UDC 621.9
DOI: 10.15587/1729-4061.2021.224897

GENERAL PROCEDURE FOR DETERMINING THE GEOMETRIC PARAMETERS OF TOOLS IN THE TECHNOLOGICAL SYSTEMS INVOLVING MACHINING BY CUTTING

S. Botvinovska
Doctor of Technical Sciences, Professor*
E-mail: Botvinovska@ua.fm, botvinowska@gmail.com
G. Getun
PhD, Professor
Department of Architectural Constructions**
E-mail: GalinaGetun@ukr.net
A. Zolotova
PhD, Associate Professor*
E-mail: zolotovaav1@gmail.com
I. Korbut
PhD, Associate Professor***
E-mail: korbut113@gmail.com
T. Nikolaenko
PhD, Associate Professor*
E-mail: tatyana.rodina@gmail.com
V. Parnenko
PhD, Assistant***
E-mail: art@artograph.com.ua
R. Rodin
PhD, Senior Researcher***
E-mail: insrad@ukr.net
*Department of Descriptive Geometry and Engineering Graphics**
**Kyiv National University of Construction and Architecture
Povitroflotskyi ave., 31, Kyiv, Ukraine, 03037
***Department of Machine Design
National Technical University of Ukraine
«Igor Sikorsky Kyiv Polytechnic Institute»
Peremohy ave., 37, Kyiv, Ukraine, 03056

This paper reports a study aiming at devising a common procedure for determining the geometric parameters of tools' cutting part in the technological systems that involve machining by cutting. Underlying the development of this procedure is the generalized theory of determining geometric parameters on tools' cutting blades.

The analysis of determining the geometry of tool cutting edges in different coordinate systems has shown that the procedure used by a given theory depends on the type and design of tool cutting edges. In the process of cutting, the geometric parameters of tools change along the cutting edges while existing ones do not fully take into account this phenomenon. This is because geometric parameters are determined in the kinematic system of coordinates.

Particularly important to meet these requirements is for the cutting process whose effectiveness depends significantly on the accuracy in selecting methods for determining tool operational parameters.

In this regard, the current work has devised and proposed a general procedure for determining the geometry of tool cutting edges, directly during its application in the kinematic system. The procedure is based on the consideration of the resulting speed, in the form of the vector amount of the main movement and the amount of movement of feeds, which can consider feeds specified by the system's equipment.

This approach to the development of a general procedure ensures that the geometry of the cutting part of a tool of any design is determined along its cutting edges during operation.

The devised procedure has significantly reduced the time of calculations and ensured the required geometric parameters of the cutting part of a groove cutter

Keywords: cutting tool, machining by cutting, procedure for determining tool geometry, geometric parameters, groove cutters

Received date 20.10.2020
Accepted date 21.01.2021
Published date 19.02.2021

1. Introduction

The method of machining by cutting represents at the present stage of equipment development a complex technological system. This method of making parts of different shapes from different materials has become widespread among other shape formation methods. It is characterized by high precision and flexibility in industrial processes and enables the rapid transition the machining blanks of different shapes and sizes at the same equipment [1–4].

Underlying the technological systems involving machining by cutting are equipment and cutting tools. In addition to the size and shape of the surfaces being machined, they determine their accuracy and quality, as well as a number of economic indicators of the cutting process under consideration.

Modern technological systems are characterized by a high degree of versatility, which is achieved using multi-coordinate metal cutting equipment, automated control systems, and tools that enable this versatility. This, in turn, leads to an increase in the support time of equipment installation and in the cost of tools, which is up to 10–15 % of the machining overall cost. At multi-spindle adjustments, as well as when using expensive tools – up to 50 % of the cost of machining [12, 13].

In a general case, the design of a tool is defined by its cutting part, which, first of all, depends on the material and its geometric parameters [5–7].

The choice of the brand of tool material is based on machining conditions, which are determined by the properties of the material being machined and the nature of the contact interaction between the tool and machined materials during cutting [8–10].

There are different requirements for the properties of tool materials. They include the high hardness of tool material, high strength, heat resistance, durability, manufacturability, and affordability. An important characteristic of tool material relative to the material being machined is its low physical and chemical activity [14, 15].

These requirements are met subject to the constant values of the cutting modes and the geometric parameters of tool cutting edges [16, 17]. Cutting modes are ensured by the brand of material, coating, and various technological methods that enhance their properties.

Each brand of tool material, as well as methods that improve their properties, are accompanied by the recommended scope of application. In addition, cutting modes and the geometric parameters of cutting edges are recommended for each brand of tool material [18–21].

In machine building, many types of tools are used to machine blanks of various shapes. Their classification according to different attributes is set by different standards [22–24] and is given in the catalogs of tool manufacturers, each of which is characterized by its specific geometry.

Since the equipment for modern technological systems involving machining by cutting is multifunctional, some of the tool structural functions are implemented through its kinematics. However, the existing procedure for determining geometric parameters does not take that into account, which not only introduces errors into the calculations of their values but also causes a decrease in the performance of the tool and a decrease in the efficiency of the cutting process. This hinders the development of new tool designs for multifunctional technological systems. Therefore, it has become necessary to consider features in the procedure of determining geometric parameters for the technological systems involving machining by cutting.

The relevance and practical significance of tackling this task are emphasized by the simplification of tool structure, the reduction of the cost of its design, manufacture, as well as the calculations of its geometric parameters.

2. Literature review and problem statement

The main provisions for determining geometric parameters are set out in the standards DSTU 2249-93, GOST 25762-83, ISO 3002/1-77.

Paper [25] proposes to calculate the geometric parameters of the tool based on the calculation of static ones. This approach in determining the tool geometry in modern technological systems involving machining by cutting leads not only to an increase in the volume of calculations but also to certain errors since deciding on the depth of cut is subjective.

At the same time, it should be noted that the standards imply the determination of geometry in three coordinate systems; tool, static, and kinematic. The geometry in each system is determined relative to the planes oriented relative to the main or resulting movements.

According to the standard, regardless of the coordinate system, there is a complete methodological identity in determining geometric parameters.

The authors of [26], based on the use of this identity, describe a theory of determining the geometric parameters of tool cutting edges in both static and kinematic coordinate systems. It is shown that the geometric parameters of the cutting part of the tool characterize the mutual arrangement of the front surface, the rear surface, and the cutting plane at the examined point of the cutting edge.

But the issues related to determining the total depth of cut in complex technological systems remain unresolved.

A solution to remove the difficulty may be to determine the resulting cutting rate taking into account all the kinematic movements of the system. This is the approach used in work [28]; however, determining in such a way is of a particular nature; it is given for specific tools and requires further research.

The authors of [27] report a procedure of determining the static front and rear angles of the shaped tool with complex kinematics. They demonstrated determining the vector of the resulting cutting speed and the calculation of the geometric parameters of the shaped tool during its application. But the issues related to the design of the shaped tool, taking into account the implementation of kinematic movements, remained unresolved. Solving these issues would make it much easier to design the cutting tool [26].

The proposed solutions are not general and imply determining the geometry for each type and design of the tool. The geometric parameters in the cited work were determined in the kinematic system using their values in the static coordinate system.

All this allows us to argue about the expediency of a study to devise a general procedure for determining the geometric parameters of the cutting part of tools based on the resulting cutting movement. Such a study, first of all, could form the prerequisites for designing new tool structures taking into account the modern equipment for the technological systems involving machining by cutting. The application of such a procedure, based on the current study would, in turn, help improve accuracy in determining the tool geometric parameters.

3. The aim and objectives of the study

The aim of this work is to improve accuracy in determining the geometry of tools and to simplify their designs based on the general procedure of determining the tool geometric parameters for the technological systems involving machining by cutting.

To accomplish the aim, the following tasks have been set:

– to investigate patterns in devising a general procedure for determining the geometric parameters of complex technological systems;

– to design a tool structure using an example of groove cutters that cut teeth for circular cut-off saws.

4. The study materials and methods

Underlying the development of a procedure are the basic provisions in the theory of determining the tool geometric parameters, outlined in work [26].

Vector algebra methods have been applied to study patterns in devising a general procedure for determining the geometric parameters of tools in the technological systems involving machining by cutting.

As already noted, the general procedure is based on a kinematic system of coordinates. Currently, the calculation of geometric parameters in this system is carried out in two stages – the static parameters are defined and, on their basis, kinematic. The sequence of their determining is shown in Fig. 1.

The initial data for calculating geometric parameters in the static and kinematic coordinate systems are:

– the shape of the front and rear surfaces;

– the speed of main movement *V* and the speed of feed movement *S*;

– the tool geometric parameters, the front angle γ_i, the rear angle α_i, the inclination angle of the cutting edge λ, the main angle in the plan φ;

– the shape of the cutting edge;

– the angles that determine the direction of the main movement and the feed movement.

These initial data are considered to be known or can be determined on the basis of the shape of the cutting edge or the profile of the surface being machined.

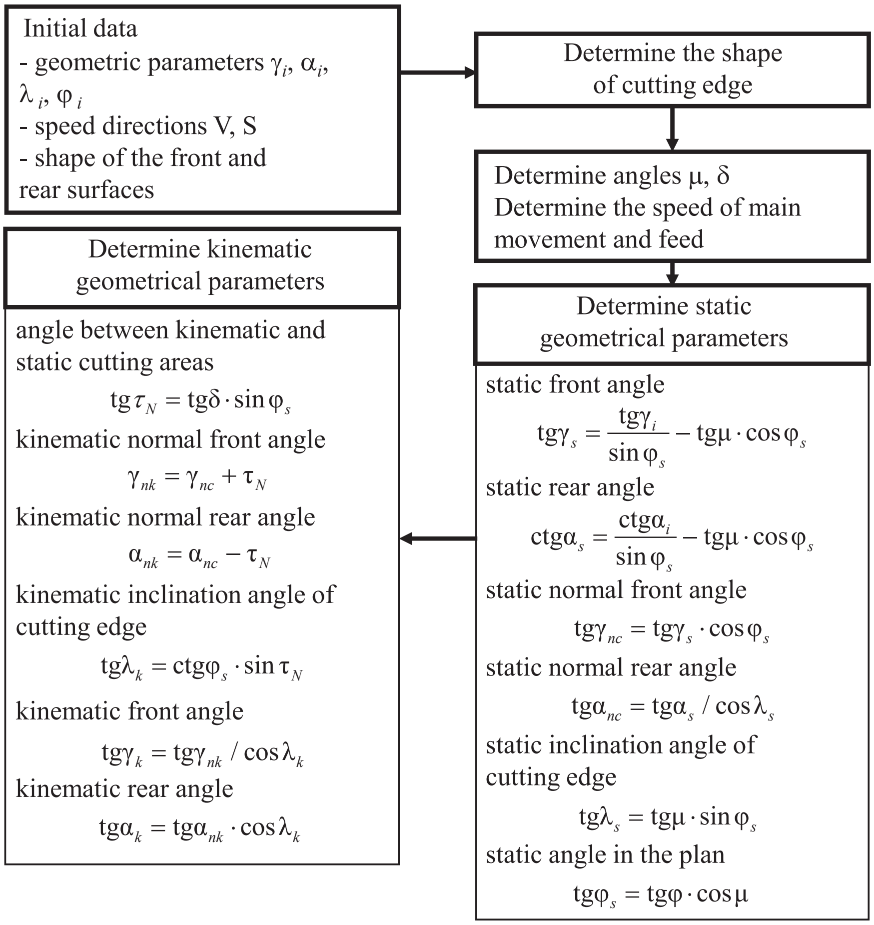

Fig. 1. Algorithm for determining the static and kinematic geometric parameters of the cutting tool

Since the kinematic coordinate system is based on the resulting movement and is more general in comparison with static, it makes it possible to take into account the versatility of modern technological systems. The standards DSTU 2249-93, GOST 25762-83, ISO 3002/1-77 set the geometric parameters for the cutting part as an integral element of the tool design, without which the cutting process is not feasible under the specified conditions.

These standards are fully compatible with each other and specify the country or region of their validity. The standards describe a procedure for determining the geometric parameters of tools produced by different manufacturers in accordance with the standards or technical specifications on their design.

The standards for determining kinematic geometric parameters are set relative to the planes defined by the direction of the resulting movement. According to the standard, regardless of the coordinate system, the planes P_γ and P_α are considered, respectively, tangential to the front and rear surfaces, as well as:

– P_s is the working plane, which hosts the speed of the main movement and the feed movement;

– P_{vk} is the main plane, drawn through the examined point of the cutting edge, perpendicular to the speed of the resulting movement;

– P_{nk} is the cutting plane, tangent to the cutting edge at the examined point and perpendicular to the main plane;

– $P_{\tau k}$ is the main secant plane, perpendicular to the line of intersection between the main plane and the cutting plane;

– P_H is the normal secant plane perpendicular to the cutting edge.

Similarly, the values of the tool's geometric parameters (static and kinematic) are oriented.

The existing theory to determine them provides for the relationship between the geometric parameters of the cutting part of the tool in the tool, static, and kinematic systems. This relationship is executed through the angle τ_n, located between the tool cutting plane and static plane, also between the static and kinematic, respectively.

Based on the standard for determining the angle τ_{nk} between the static and kinematic cutting planes, an angle between the tool and static planes is determined.

Thus, in order to determine the angle τ_{nk}, it is necessary to determine the cutting angle τ_{nc} between the tool and static planes.

The angle τ_n is equal to the angle between the normals and the planes under consideration; to determine the geometric parameters in the kinematic coordinate system, it is calculated from the following dependence:

$$\cos\tau_{nk} = \frac{\bar{N}_k\cdot\bar{N}_s}{\left|\bar{N}_k\right|\cdot\left|\bar{N}_s\right|}, \qquad (1)$$

where N_K is the normal to the kinematic cutting plane at the examined point; N_C is the normal to the static cutting plane.

According to the analysis given in works [25, 26], if the tool front γ_i and rear α_i angles, as well as the speed vector V of the main movement, are known, the static front and rear angles in the normal cutting edge of the cut are equal to:

$$\gamma_{nc} = \gamma_i + \tau_{nc}, \tag{2}$$

$$\alpha_{nc} = \alpha_i - \tau_{nc}. \tag{3}$$

The angle τ_{nc} is the angle between the tool and static cutting planes, which is equal to the angle between the normals N_{nc}, $\bar{N}_{ni}$, and is calculated from the following dependence:

$$\cos\tau_{ns} = \frac{\bar{N}_{ns} \cdot \bar{N}_{ni}}{\left|\bar{N}_{ns}\right| \cdot \left|\bar{N}_{ni}\right|}. \tag{4}$$

5. The study results

5. 1. Investigating patterns in devising a general procedure for determining the tool geometric parameters

To develop a more general theory of determining geometric parameters in different coordinate systems, we shall consider the procedure for determining them in a static system.

The position of the tool cutting plane is determined by the vector $\bar{P}$, which runs tangent to the cutting edge, and the vector $\bar{V}_n$, perpendicular to the tool main plane. Then the normal's vector to the tool cutting surface is determined:

$$\bar{N}_{ni} = \left[\bar{P} \times \bar{V}_n\right]. \tag{5}$$

Further calculations in determining geometric parameters are as follows: the original data that can be considered are the aggregates of the vectors $\bar{P}$, $\bar{V}$, $\bar{F}$, $\bar{R}$ and $\bar{S}$ in the selected system of coordinates. The vector $\bar{F}$ is tangential to the front surface at the examined point of the cutting edge, the vector $\bar{R}$ is tangential to the rear surface at the examined point of the cutting edge. With known initial data, a calculation order of the static geometric parameters of the cutting part of the tool, at the examined point of the cutting edge, is as follows:

– the static angle of the cutting edge:

$$\sin\lambda_s = \frac{\left(\bar{V} \cdot \bar{P}\right)}{\left|\bar{V}\right| \cdot \left|\bar{P}\right|}; \tag{6}$$

– the vector of the normal N_p to the static cutting surface:

$$\bar{N}_p = \left[\bar{V} \cdot \bar{P}\right]; \tag{7}$$

– the vector of the normal to the front surface:

$$\bar{N}_n = \left[\bar{V} \cdot \bar{F}\right]; \tag{8}$$

– the vector of the normal to the rear surface:

$$\bar{N}_r = \left[\bar{P} \cdot \bar{R}\right]; \tag{9}$$

– the static front angle in the cross-section normal to the cutting edge:

$$\sin\gamma_n = \frac{\left(\bar{N}_p \cdot \bar{N}_n\right)}{\left|\bar{N}_p\right| \cdot \left|\bar{N}_n\right|}; \tag{10}$$

– the static front angle γ in the main secant plane:

$$\operatorname{tg}\gamma_s = \frac{\operatorname{tg}\gamma_n}{\cos\lambda_s}; \tag{11}$$

– the static rear angle in the cross-section normal to the cutting edge:

$$\sin\alpha_n = \frac{\left(\bar{N}_p \cdot \bar{N}_r\right)}{\left|\bar{N}_p\right| \cdot \left|\bar{N}_r\right|}; \tag{12}$$

– the static rear angle in the main secant plane:

$$\cos\alpha_s = \alpha_n \cdot \cos\lambda_s; \tag{13}$$

– the vector of the normal N_s to the working plane, which hosts the direction of the speed of the main movement $\bar{V}$, and the feed movement $\bar{S}$:

$$N_s = \left[\bar{V} \cdot \bar{S}\right]; \tag{14}$$

– the static angle in the plan φ_s is an angle between the static cutting plane and the working plane P_s:

$$\cos\varphi_s = \frac{\left(\overline{N_p} \cdot \overline{N_r}\right)}{\left|\overline{N_p}\right| \cdot \left|\overline{N_r}\right|}. \tag{15}$$

When analyzing the static geometric parameters of the cutting part of the shaped tools, the order of calculation differs by replacing the normal to the front surface N_F with the normal to the original tool cutting surface N_Σ.

The original tool surface depends on the accepted shape-formation scheme and is determined at profiling.

As a rule, in the shaped tools, the normals are set at the examined point of cutting edge by two vectors $\bar{F}_1$ and $\bar{F}_2$. In this case, the cutting edge is defined as the line of intersection between the front plane and the original tool surface. Thus, the vector of the normal to the front surface is determined from the following formula:

$$N_F = \left[\bar{F}_1 \cdot \bar{F}_2\right], \tag{16}$$

and the vector $\bar{P}$ to the cutting edge is:

$$P = \left[\overline{N_p} \times \overline{N_\Sigma}\right]. \tag{17}$$

Given the versatility of the equipment of modern technological systems involving machining by cutting, there is a need to determine the geometric parameters of the tool directly in the kinematic system. In this case, the knowns are the geometric parameters γ_i, α_i, λ_i and φ_i in the tool system of coordinates, the shape of the front and rear surfaces, and the resulting speed of the tool relative to the blank, which is recorded as:

$$\bar{V}_e = \bar{V} + \bar{V}_{se}, \tag{18}$$

where the vector $\bar{V}$ is the speed of the main movement, $\bar{V}_{se}$ is the vector sum of feeds implemented in the technological system to machine a surface of a certain shape.

In this regard, there is a task to determine the geometric parameters of the front, rear, inclination angles of the cutting edge of the tool in the process of machining the surface, and an angle in the plan in the kinematic coordinate system.

In any coordinate system, the front angle is measured in the main secant plane P_τ between the front surface and the main plane P_v, and the rear angle – in the same plane between the rear surface and the cutting plane P_n.

A technique to determine the (γ, α, φ and λ) angles is set by the standard. So, by definition, the front angle is between the front surface and the main plane, which is perpendicular to the cutting plane. Then the angle between the normal to the front surface $\overline{N}_F$ and the normal to the cutting plane equals (90°–γ).

In accordance with this, the normal to the kinematic cutting plane is defined. Then the kinematic front angle in the cross-section normal to the cutting edge equals:

$$\operatorname{tg}\gamma_k=\frac{\overline{N}_{nk}\cdot\overline{N}_F}{\left|\overline{N}_{nk}\right|\cdot\left|\overline{N}_F\right|}. \tag{19}$$

The normal $\overline{N}_{nk}$ to the front surface is determined by the resulting speed and the tangent to the cutting edge $\overline{P}$:

$$\overline{N}_{nk}=\left[\overline{P}\times\overline{V}_e\right]. \tag{20}$$

The position of the vector $\overline{F}$ depends on the shape of the predefined front surface and is determined as:

$$\overline{N}_F=\left[\overline{P}\times\overline{F}\right]. \tag{21}$$

According to a similar procedure, α_k is determined:

$$\cos\alpha_k=\frac{\left(\overline{N}_{nk}\cdot\overline{N}_R\right)}{\left|\overline{N}_{nk}\right|\cdot\left|\overline{N}_R\right|}. \tag{22}$$

An angle in the plan φ is the angle in the main plane P_v between the cutting plane and the working plane P_s. A kinematic angle in the plan is generally determined from the following formula:

$$\cos\varphi_k=\frac{\left(\overline{N}_{nk}\cdot\overline{N}_R\right)}{\left|\overline{N}_{nk}\right|\cdot\left|\overline{N}_R\right|}. \tag{23}$$

Here, the position of the working plane in technological systems is determined by the vector of its normal:

$$\overline{N}s=\left[\overline{P}\cdot\overline{V_{se}}\right]. \tag{24}$$

Knowing the vector $\overline{P}$, tangential to the cutting edge at the examined point of the cutting edge, and the position of the working plane at this point, we can determine the kinematic angle in the plan at different points of the cutting edge.

The kinematic inclination angle of the cutting edge λ, according to DSTU 2249-93, is measured in the kinematic cutting plane between the cutting edge and the kinematic main plane:

$$\sin\lambda_k=\frac{\left(\overline{V}_e\cdot\overline{P}\right)}{\left|\overline{V}_e\right|\cdot\left|\overline{P}\right|}. \tag{25}$$

Our analysis of the proposed approach to determining geometric parameters reveals that we should consider, excluding the component V_{se}, in formula (18), only the main movement.

The algorithm for implementing the general procedure of determining the tool geometric parameters is shown in Fig. 2.

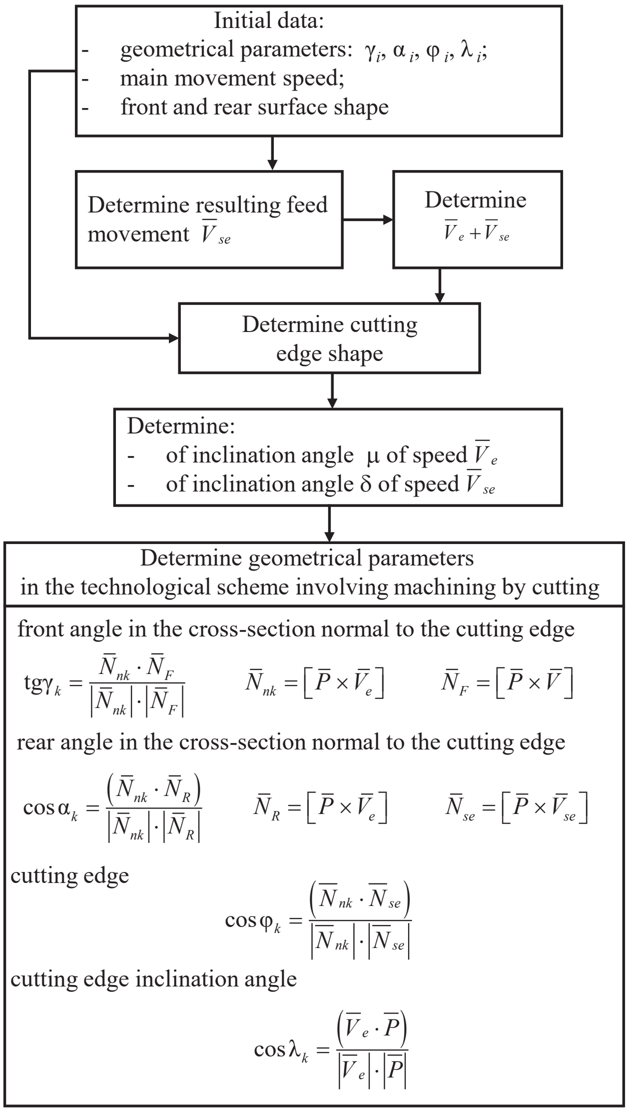

Fig. 2. Algorithm to analytically determine a tool's geometric parameters in the technological system of cutting

Thus, considering patterns in the procedure of determining geometric parameters in the technological systems involving machining by cutting, it is possible to determine parameters in different systems of coordinates.

5. 2. Designing a tool structure for machining cutoff cutters at a gear-hobbing machine

Cutoff cutters are typically machined by a special tool by cutting the grooves between their teeth.

As an example of the implementation of the general procedure for determining the tool geometric parameters, we shall consider the process of cutting at a gear-hobbing machine the teeth of the circular cut-off saw with a diameter of 315 mm and the number of teeth Z=200, by the disk groove cutter ∅140 mm, Z_m=5, and thickness B=15 mm (Fig. 3).

The main movement is the rotation of the cutter ω_m.

The resulting movement is determined by the sum of the vectors of the main movement and the movement of the feed. At rolling, the feed movement is a complex motion that involves directly the axial feed of the saw blank and the movement of the roll, that is the rotation of the blank V_{rot}.

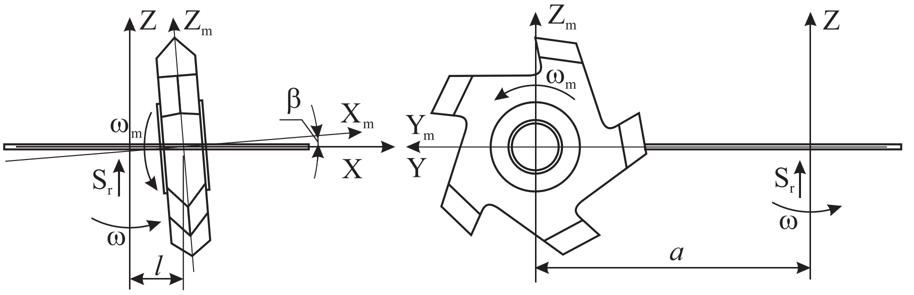

Fig. 3. Schematic of movements of a groove cutter and a cutter blank

The complex movement of the groove tool is determined, in a general form, by the following dependence:

$$\overline{V}_{se} = \overline{S} + \overline{V}_{rot}. \tag{26}$$

Since the cutter single rotation cuts the number of teeth equal to the number of teeth of the cutter, the rotation of the saw (ω) and cutter (ω_m) are kinematically linked in and determine the number of teeth of the saw (Z) and groove cutter (Z_m), the angular velocity of the saw's rotation is:

$$\omega = \frac{\omega_m \cdot Z_m}{Z}. \tag{27}$$

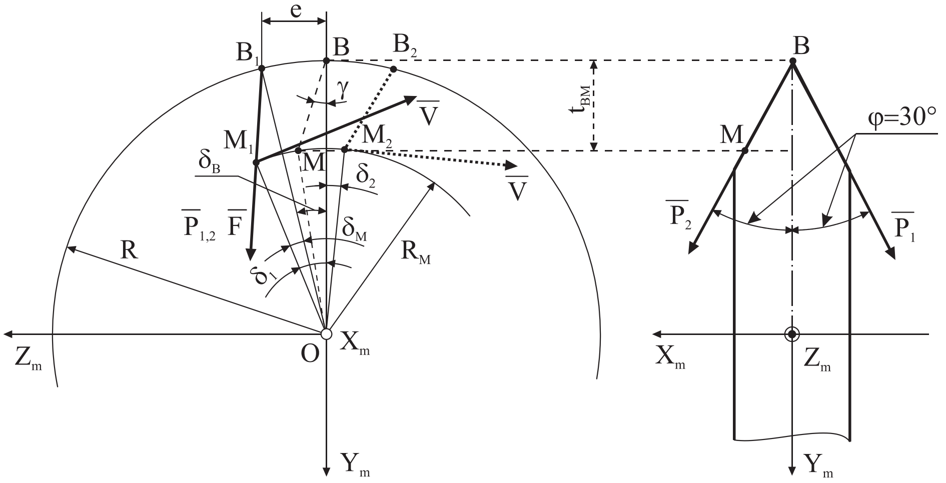

Fig. 4. Scheme to determine the vector of the speed of the main movement and the radius of any point of the cutter's cutting edge

In order to analyze the geometric parameters of the cutting part of the groove cutter, we determine the direction of the vector of the speed of the resulting movement according to the procedure outlined in work [26].

To this end, we determine the vector of the speed of the main movement in the system of coordinates associated with the disk groove cutter $X_mY_mZ_m$ whose axis coincides with the axis of the spindle of the machine and in the system $OXYZ$, associated with the blank of the saw whose axis coincides with its axis.

The main cutting movement is:

$$\overline{V} = \left[\omega_m \cdot R_M\right], \tag{28}$$

where R_M is the radius vector of any examined point M of the cutting edge in the $X_mY_mZ_m$ system.

The coordinates of the points in the system associated with the groove cutter are determined [27, 28].

A scheme to determine the vector of the speed of the main movement and the radius of any point of the cutting edge is shown in Fig. 4.

After determining the radius-vector of any cutting edge point in the $X_mY_mZ_m$ system, we determine in the same system the radius vector of the examined point of the circular cut-off saw tooth profile, the vector of the feed speed V_s defined by the vector sum of the rolling motion and the feed movement.

As a result, the vector of the resulting movement V_e is determined as follows:

$$\overline{V_e} = \overline{V} + \overline{V}_s. \tag{29}$$

The proposed procedure makes it possible to machine cutoff cutters at a gear-hobbing machine, which ensures, based on the data from tests, a two-fold increase in performance, as well as significantly simplifies the design of the tool.

6. Discussion of results of studying the development of a general procedure for determining the geometry of the cutting part of tools

The general procedure and the algorithm for determining geometric parameters (Fig. 2), devised on the basis of this study, make it possible, regardless of the complexity of the shape of the machined article, its size, and the number of permitted movements in the technological system, to calculate the kinematic parameters excluding the stage of determining static parameters. This reduces the time for calculations by at least half.

However, if one needs to reduce the number of movements considered, one can change the depth of cut.

Reducing the number of movements taken into account and simplifying the design of the tool reduces the auxiliary time to adjust equipment and the cost of the tool up to 25 % of the existing standards.

The general procedure is the basis for simplifying the designs and developing more advanced technological systems.

Thus, our studies considered an example machining cutoff cutters at a gear-hobbing machine, which showed that it is possible, based on the general procedure for determining geometric parameters, to machine complex surfaces using modern multifunctional cutting systems in order to improve the performance of the machining process. This greatly simplifies the design of the tool and reduces the cost of manufacturing.

The tests have shown a 2-fold increase in performance when machining cutoff cutters at a gear-hobbing machine, even though the devised procedure is general. Our study has not considered the possibility of determining the geometric parameters of the tool in high-speed machining using this procedure.

7. Conclusions

1. Our study into the development of a general procedure for determining geometric parameters in the technological systems involving machining by cutting has shown that the proposed procedure could significantly improve the accuracy of determining them, simplify the design of the tool, and improve machining efficiency through the use of modern multifunctional systems.

2. An example of the development of cutoff cutters has been given to show that the proposed procedure makes it possible to employ, in order to machine articles, modern technological systems, as well as simplify the design of the tool using it. Our test results of machining cutoff cutters at a gear-hobbing machine demonstrated a two-fold increase in the machining efficiency.

References

1. Borovskiy, G. V., Grigor'ev, S. N., Maslov, A. R. et. al. (2005). Spravochnik instrumental'shchika. Moscow, 464.
2. Vasin, S. A., Vereshchaka, A. S., Kushner, V. S. (2001). Rezanie materialov. Termomehanicheskiy podhod k sisteme vzaimosvyazey pri rezanii. Moscow, 448.
3. Grabchenko, A. I., Zaloga, V. A., Vnukov, Yu. N. et. al.; Grabchenko, A. I., Zaloga, V. A. (Eds.) (2017). Integrirovannye protsessy obrabotki materialov rezaniem. Sumy, 451.
4. Grechishnikov, V. A. (1984). Sistemy avtomatizirovannogo proektirovaniya rezhushchih instrumentov. Moscow, 52.
5. Mazur, M. P., Vnukov, Yu. M., Zaloha, V. O.; Mazur, M. P. (Ed.) (2010). Osnovy teorii rizannia materialiv. Lviv, 422.
6. Tate, C. (2017). The fundamentals of industrial sawing. Cutting Tool Engineering. Available at: https://www.ctemag.com/news/articles/fundamentals-industrial-sawing
7. Altintas, Y. (2012). Manufacturing automation: metal cutting mechanics, machine tool vibrations, and CNC design. Cambridge University Press. doi: https://doi.org/10.1017/cbo9780511843723
8. Muzykant, Ya. A., Arpaz, Ya., Volosova, M. A. et. al. (2009). Entsiklopedicheskiy spravochnik-katalog. Moscow, 464.
9. Saharov, G. N., Arbuzov, O. B., Borovoy, Yu. L. et. al. (1989). Metallorezhushchie instrumenty. Moscow, 328.
10. Ordinartsev, I. A., Filippov, G. V., Shevchenko, A. N. et. al. (1987). Spravochnik instrumental'shchika. Leningrad, 846.
11. Klimenko, S. A., Manohin, A. S., Kopeykina, M. Yu. et. al. (2018). Vysokoproizvoditel'naya chistovaya lezviynaya obrabotka detaley iz staley vysokoy tverdosti. Kyiv, 304.
12. Tungsten carbide tipped circular saw blades for steel cutting. BLECHER GmbH & Co. Available at: https://www.blecher.com/en/products/tungsten-carbide-tipped-circular-saw-blades-for-steel-cutting/
13. Stephenson, D. A., Agapiou, J. S. (2016). Metal Cutting Theory and Practice. CRC Press, 969. doi: https://doi.org/10.1201/b19559
14. Tchernogorova, O. P., Bannykh, O. A., Blinov, V. M., Drozdova, E. I., Dityat'ev, A. A., Mel'nik, N. N. (2001). Superhard carbon particles forming from fullerites in a mixture with iron powder. Materials Science and Engineering: A, 299 (1-2), 136–140. doi: https://doi.org/10.1016/s0921-5093(00)01400-3
15. Ranganath, B. J. (2008). Thermal Metal Cutting Processes. I.K. International Publishing House Pvt. Limited, 164.
16. Stark. HSS Circular Saws (2017). GMV-Grafiche Marini Villorba, 27.
17. Vertriebsgesellschaft. Stark GmbH & Co. Available at: http://www.starktools.com/sites/503250bb96803b6018000004/theme/pdfs/pdfs/Catalogo_Metal_Cutting_2018_LOW.pdf
18. Volosatov, V. A. (1988). Spravochnik po elektrohimicheskim i elektrofizicheskim metodam obrabotki. Leningrad, 719.
19. Preimushchestva i nedostatki plazmennoy rezki (2012). Available at: http://metalurg.su/preimushhestva-i-nedostatki-plazmennoj-rezki.html
20. Droba, A., Svoreň, J., Marienčík, J. (2015). The Shapes of Teeth of Circular Saw Blade and Their Influence on its Critical Rotational Speed. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 63 (2), 399–403. doi: https://doi.org/10.11118/actaun201563020399
21. Williston, E. M. (1989). Saws: design, selection, operation, maintenance. San Francisco, CA: Miller Freeman Publications, Inc. 450.
22. Rodin, P. R. (1990). Osnovy proektirovaniya rezhushchih instrumentov. Kyiv, 423.
23. Tandon, P. (2011). Cutting Tool Geometry: 3D Perspective. LAP Lambert Academic Publishing, 240.
24. Chang, W.-T., Chen, L.-C. (2015). Design and experimental evaluation of a circular saw blade with self-clamped cutting inserts. The International Journal of Advanced Manufacturing Technology, 83 (1-4), 365–379. doi: https://doi.org/10.1007/s00170-015-7563-7
25. Ravska, N. S. (2009). Osnovy kinematychnoi teoriyi vyznachennia heometrychnykh parametriv rizalnoi chastyny instrumentu. Nadiynist instrumentu ta optymizatsiya tekhnolohichnykh system, 24, 9–18.
26. Ravska, N. S., Kovalova, L. I., Okhrimenko, O. A., Vovk, V. V. (2008). Zvit pro naukovo-doslidnu robotu «Uzahalnena teoriya vyznachennia heometrychnykh parametriv rizalnoho instrumentu» vykonanyi po temi No. 2914f. Kyiv, 208.
27. Ravska, N. S., Okhrimenko, O. A. (2009). Determination of the cutting speed using different kinematic cutmaps. The processes of mechanical processing in machine building, 8, 158–163.
28. Ravska, N., Parnenko, V. (2016). The definition of the static front angles and static rear angles for shaped milling cutter in the vertex point of the cutting edge. Perspektyvni tekhnolohiyi ta prylady, 8, 89–93.