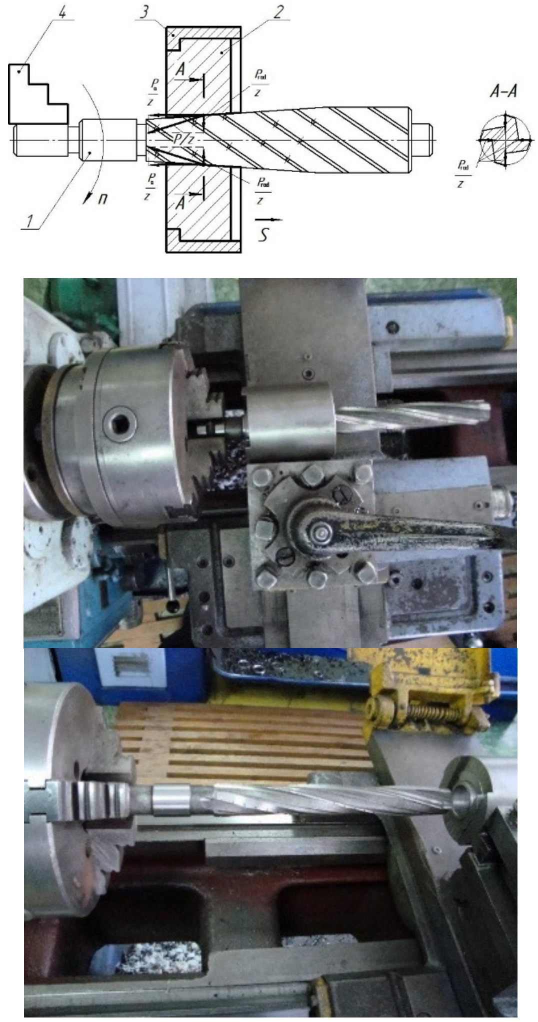

Fig. 5. Scheme of processing a hole using a reamer-broach: (a) processing scheme, where: 1. reamer-broach, 2. workpiece, 3. device housing, 4. jig, (b) starting position, (c) ending position.

During the pulling process, the reamer-broach is centered, excluding bending and axis drift, which further improves process quality. According to the proposed method, the tool is given a longitudinal relative movement, as in pulling, or the longitudinal movement is coming from the workpiece, which corresponds to pulling action. The rotational motion, typical of reaming, is applied either to the reamer-broach or the workpiece, effectively replicating the reaming process [15].

III. PREPARATION OF EXPERIMENTAL RESEARCH

A. Equipment for Experimental Rresearch

When processing holes in machine parts with a reamer-broach, without the use of special equipment (unit machines), it is necessary to design devices for fixing parts and tools. According to the classification of machines, the most suitable and available machine is a screw-cutting lathe GOST 18097-2024 (ISO 1708:1989, NEQ)).

There are two options for processing holes with a reamer-broach:

- Securing the workpiece in the lathe chuck while installing the tool in the machine holder of the machine support.
- Securing the tool in the lathe chuck and the workpiece in the tool holder.

To secure the tool in the tool holder, a designed device is used, as shown in Figure 6. To rotate the tool around its axis, a pin or wedge is provided.

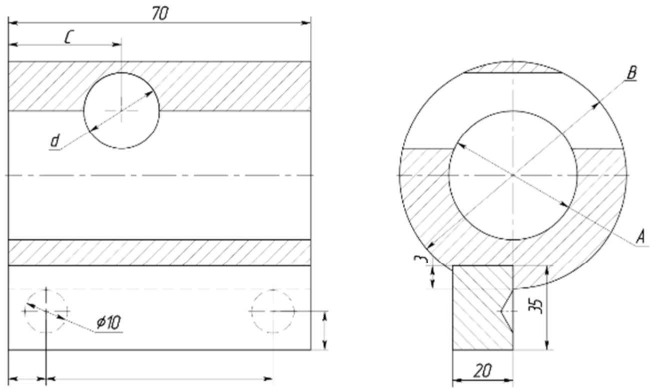

Fig. 6. Device for securing the reamer-broach in the tool holder of the machine support. A: the inner diameter of fixture, B: the outer diameter of the fixture, C: the distance to the axis of the pin, and d: the outer diameter of the pin.

For the second method of processing holes, a device has been designed to hold the workpiece in the tool holder of the machine support, without applying clamping forces, which does not affect the walls of the part, as portrayed in Figure 7.

Before carrying out the experiments, the outer surface of the samples will be machined, a hole will be drilled to match the diameter of the front guide of the reamer-broach, and also a flat on the workpiece will be milled on the part (position 2 in Figure 7), which is necessary to prevent the part from rotating around its axis.

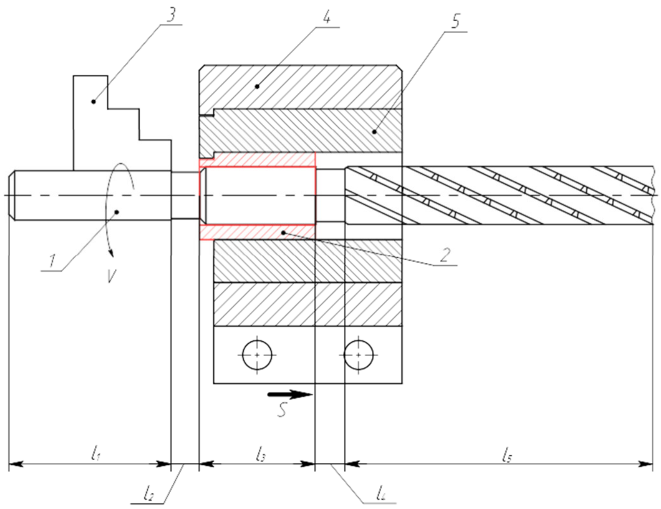

Fig. 7. Installation of workpiece in fixture. 1. reamer-broach, 2. workpiece, 3. jig, 4. device housing, 5. insert, V is the cutting speed, S is the supply, ℓ_1 is the front shank length, ℓ_2 is the neck length, ℓ_3 is the front guide length, ℓ_4 is the length of the annular groove, and ℓ_5 is the length of the cutting part.

B. Evaluation of the Geometric Accuracy of a Screw-Cutting Machine

To obtain reliable results about a new processing tool, it is necessary to examine the suitability of the equipment for geometric accuracy, rigidity, selectively for vibration resistance, and kinematic accuracy in accordance with GOST 18097-2024. A total of nine checks should be performed:

- Check 1: Straightness of longitudinal movement of the support in the horizontal plane. Permissible deviation for machines of accuracy class H (normal accuracy) with a support stroke length of up to 1250 mm: 20 µm.
- Check 2: The same height of the rotation of the headstock spindle and the axis of the tailstock quill hole in relation to the bed guides in the vertical plane. For machines of accuracy class H, with a processing diameter of up to 400 mm, the permissible deviation is 40 µm.
- Check 3: Parallelism of the rotation axis of the headstock spindle to the longitudinal movement of the support: in the horizontal plane 8 µm and in the vertical plane 16 µm.
- Check 4: Radial runout of the conical hole axis of the headstock spindle checked at: the chump: 10 µm; a length of L = 200 mm: 16 µm.
- Check 5: Axial runout of headstock spindle. Permissible axial runout for normal accuracy machines: 10 µm.
- Check 6: Radial runout of the spindle flange centering ring. Permissible deviation for machines of accuracy class H and processing diameter up to 400 mm: 10 µm.
- Check 7: End runout of the headstock spindle support flange. Permissible deviation for normal accuracy machines: 20 µm.
- Check 8: Parallelism of the axis of the conical hole of the tailstock quill to the movement of the caliper: in the vertical plane: 20 µm; in the horizontal plane 20 µm.
- Check 9: Parallelism of the tailstock movement relative to the caliper movement, verified in: the vertical plane: 40 µm; in the horizontal plane: 25 µm, for machines of accuracy class H with a support stroke length from 500 to 2000 mm.

C. Instruments for Measuring the Surface Quality of Holes

1) Determination of Accuracy and Deviation of Diameter Dimensions

To control the accuracy and deviation of the hole's shape, the following measuring instruments and devices are employed:

- Inside calipers type CI (GOST 868-82) are designed to measure the dimensions of internal surfaces using the relative method of comparison with a measure.
- Optimeter ICC 3 designed for contact measurements of external and internal linear dimensions by comparing the measured product with end measures of classes 1 and 2 or sample parts.

2) Determination of Surface Roughness

The surface roughness was evaluated element by element, measuring the surface roughness parameters separately with a probe device, a block-design profilograph-profilometer mod. 259.

3) Determination of the Surface Hardness of a Hole

Hardness is established by the size of the imprint from indentation (Brinell methods).

4) Determination of the Microstructure of the Surface of a Hole

The microstructure of the surface is analyzed using the Altami MET 3 metallographic non-inverted digital complex. Therefore, the sample's surface (microsection) should be specially prepared. The microanalysis of thin sections consists of the preparation of microsection-sample surface for microstructure research, the etching of thin section-identification of microstructure, and the examination of microsections using a metallographic microscope. The process of preparing a microsection for examination is: cutting out the sample, filling and fixing the sample, grinding, and polishing.

IV. EXPERIMENTAL SETUP

During production tests, new metal-cutting tools were evaluated on Bush-type parts, by processing samples of parts of three standard sizes:

- Standard machine reamer: Processed hole diameter of 14 mm, 20 mm, and 30 mm, with part lengths of d, 2d, and 3d.
- Reamer-broach: Diameter of the processed hole 14 mm, 20 mm, and 30 mm with part lengths of d, 1.5d, and 2d.

Prototypes of the tools were made from high-speed steel grade R18 according to GOST 19265-73 at LLP Format Mach Company, and tested in the educational and production workshops of the Faculty of Engineering of Toraighyrov University.

Production tests were carried out under various conditions, provided in Tables I and II, by comparing the findings of processing holes with a machine reamer and a reamer-broach, as showcased in Figure 8.

TABLE I. TESTING CONDITIONS

Equipment	Screw-cutting lathe mod. 1A616					
Material	Steel, St3 GOST 380-2005 (C – 0.14% - 0.22%; Mn 0.30%-0.60%; Si no more than 0.05)					
Processing length, *L* (mm)	15, 20, 30		20; 25; 30		20; 30; 40	
Processing diameter, *D* (mm)	14		20		30	
Rotation frequency, *n* (rot/min)	280	140	224	112	180	90
Feed, *S* (mm/rot)	0.1	0.36	0.1	0.36	0.1	0.36

TABLE II. DIMENSIONS OF EXPERIMENT SAMPLES

No. of experiment	**Diameter (mm)**	**Length (mm)**
1	14	15
2	14	20
3	14	30
4	20	20
5	20	25
6	20	30
7	30	20
8	30	30
9	30	40

Fig. 8. Experimental samples of the reamer-broach.

Experimental studies were carried out according to the conditions presented in Table III.

TABLE III. VALUES OF TECHNOLOGICAL FACTORS IN EXPERIMENTS

Variation levels	**Values of factors**			
	Spindle rotation frequency		**Longitudinal cutting supply**	
	Natural Value	Coded Value	Natural Value	Coded Value
	n (rot/min)	x_1	S (mm/rot)	x_2
Basic level	210	0	0.19	0
Upper level	280	+1	0.3	+1
Lower level	140	–1	0.08	–1
Interval of variation	70	Δx_1	0.11	Δx_2

Using coded values (-1, +1), a 2^k planning matrix was constructed, where $2^k = N$, represents the number of full-factorial design (assumption: $k = 2$). For the 2^2 planning matrix, as depicted in Table IV, each experiment was performed three times ($m = 3$) and a total of 12 runs were completed. A table of random numbers was utilized from 1 to 12 to ensure that each number appears only once. These numbers were then entered into the planning matrix and the trials were carried out according to the order in which these numbers are written, as illustrated in Table IV, i.e., trial No. 3, is carried out first, trial No. 2 is carried out second, and so on. The results of the experiments are presented in Table VI.

TABLE IV. PLANNING MATRIX

Trial number	**Factors**			
	x_0	x_1	x_2	$x_2\,x_1$
1	+1	-1	-1	+1
2	+1	+1	-1	-1
3	+1	-1	+1	-1
4	+1	+1	+1	+1

The reproducibility of the experiment was assessed using the Cochran criterion. Then, the significance of the coefficients was checked using the Student criterion. Regression equations were obtained and checked for adequacy using the Fisher criterion. After processing the holes with a machine reamer and a reamer-broach, the accuracy of the diametrical size of the hole and the roughness of the hole surface were examined.

Based on data, graphs were constructed to illustrate the dependence of the accuracy of the diametrical dimensions of the processed holes on rotational frequency (Figure 9(a)), and supply (Figure 9(b)), for a hole diameter of 20 mm with processing lengths of 20 mm, 25 mm, and 30 mm (on a screw-cutting lathe).

TABLE V. IMPLEMENTATION OF EXPERIMENTS

$n_{max} = 280$			$n_{min} = 140$			$S_{max} = 0.3$				$S_{min} = 0.08$			
No. trial/Trial no.			**Implementation procedure**			**Factors**				**Parameters, *Ra***			**Average Value**
						x_0	x_1	x_2	$x_2\,x_1$				
1	5	9	6	4	5	+1	+1	+1	+1	0.24	0.20	0.22	0.22
2	6	10	2	9	3	+1	-1	+1	-1	0.16	0.18	0.18	0.173
3	7	11	1	12	8	+1	+1	-1	-1	0.24	0.26	0.25	0.25
4	8	12	7	10	11	+1	-1	-1	+1	0.18	0.20	0.18	0.187

TABLE VI. RESULTS OF THE EXPERIMENTS

No. trial/Trial no.			Results, y_{il}			Average value, $\bar{y}$	Dispersion, Si^2	Optimization parameter, $\hat{y}$
1	5	9	0.24	0.20	0.22	0.22	0.00040	0.224
2	6	10	0.16	0.18	0.18	0.173	0.00013	0.165
3	7	11	0.24	0.26	0.25	0.25	0.00010	0.250
4	8	12	0.18	0.20	0.18	0.187	0.00013	0.187

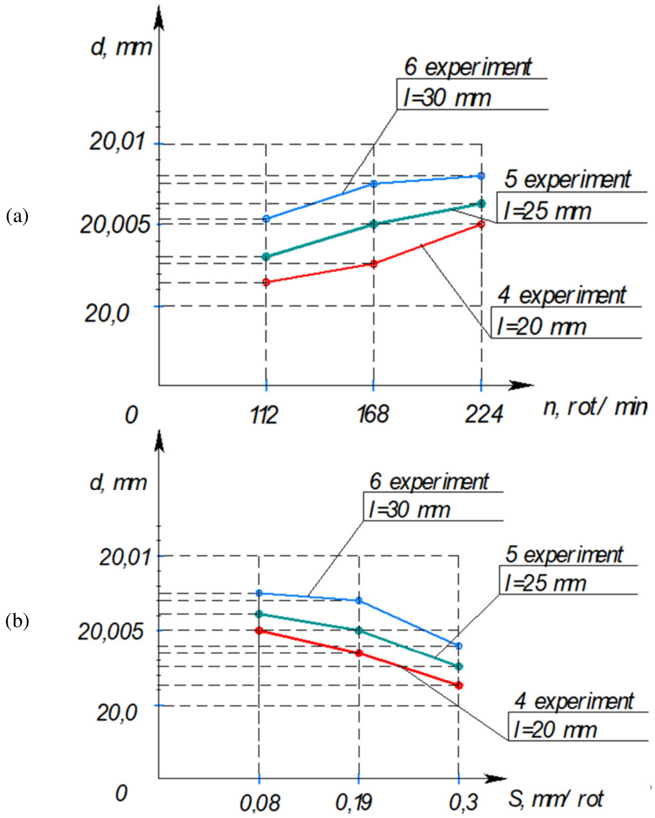

Fig. 9. Dependence of diametrical dimensions on: (a) rotational frequency, and (b) feed.

The surface roughness of the holes was measured using a profilometer with the contact method. Based on the measurements, graphs were constructed showing the roughness dependence on rotation frequency (Figure 10(a)), and supply (Figure 10(b)), for a hole diameter of 20 mm with processing lengths of 20 mm, 25 mm, and 30 mm. To determine the surface microstructure, microsections of the hole were prepared at a magnification of x200 (Figure 11(a)), and the surface microstructure of the samples was presented in Figure 11(b). Microstructure influences significantly the cutting process. During this procedure, when heated in air, carbon or alloy steel shavings oxidize faster than the monolith of the workpiece. The smaller the shaving particle size is, the higher the oxidation rate. In carbon steel chips, iron and carbon are oxidized most intensively. The ferrite-pearlite base of the shaving is grade St3 steel and contains elongated cementite plates in pearlite. Increased microhardness indicates significant chip strengthening during the cutting process. The analysis of the microstructure of samples processed by reaming-pulling showed that there are isolated sections of the inner surface with a deformed layer, with the maximum depth of the deformed layer being 5 µm. As a result, the obtained microstructure proves the workability of the material.

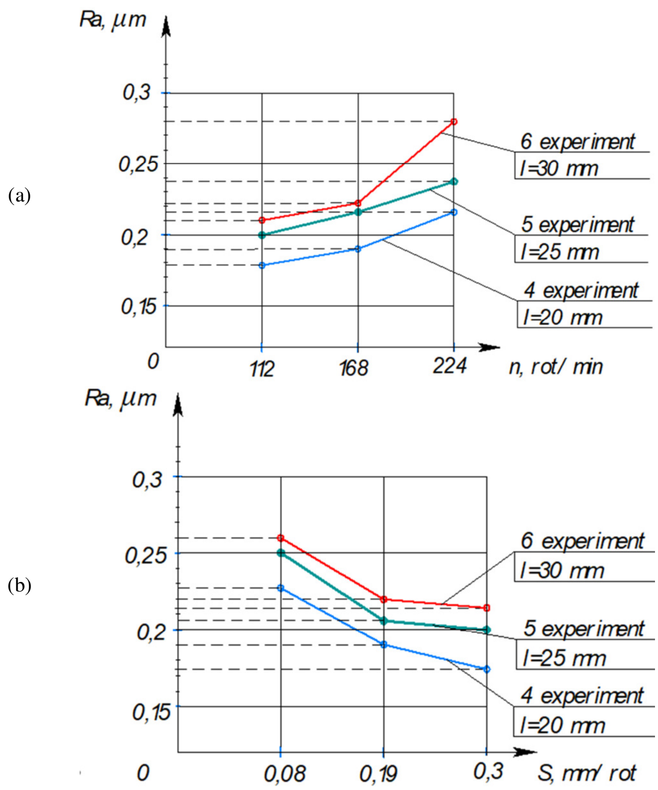

Fig. 10. Dependence of the surface roughness on: (a) rotational frequency, and (b) feed.

V. RESULTS AND DISCUSSION

As can be seen from the graphs, the deviation in the diameter sizes increases with the rise in rotation speed and decreases as the feed rate increases. The accuracy of the hole diameters (breakdown) ranges from 0.011 to 0.021 mm (6-7 accuracy grade). This is explained by the fact that the process of machining holes with a reamer-broach is closer to the process of broaching [17]. An increase in the rotation speed, leads to a higher breakdown of the hole, while an increase in feed results in higher radial centering forces, reducing the breakdown.

As rotation speed increases, both the hole breakdown and surface roughness rise. However, with an increase in feed, the centering forces grow, stabilizing the tool position and leading to a reduction in surface roughness [18]. The surface roughness of the holes with a reamer-broach is within the range of R_a = 0.08-0.16 µm, which corresponds to roughness classes 10 and 11.

(a)

(b)

Fig. 11. Results of the microstructure of the surface of holes processed by a reamer-broach.

As a result of the analysis of cutting conditions during hole machining, the design of a new metal-cutting tool was substantiated, combining the design features of a reamer and a broach. The tool distributes the cutting work along a long cutting edge, reduces temperature in the cutting zone, and sharpens the teeth on the rear surface, thus improving the quality of hole machining. An analysis of the test results and measurements of the processed samples showed that the accuracy of the diametrical dimensions of the holes after machining with a reamer-broach increased by 1.2 quality grades compared to a machine reamer, while roughness decreased by 1.2 grades.

VI. CONCLUSIONS

The utilization of a combined tool for hole machining has led to several conclusions:

- Full-factorial experiments of type 2^k ($k = 2$) were conducted to determine the influence of rotation speed, and feed on hole accuracy, roughness, and shape deviations during machining with a reamer and a reamer-broach.
- Machining with a reamer-broach improves hole quality, reducing both roughness and deviations (breakdown). This is explained by favorable cutting conditions, compared to reamer and broach, due to the combination of positive features of broaching and reamer in one tool.
- Increased spindle speed raises hole diameter deviations while further increase leads to stabilization.
- Higher supply results in reduction of dimeter deviations.
- An increase in spindle speed leads to an increase in roughness, while an increase in feed leads to a decrease in roughness.
- The hardness of hole surface decreases with higher spindle speed and feed.
- A reamer-broach is proposed for machining cylindrical holes with a diameter of up to 40 mm and a length of up to two machining diameters, with a surface roughness of Ra = 0.08-0.16 μm and an allowance equal to the allowance for machining with reamers.

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REFERENCES

[1] M. Das, V. N. A. Naikan, and S. C. Panja, "A review of cutting tool life prediction through flank wear monitoring," *International Journal of Quality & Reliability Management*, vol. 42, no. 2, pp. 425–473, May 2024, https://doi.org/10.1108/IJQRM-11-2022-0318.

[2] K. Ma, Z. Liu, B. Wang, Q. Song, and Y. Cai, "How does the uncut chip thickness affect the deformation states within the primary shear zone during metal cutting?," *International Journal of Machine Tools and Manufacture*, vol. 199, Jun. 2024, Art. no. 104161, https://doi.org/10.1016/j.ijmachtools.2024.104161.

[3] Y. Guo, J. Chen, and A. Saleh, "In Situ Analysis of Deformation Mechanics of Constrained Cutting Toward Enhanced Material Removal," *Journal of Manufacturing Science and Engineering*, vol. 142, no. 2, Dec. 2019, Art. no. 021002, https://doi.org/10.1115/1.4045613.

[4] D. Chemezov *et al.*, "Destruction of the Billet Material During Planing.," *Theoretical & Applied Science*, vol. 3, no. 83, pp. 34–38, 2020, https://doi.org/10.15863/TAS.2020.03.83.9.

[5] X. Liang, Z. Liu, B. Wang, C. Wang, and C. F. Cheung, "Friction behaviors in the metal cutting process: state of the art and future perspectives," *International Journal of Extreme Manufacturing*, vol. 5, no. 1, Aug. 2022, Art. no. 012002, https://doi.org/10.1088/2631-7990/ac9e27.

[6] S. N. Melkote *et al.*, "Advances in material and friction data for modelling of metal machining," *CIRP Annals*, vol. 66, no. 2, pp. 731–754, Jan. 2017, https://doi.org/10.1016/j.cirp.2017.05.002.

[7] J. Loizou, W. Tian, J. Robertson, and J. Camelio, "Automated wear characterization for broaching tools based on machine vision systems," *Journal of Manufacturing Systems*, vol. 37, pp. 558–563, Oct. 2015, https://doi.org/10.1016/j.jmsy.2015.04.005.

[8] Y. Altintas, *Manufacturing Automation: Metal Cutting Mechanics, Machine Tool Vibrations, And Cnc Design*, 2nd ed. Cambridge, UK: Cambridge University Press, 2012.

[9] "Hole machining - drilling and reaming - MorekTECH," *Techniki Wytwarzania i Procesy Technologiczne*, Jul. 15, 2019. https://technologicalprocess.com/hole-machining-drilling-and-reaming/.

[10] Z. Ye, D. Lv, and Y. Wang, "Design of chip breaker and study on cutting performance in reaming 7050 aluminum alloy," *The International Journal of Advanced Manufacturing Technology*, vol. 116, no. 1, pp. 159–173, Sep. 2021, https://doi.org/10.1007/s00170-021-07393-9.

[11] Endwart, "Broaching: Introduction, Features, Methods, Types," *Chengchun Automation Equipment*, Jul. 17, 2022. https://broaching-machine.net/broaching-machine/automatic-broaching-machine/.

[12] J. P. Davim, Ed., *Surface Integrity in Machining*. London, UK: Springer-Verlag London Limited, 2010.

[13] V.-L. Trinh, "A Review of the Surface Roughness Prediction Methods in Finishing Machining," *Engineering, Technology & Applied Science Research*, vol. 14, no. 4, pp. 15297–15304, Aug. 2024, https://doi.org/10.48084/etasr.7710.

[14] K. A, "Precision of Hole Processing by Reamer-Broaching," *Science and Technology of Kazakhstan*, no. 1, pp. 28–36, 2023.

[15]E. Y. Evseev, V. S. Kochergin, "Analysis of methods for determining cutting forces for internal broaching. Product quality: monitoring, management, improvement, planning", in *Proceedings of the third International Youth Scientific and Practical Conference*, 2016, pp. 252-254.

[16] D. A. Stephenson and J. S. Agapiou, *Metal Cutting Theory and Practice*, 3rd ed. Boca Raton, FL, USA: CRC Press, 2018.

[17] P. J. Arrazola, J. Rech, R. M'Saoubi, and D. Axinte, "Broaching: Cutting tools and machine tools for manufacturing high quality features in components," *CIRP Annals*, vol. 69, no. 2, pp. 554–577, Jan. 2020, https://doi.org/10.1016/j.cirp.2020.05.010.

[18] D. Fabre, C. Bonnet, J. Rech, and T. Mabrouki, "Optimization of surface roughness in broaching," *CIRP Journal of Manufacturing Science and Technology*, vol. 18, pp. 115–127, Aug. 2017, https://doi.org/10.1016/j.cirpj.2016.10.006.

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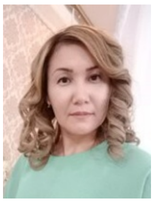

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