INTERNATIONAL JOURNAL OF PRECISION ENGINEERING AND MANUFACTURING Vol. 18, No. 10, pp. 1425-1432 OCTOBER 2017 / 1425
REGULAR PAPER
DOI: 10.1007/s12541-017-0170-9
ISSN 2234-7593 (Print) / 2005-4602 (Online)

Hole Machining Based on Using an Incisive Built-Up Reamer

Nikolay Dudak[1], Aizhan Taskarina[1], Asylbek Kasenov[1], Galiya Itybaeva[1,#], Zhanara Mussina[1], Kairatolla Abishev[2], and Ruslan Mukanov[2]

1 Department of Mechanical Engineering and Standardization, S. Toraighyrov Pavlodar State University, 64 Lomov str., Pavlodar, 140008, Kazakhstan
2 Department of Transport Equipment and Logistics, S. Toraighyrov Pavlodar State University, 64 Lomov str., Pavlodar, 140008, Kazakhstan
Corresponding Author / E-mail: galia-itibaeva@mail.ru, TEL: +8-778-636-19-31, FAX: +8-718-267-19-31

KEYWORDS: Cutting tools, Hole machining, Reamer, Roughness, Working life

This article deals with analyzing the existing cutting tools and ways of hole-making operations. The newly designed tool consists of four false teeth-incisors and the curved cutting edge. This tool provides the possibility to increase the hole quality (tolerance of size, surface roughness), to facilitate cutting and to increase tool life. Experimental studies related to hole processing were carried out by using a scanner. Reproducibility of the experiment was determined according to Cochran's criterion G. The obtained results were processed through the mathematical apparatus of the full factorial experiment of type 23. Based on relevant data measurements, the authors of this research built graphics based on the accuracy of diametric dimensions of the processed holes, spindle rotation frequency and cut feed, as well as on the dependence of surface roughness from technological factors (workpiece speed, feed and length). The graph shows that deviation of the diametric size increases with increase in feed and decreases with the speed increase; surface roughness is inversely proportional to workpiece speed. Precision machining of holes corresponds to 5-6 accuracy degree, which is higher by one or two orders of magnitude compared to using standard hole boring cutters and scans.

Manuscript received: January 26, 2017 / Revised: May 3, 2017 / Accepted: June 14, 2017

1. Introduction

In recent decades, development of engineering in the world aims not only at “intellectualization” of vehicles, but also at the use of various metals and their alloys in order to reduce weight, increase durability and reliability of vehicles.[1] Working with such materials demands accurate, high-tech and reliable equipment and tools.

All cutting tools have the tool nose as the intersection point of the major and minor cutting edges. The tool nose is subject to increased abrasion. Its working life depends on the surface layer roughness. In hole machining, the tool nose is subject to increased thermal stress, which reduces resistance and requires additional regrinding; this reduces its working life, leads to reduced productivity and increases its treatment costs.

There are various hole-machining methods – honing operation, laser processing, electro-chemical machining. Operation with these methods requires the purchase of expensive equipment.

Thus, this research is aimed at the development of an incisive built-up reamer with peakless teeth and housing guide elements and a relevant hole machining method.

Research methods included the experimental drilling tool scan; mathematical and statistical analysis – regression equations were used to check reproducibility of the experiment according to Cochran's criterion G. Mathematical apparatus of the full factorial experiment of type 23 was used to determine the minimum required number of experiments. The principle of randomization was used to exclude systematic errors. In addition, the authors used statistical analysis of regression equations along with verifying significance of coefficients (criterion); graphical visualization was used to determine suitability or adequacy of the obtained equations or descriptions of the process (Fisher criterion F).

In order to assess the quality of drilled holes, the authors used the following devices and equipment: vertical drilling machine, tool horizontal optimeter IKG-3 and profilometer (Model 259).

Research tasks included analysis of modern metalworking tools and techniques as well as examination of conditions referring to the drilling tool scan.

Cutting tools should meet the highest possible requirements, such as sufficient rigidity, strength, hardness, heat and wear resistance.[2] Cutting tools are classified according to the principle of interaction with the material; with regard to application of the machined surface; design; type of manufacture; type of connection with the machine as well as with regard to their application method.

Alternative metal processing tools were developed according to these requirements. These tools are made of layered composite ceramics with nano-multilayer coating for cutting hardened steels and nickel alloys.[3] Their life (compared with the relevant standard) is increased by 2.5 - 8.0 times, and their cutting performance – by 1.2-1.5 times.

This also refers to magnetic impulse tools used for forming, welding, crimping and cutting of ferrimagnets and related materials.[4-6] Their working principle is based on the interaction between magnetic fields of the tool and the metal workpiece. Depending on the operating frequency, one can observe attraction or repulsion of the treated area from the instrument (the inductor). Powerful magnetic pulse serves as the source signal.

Toolmakers developed milling tools with improved cutting performance as regards various materials, for example, titanium, tool steel, stainless steel, and tungsten carbide instruments. These tools were designed to extend the working life of technological equipment.[7,8]

In Ref. 7, this is achieved through positive-rake cutting geometry of the milling tools with a sharper and lighter cutting shape.

In order to maintain high quality of operations, one should assess and predict cutter wear rate, for example, through nonlinear reduction methods and support vector regression.[9]

Since more than 70% of machine parts have holes of various shapes and sizes, their processing is important in terms of mechanical engineering.

Generally, holes are machined through rod tools, the choice of which depends on the accuracy requirements of these holes. Drilling and core drilling present roughing operations, while deployment and pulling are the finishing ones.[10,11]

Deployment is a processing stage intended to reduce roughness of the processed holes. Accuracy and quality are the main characteristics of deployment.

Examining the design of different reamers, the material they are made of as well as their impact on precision machining, one can confirm that tool geometry affects stability of its working position and therefore the machining accuracy.[12-15]

Thus, the abrasive-pressing deployment with bars made of superhard materials (borazon) on metal or electroplating ligaments reduces damage to the abrasive working surfaces of the guide elements and provides efficient removal of stock without clogging the working surface of the abrasive elements.[12]

Cutting edge of any tool is among its mortality parts. Therefore, optimization of its geometry aims at improving its quality. This part requires an additional production process. The developed cutting edge gives the possibility to influence chip formation. This is achieved by reducing cutting forces and improving the workpiece quality.[13]

Cutters with floating heads are used to finish holes with diameters greater than 70 mm, followed by lamination rollers.[14] High stiffness of the cutters increases accuracy of hole processing within the range of 6...8 (qualitative accuracy).

One can use a bulb in order to increase the accuracy of hole processing. This method consists in pushing the ball of hard material through the previously drilled hole in the metal made of any softer material (soft steel, aluminum).[15] The ball diameter should be larger than the hole diameter. Therefore, the hole diameter will increase.

Firms located in Germany,[16,17] Israel[18] and Switzerland[19] take the lead in the production of cutting tools for boring and reaming purposes.

Application of modern materials allows improving quality, reliability, durability and precision of such tools. This provides the opportunity to work with both heavy-duty and brittle materials.[3,7-9,13]

Quality of the scanner and its construction depends on hole processing costs. For example, comparative analysis of final processing costs of the hole about 20 mm in diameter by using a boring bar showed that sweep application gave the possibility to reduce total processing costs by 2.5 times through increasing supply and the number of processed holes, despite high cost of the relevant equipment.[20]

Scientists around the world paid great attention to the development and improvement of boring and cutting heads being the main part of any cutting tool[21-23] as well as metal processing methods and techniques.[4-6,11-14,26,27]

Therefore, development and improvement of hole processing methods and tools is a topical task; its solution will provide wide application of results obtained not only in engineering and metalworking but also in industries requiring high-precision processing of various materials.

2. Design of Incisive Built-Up Reamer

Specificity of a tool sweep is the absence of teeth peaks as regards cutters and cutting edges made on the arc of a circle with the inclination of the plane of the main cutting edge relative to the plane perpendicular to the sweep axis.[24,25] This reduces power and thermal stress on the cutting edge, which leads to reduced wear, increased durability and better surface quality, including roughness reduction due to changing conditions and kinematics of chip formation.

Hole-machining operation with incisal built-up reamer is carried out on a universal vertically oriented drilling machine, which does not require equipment costs. It is available in any machine-building enterprise.

Teeth-cutters (their optimal number is four) are permanently displaced along the sweep axis so that the appropriate teeth points of the cutters are located on a helix. Treatment quality is improved through alternating the angular step between the teeth of unequal axial sweep or step sweep. All teeth-cutters have cutting edges formed by the arc of a circle, the plane of which is inclined at an angle to the axis of rotation (holes). At the roundabout, corners of the cutting teeth are eliminated and cutting conditions are improved. All teeth-cutters have similar height, i.e., the tool is configured to handle one hole diameter. Minimum runout of cutting teeth ensures high processing accuracy. The sweep includes guide elements to improve processing accuracy. Teeth-cutters are attached to the reamer by means of special clamps and screws. Teeth- cutters are either made of high heat steel or equipped with plates of hard alloy.

Material of the incisal built-up reamer: base – Steel 45; teeth (cutting elements) – T30K4 solid alloy.

The mechanical and chemical characteristics of steel 45 are presented in Tables 1 and 2.

Forging temperature (C) is 1250 at the beginning and 700 at the end. Cross sections (up to 400 mm) are cooled in air.

Overall weldability – it is difficult to weld. It requires heating and

Table 1 Chemical composition of steel 45 defined in the standard GOST 4543-71

Carbon C,%	Manganese Mn, %	Silicon Si, %	Cuprum Cu, %	Chromium Cr, % max	Sulphur S, %	Phosphourus P, %
					max	
0,40-0,45	0,50-0,80	0,17-0,37	0,25	0,25	0,04	0,035

Table 2 Mechanical characteristics of steel 45 defined in the standard GOST 4543-71

Yield stress, σT, MPa	Ultimate stress limit, σB, MPa	Stretch ratio, δ , %	Percentage reduction, Ψ,%	Brinnel hardness number, HB, max	
minimum				Hot-rolled	Annealed
360	610	16	40	241	197

Table 3 Mechanical and chemical characteristics of the T30K4 solid alloy

Tungsten carbide, WC,%	Titanium carbide, TiC, %	Tantalum carbide, TaC, %	Cobalt, Co, %	Bending stress σ, MPa	Hardness, HRA	Density, ρ, g/cm^3	Thermal conductivity, W/(m·°C)
66	30	—	4	1000	92	9,8	12,57

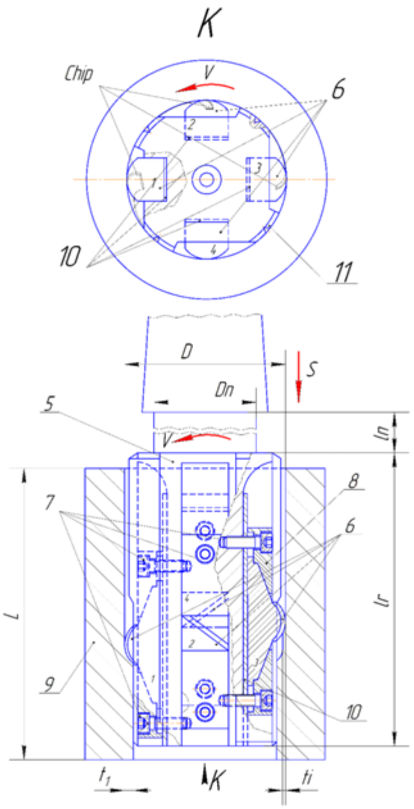

Fig. 1 Scheme of an incisive built-up reamer

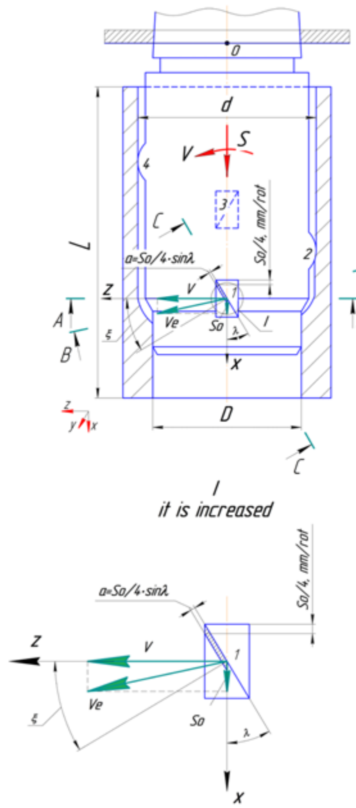

Fig. 2 Parameters of cut material layer (anchors for teeth (cutting elements) are not shown)

subsequent heat treatment.

Cutting property – in hot-rolled steel under HB 170-179 and σB = 640 MPa, KCU of solid alloy = 1.

Flake susceptibility – low.

Susceptibility to temper brittleness – not inclined.

The processing scheme using an incisal built-up reamer with peakless teeth is shown in Fig. 1. Fig. 1 defines: *1, 2, 3, 4* – the order numbers of the reamer cutting teeth; *5* – reamer body; *6* – four displaced relatively to each other reamer points; *7* – fixing screws; *8* – clips; *9* – a workpiece; *10* – flat compensation plate with holes for the fixing screws; *11* – reamer body guiding rails; *D* – reamer (hole) diameter; D_n – the neck diameter; *L* – length of the workpiece; ℓ_p – reamer working length; ℓ_n – length of the neck; *S* – axial feed of the tool; *V* – speed of the tool rotation; V_e – bulk velocity, t_1 – the surplus removed by the first tooth point; t_i – the surplus removed by the second and third tooth points.

Cutting process during hole-machining occurs due to the cutting tool overcoming (through the cutting elements) the cutting resistance of a cut layer and due to turning it into chips under the cutting force, emerged under the rotational motion of cutting and axial direction.

Elastic and plastic deformations may occur during the cutting. Their forces act directly in the direction from the sheared layer on the front

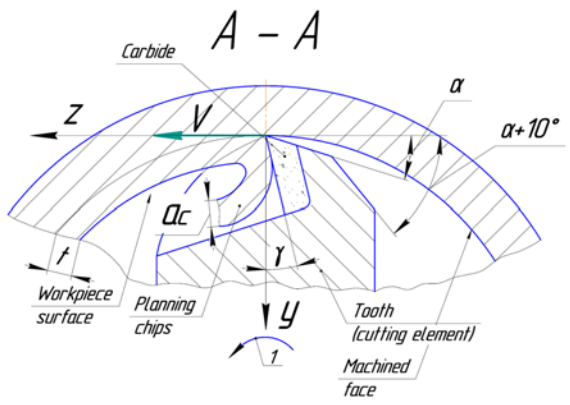

Fig. 3 Parameters of the cut-off layer in section A-A (Fig. 2)

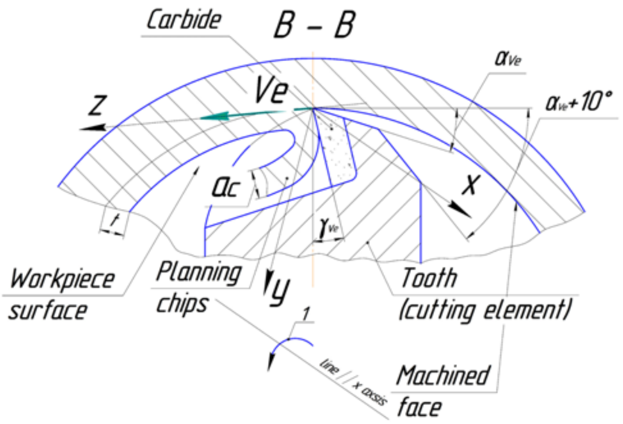

Fig. 4 Parameters of the cut-off layer in section *B–B* (Fig. 2)

surface of the tool. The force acting directly in the direction from the machined surface to the back surface of the tool emerges due to the elastic pressing of treated surface. If there is a normal pressure and relative movement of the tool and chips, as well as the tool and workpiece, frictional force will arise and act on the front and back surfaces of the tool.

The force of resistance to movement along the trajectory of relative working motion acts on the blade of the tool during the cutting.

The first tooth point removes the surplus for machining, while the others calibrate the processed hole, which lowers the surface roughness and raises the accuracy of machining.

Thus, the main job is performed by the first tooth point. The others successively calibrate the processed hole. The chip removed by the first tooth point is wide, while the one removed by the second and third is narrow.

Fig. 2 shows the parameters of the cut material layer.

S_o – axial feed (width of cut layer); V – rim speed; V_e – effective velocity.

Fig. 3 shows the section A-A: *1* – rotational direction of a reamer; S_o – axial feed of the tool; t – removable allowance; L – length of the workpiece; α – end-clearance angle; γ – front clearance angle.

Fig. 4 shows the section B-B: *1* – rotational direction of a reamer; S_o – axial feed of the tool; t – removable allowance; a_c – chip thickness ($a_c > t$); L – length of the workpiece; α – end-clearance angle; γ – front clearance angle.

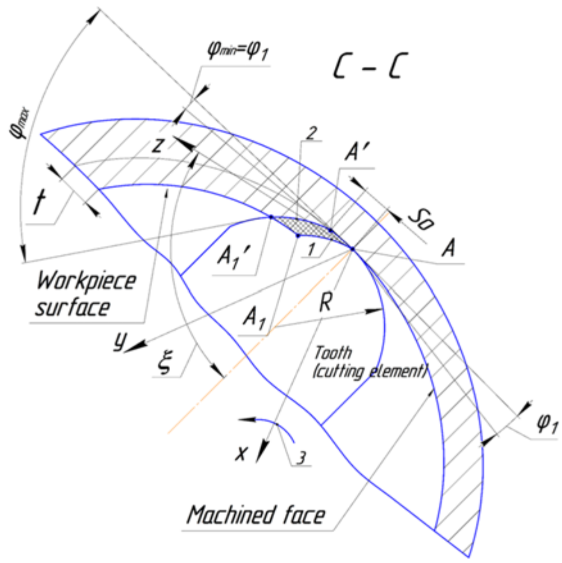

Fig. 5 Geometrical parameters of a tooth (cutting tool)

Fig. 5 shows the section C-C (Fig. 2) on the circular cutting edge of the tooth (cutting tool): *1* – profile of the intermediate machined face (cutting surface); 2 – profile of the workpiece surface (cutting); 3 – rotational direction of a reamer; D – diameter of hole before processing; d – diameter of the hole after processing; L – length of the workpiece; R – radius of the tooth (cutting tool); t – removable allowance; a_c – chip thickness ($a_c > t$); φ, φ_1 – major and minor cutting angles in the plan; AA_1 – max thickness of a cut while each tooth (cutting tool) of a reamer is operating.

The major angle in the plan of an incisive built-up reamer with peakless teeth $\varphi = 2°51'$. The major end-clearance angle is $\alpha = 6\text{-}8°$.

The front clearance angle is $\gamma = 0$, because allowance is small, as well as the thickness of the cut layer; tip angle is $\lambda = 45$

Structural dimensions of the incisive built-up reamer with peakless teeth

Removable allowance t = 0.25 mm and diameter of the front guide (catcher) is equal to $D_{f.g.} = 39.5$ mm.

Length of the working part of the built-up reamer is l = 212 mm with processing diameter D = 40 mm and structural factors.

The number of teeth is z = 4, tooth spacing angle is $\theta = 90°$. In this case, each pair of opposite teeth lies on the same diameter along the helicoidal line. This simplifies the manufacture and control over the reamer.

Geometric and structural parameters of inserted teeth (width and length of a tooth, radius of the cutting edge) are specified by graphical profiling.

Abrasive friction between the guiding and the treated surfaces has to be eliminated to improve the treatment quality.

Chip-excluding grooves were formed along the forming parts of a leading cylinder to eliminate the abrasive friction and abrasive wear of body parts. In order to exclude the possibility of fore edge entering the machined surface, the guide circle was chamfered. Chamfering makes the process of entering difficult while there are vibrations during the cutting process. This also improves the quality of machining.

Table 4 Values of technological factors during experiments

The variation levels	Values of factors					
	Spindle rotation frequency		Longitudinal pitch of cutting		Workpiece length	
	n, rpm	x_1	S, mm/rot	x_2	L, mm	x_3
Main level	104	0	0,735	0	40	0
Upper level	140	+ 1	1,22	+ 1	60	+ 1
Lower level	68	– 1	0,25	– 1	20	– 1
Variation range	36	Δx_1	0,485	Δx_2	20	Δx_3

There are replaceable compensation plates installed under the base of teeth-cutters to increase the service life of a reamer by increasing the number of regrinding cycles. They could be replaced after each regrinding in order to compensate the loss of cutting tool's height.

Thus, design features of incisal built-up reamer and the quality of cutting teeth ensure high efficiency of reaming, high accuracy of machining, long tool life and a reduction in roughness of machined parts.

Further improvement has led to the development of the incisal built-up reamer, with the double number of cutting teeth for better hole calibration.[25]

3. Experimental Study of Hole Machining Based on Using an Incisive Built-Up Reamer

Hole machining was performed on a vertical drilling machine during training workshops held on the Faculty of Metallurgy, Mechanical engineering and transport of S. Toraigyrov Pavlodar State University at the Department of Engineering and Standardization.

Before carrying out experiments the samples were turned along the outer surface and a hole was drilled to the diameter of reamer catcher.

Then the geometric accuracy of the vertical drilling machine was evaluated according to GOST 370-93 Vertical Drilling.

The treatment was performed with a cutting fluid. We have used a 10% solution of emulsion while processing the steel.

The quality of drilled holes was measured by using the following devices:

– instrumental horizontal optimeter BRU-3 – measurement of accuracy of diametric dimensions;

– profilometer (Model 259) – evaluation of surface roughness.

Preparations for the experiment:

1. Putting protective experimental samples on the outer surface and drilling holes with diameters relevant to the separator base;

2. Evaluating geometric accuracy of a vertical drilling machine according to Ref. 28.

This study required determining the minimum required number of experiments. This problem was solved using a mathematical apparatus of the full factorial experiment of the type 23.[29]

Planning the experiment involved finding a function defining the relationship between the problem formulation and factors influencing independent variables.

The objective of the experiment was to create a model, i.e., dependencies, which could be used to determine the value of the studied parameter.

Optimization parameters of the selected deviation of diameter and roughness involved the following factors: spindle rotation frequency (max – 140 rpm; min – 68 rpm), workpiece feed (max – 1.22 mm/rev; min – 0.25 mm/rot) and length (max – 60 mm; min – 20 mm).[29]

The authors of this research developed a planning matrix 2^3 for two factors. The rows in columns x_1 and x_2 of the matrix specify the plan of the experiment, that is, conditions of the experiments, carried out under all possible combinations of factors.

The planning matrix is as follows: the first row of the matrix was selected so that all the studied factors were at lower levels, that is x_1 = -1, x_2 = -1, x_3 = -1.

The experimental procedure was subject to errors and their detection was necessary in terms of the obtained results. In this regard, the procedure was chosen so that it was possible to assess the random error of the experiment and to avoid the impact of possible systematic errors. Randomization was used to eliminate the random interference factors, which could have a systematic character.

Before defining a model of this experiment, its reproducibility was determined according to Cochran's criterion G. The experiment was reproducible, because G_{max} = 0,440 < G_{tab1} = 0,5157.

The authors performed statistical analysis of the obtained regression equations, which included testing the significance of equation coefficients (Student's t-test); suitability or adequacy of the obtained equations or descriptions of the process (F-test).

The model in coded variables is described as follows:

$$y = 0{,}28 - 1{,}47x_1 + 1{,}67x_2 \tag{1}$$

According to the obtained and adequate model, the authors calculated the value of the studied parameter (deviation of diameter, surface roughness) under any combination of factor values being within the scope of experimentation. The value of the coefficient standing in front of a particular factor in the model gives the possibility to assess the impact of this factor on the studied parameter. The more the numerical value of the coefficient, the more influential is that factor. The sign of the coefficient indicates direction of the influence factor, i.e., a plus sign indicating increase in the numerical values of the coefficient leads to an increase of the studied parameter, while a minus sign indicates its decrease.[29]

We obtain the mentioned model in the natural variables n, S, and L instead of x_1, x_2, x_3 according to the following expression:

$$x_1 = \frac{2(\ln\hat{X}_1 - \ln 140)}{\ln 140 - \ln 68} + 1, \quad x_2 = \frac{2(\ln\hat{X}_2 - \ln 1{,}22)}{\ln 1{,}22 - \ln 0{,}25} + 1, \quad x_3 = \frac{2(\ln\hat{X}_3 - \ln 60)}{\ln 60 - \ln 20} + 1 \tag{2}$$

We obtain transformation equations by substituting the upper and

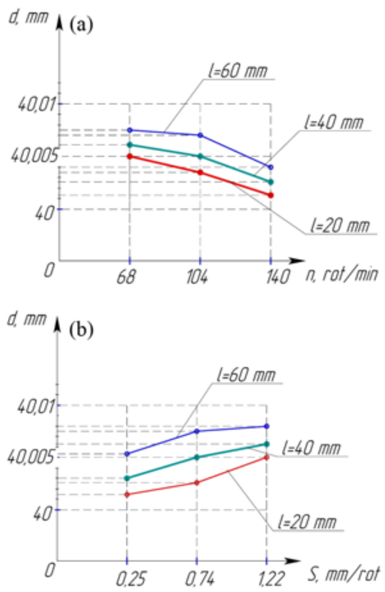

Fig. 6 Dependence of the accuracy of diametric dimensions of a hole about 40 mm in diameter on: (a) spindle rotation frequency, rpm, (b) cut feed S, mm/rot

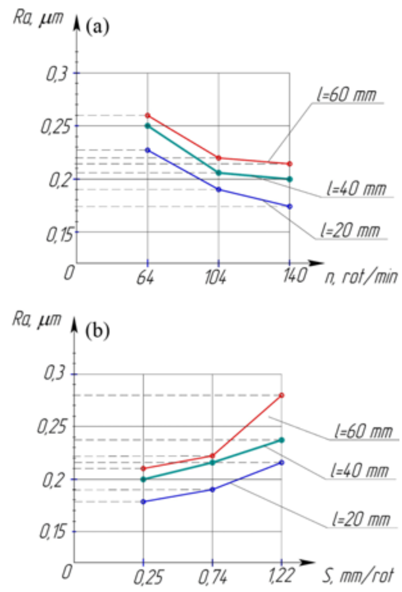

Fig. 7 Dependence of surface roughness of holes about 40 mm in diameter on: (a) spindle rotation frequency, rpm, (b) cut feed S, mm/rot

lower levels of factors in the expression Eq. (1):

$$\ln\Delta d = 0{,}28 - 1{,}47\left[\frac{2(\ln n - \ln 140)}{\ln 140 - \ln 68}+1\right] + 1{,}67\left[\frac{2(\ln S - \ln 1{,}22)}{\ln 1{,}22 - \ln 0{,}25}+1\right] \quad (3)$$

After conversion, we obtain the following resulting equation:

$$\ln\Delta d = 0{,}28 \cdot 2{,}33 - \ln n \cdot 3{,}71 - \ln S \quad (4)$$

Potentiating the obtained expression, we find dependence of the diameter deviation on the studied factors related to hole machining:

$$\Delta d = 0{,}2998\frac{S^{0{,}077}}{V^{0{,}056}} \quad (5)$$

Similarly, data were processed to determine surface roughness of the hole:

$$R_a = 9{,}57\frac{S^{0{,}53}}{V^{0{,}01}} \quad (6)$$

4. Results

For measuring the quality of processed holes the following instruments were used: IKG3 instrumental horizontal optimeter for measurement of diametrical size accuracy, and Model 259 profilometer to evaluate the surface roughness.

In the basis on the findings on diametrical size deviations we built diagrams of dependence of the diametrical size precision of the machined holes on the spindle speed and cutting feed. The deviation of diametrical sizes increases with the increase of feed (Fig. 6(a)) and decreases with the increase of speed (Fig. 6(b)).

Surface roughness of the mentioned holes was measured by using a contact profilometer.

Fig. 7 shows dependence of roughness on technological factors (workpiece speed, feed and length), based on these measurement results.

As shown by the above graphs, surface roughness decreases with increase in rotation frequency (Fig. 7(a)), while increase in cut feed leads to increase in surface roughness (Fig. 7(b)).

5. Discussion

Despite the large number of studies in the field of metal processing, no cutting tools that would meet reliability, quality, durability and versatility requirements have been developed.

Attempts aiming at unification of tools do not give significant results for various reasons. For example, improvement of processing accuracy entails increase in operating costs. Quite often, selection of processing equipment and tools is determined by the need to find a compromise between the desired quality and price.[3,10,12-15] Besides, one needs to consider relevant characteristics of the processed material as well as the size and position of the hole.

Therefore, application of tools made of layered composite ceramics with nano-multilayer coating for cutting hardened steels and nickel alloys[3] is not always appropriate. Their essential drawback is production complexity resulting in high maintenance costs. There are cheaper options referring to processing of soft metals, such as mild steel and aluminum. For example, one can consider the method, which consists in pushing the ball made of hard material through the hole previously drilled in the metal made of a soft material.[15] This method can be applied for mass calibration and finishing of holes.

For holes over 70 mm in diameter, one can use heads with floating cutters.[14] Hole machining accuracy is improved due to high stiffness of cutters.

As regards magnetic-pulse processing methods,[4-6] they have significant limitations. In particular, they are used for processing thin-walled metals. In addition, their disadvantage is that the tool requires a powerful pulsing signal of a certain frequency. This requires special costly high-voltage magnetic pulse equipment, having large size and weight. Besides, its operation requires highly qualified personnel.

Considerable attention should be paid to the fact that design of the reamers (and material they are made of) affect the machining accuracy.

The abrasive-pressing deployment requires using bars made of superhard materials (borazon) on metal or galvanic ligaments. This reduces damage to the abrasive working surfaces of the guide elements and provides efficient removal of stock without clogging the working surface of abrasive elements.[12] Nevertheless, this method is still under research and development as a tool with optimized innovative geometry.[13]

The proposed scanning method differs from the existing ones by the presence of teeth and guide elements. In contrast to the existing modern analogues,[3,5,8,9] this design is simple enough in terms of its implementation, which will not only increase its reliability and durability but also reduce its cost.

The experiments and analysis of results allow choosing the optimal mode of operation of the tool depending on the required accuracy of bores. This will reduce working costs and increase the lifecycle of equipment, which will optimize uptime and reduce energy costs.

It should be noted that results of this research could be used to create an automated system, which (depending on the workpiece material, size and location of holes as well as required accuracy and surface roughness), will be able to automatically specify the spindle speed and cutting feed.

6. Conclusion

The developed design of incisive built-up reamer implies the presence of four false teeth-cutters with the curved cutting edge. It is possible to increase the hole quality (tolerance of size, surface roughness), which will facilitate cutting and increase tool life.

Precision machining of holes corresponds to 5-6 accuracy degree, which is higher by one or two orders of magnitude compared to using standard hole boring cutters and scans. The achieved surface roughness is within the range of 0, 32...1,25 μm.

In terms of hole machining based on using an incisive built-up reamer with peakless teeth, the length of treatment has no significant effect on the deviation of hole diameter and surface roughness.

The obtained theoretical and technological results had practical value for finishing of cylindrical holes. Key findings can be helpful in terms of improving the existing and developing new technological processes of hole machining in engineering and metalworking.

ACKNOWLEDGEMENT

The research was carried out in the framework of the topic: “Research and development of resource-energy saving metal-cutting tools” and was registered in the National Center of Science and Technology Evaluation JSC (Kazakhstan) registration number 0117PKU0382, 2017.

REFERENCES

1. Mozgovoy N. I., Markov A. M., Mozgovaya Y. G., “Problems and Perspectives of the Use of Plastic Materials for Machine Parts,” Polzunov Almanac, No. 2, pp. 92-95, 2013.
2. Stephenson, D. A. and Agapiou, J. S., “Metal Cutting Theory and Practice,” CRC Press, 2016.
3. Grigoriev, S. N., Vereschaka, A., Vereschaka, A., and Kutin, A., “Cutting Tools Made of Layered Composite Ceramics with Nano-Scale Multilayered Coatings,” Procedia CIRP, Vol. 1, pp. 301-306, 2012.
4. Gnatov, A. and Argun, S., “New Method of Car Body Panel External Straightening: Tools of Method,” International Journal of Vehicular Technology, Vol. 2015, Article ID: 192958, 2015.
5. Schäfer, R., Pasquale, P., and Kallee, S., “The Electromagnetic Pulse Technology (EMPT): Forming, Welding, Crimping and Cutting,” Biuletyn Instytutu Spawalnictwa w Gliwicach, Vol. 58, No. 2, pp. 50-57, 2014.
6. Batygin, Y. V., Golovashchenko, S. F., and Gnatov, A. V., “Pulsed Electromagnetic Attraction of Nonmagnetic Sheet Metals,” Journal of Materials Processing Technology, Vol. 214, No. 2, pp. 390-401, 2014.
7. Benes, J., “Cutting Difficult-to-Machine Materials,” American Machnist, http://www.americanmachinist.com/cutting-tool-digest/cutting-difficult-machine-materials (Accessed 15 SEP 2017)
8. Honghua, S. U., Peng, L. I. U., Yucan, F. U., and Jiuhua, X. U., “Tool Life and Surface Integrity in High-Speed Milling of Titanium Alloy TA15 with PCD/PCBN Tools,” Chinese Journal of Aeronautics, Vol. 25, No. 5, pp. 784-790, 2012.
9. Benkedjouh, T., Medjaher, K., Zerhouni, N., and Rechak, S., “Health Assessment and Life Prediction of Cutting Tools Based on Support Vector Regression,” Journal of Intelligent Manufacturing, Vol. 26, No. 2, pp. 213-223, 2015.
10. Doomra, V. K., Debnath, K., and Singh, I., “Drilling of Metal Matrix Composites: Experimental and Finite Element Analysis,” Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, Vol. 229, No. 5, pp. 886-890, 2015.
11. Holt, S. and Clauss, R., “Robotic Drilling and Countersinking on Highly Curved Surfaces,” SAE Technical Paper, No. 2015-1-2517, 2015.
12. Tonkonogiy, V. M., Perperi, L. M., Riazantsev, V. M. and Goloborodko, A. M., “Improving the Accuracy and Quality of the Conical Holes of the Abrasive-Pressing Deployment,” Cutting and Tools in Technological Systems, No. 83, pp. 264-268, 2013.
13. Byrne, G., Dornfeld, D., and Denkena, B., “Advancing Cutting Technology,” CIRP Annals-Manufacturing Technology, Vol. 52, No. 2, pp. 483-507, 2003.
14. Hartmetall, “HORN-Technologieseminar in Geretsried am 19./20.

Oktober 2016," http://www.phorn.de/veranstaltungen/technologieseminar-oktober-2016/ (Accessed 15 SEP 2017)

15. Lazarev, D. E., "Cutting Heads for Deep Hole Machining. Floating Head with the Radial Offset Possibility," Technical Science – From Theory to Practice, No. 6-1, 2012.

16. Upadhyay, P. K., Ansari, A., and Agarwal, P., "Study and Analysis of Geometric Effect of Ball Burnishing Process of Different Materials and Evaluation of Forces and Strain for Ballizing Process," Current World Environment, Vol. 7, No. 1, pp. 101-108, 2012.

17. MAPAL, "Take a Look to the Current Online Catalogues from MAPAL," https://www.mapal.com/en/download/online-catalogues (Accessed 25 AUG 2017)

18. Iscar Ltd., "New Product Announcement," http://www.iscar.com/npa.aspx/CountryId/1# (Accessed 25 AUG 2017)

19. URMA, "URMA CircoTec – High-Performance Reamers," http://www.urma.ch/en/Circo-Tec/index.php (Accessed 25 AUG 2017)

20. Zelinski, P., "Reaming Application Illustrates True Cost of Cutting Tools," http://www.mmsonline.com/articles/reaming-application-illustrates-true-cost-of-cutting-tools (Accessed 15 SEP 2017)

21. Chen, C.-C., "Boring Bit," US Patent, 8109699, 2012.

22. Fedorov, Y. N., Artamonov, V. D., Malikov, A. A. and Kondrashov, V. A., "Russia, Pat. 2445185, the IPC 23 F 21/12 (2006.01) B 23 F 21/24 Cutting head," 2012.

23. Yu, D., "Deep Hole Drill with Positive Taper and Principle for Elimination of Drill Deviation Using Cutting Fluid," The International Journal of Advanced Manufacturing Technology, Vol. 89, Nos. 9-12, pp. 3195-3206, 2017.

24. Dudak, N. S., Kasenov, A. Z., Musina, Z. K., Itybaeva, G. T., and Taskarina, A. Z., "Processing of Holes with a Reamer-Broach," Life Science Journal, Vol. 11, No. 10s, pp. 282-288, 2014.

25. Taskarina, A. Z., Mendebaev, T. M., Dudak, N. S., Itybaeva, G. T., Musina, Z. K. and Kasenov, A. Z., "Improving the Design of the Sweep Tool with Peakless Teeth," Scientific Journal of the Shakarim Semipalatinsk State University, pp. 32-35, 2012.

26. Thil, J., Haddag, B., Nouari, M., Barlier, C., and Papillon, L., "Experimental and Analytical Analyses of the Cutting Process in the Deep Hole Drilling with BTA (Boring Trepanning Association) System," Mechanics & Industry, Vol. 14, No. 6, pp. 413-429, 2013.

27. Kamath Cholpadi, R., and Kuttan, A., "Mechanistic Force Modeling for Broaching Process," International Journal of Manufacturing Engineering, Vol. 2014, Article ID: 485712, 2014.

28. GOST, "Vertical Drilling Machines Basic Dimensions. Standards of Accuracy and Rigidity," No. 370-93, 2005.

29. Taskarina, A. Z., Mendebaev, T. M., Dudak, N. S. and Kasenov, A. Z., "Planning of Experimental Studies of Hole Tool Head. Proceedings of the International Scientific and Practical Conference "Innovative Technologies, Equipment and Materials in Mechanical Engineering"," Kazan National Technical University, Almaty, pp. 152-157, 2012.