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ПОШУК РАЦІОНАЛЬНОГО ПРОФІЛЮ РІЗАЛЬНОГО КРАЮ НОЖА ПОДРІБНЮВАЧА ПЛАСТИЧНО В'ЯЗКИХ МАТЕРІАЛІВ

Стаття присвячена дослідженню процесу різання пластично в'язких матеріалів та пошуку профілю різального краю ножа, який задовольнятиме поставленим вимогам різання і забезпечить ефективність та зменшення витрат енергії під час процесу різання. Розраховано залежність між робочим і конструктивним кутами загострення ножа при ковзанні. Визначено раціональний профіль різального краю ножа, який дозволяє зменшити кінематичний кут загострення відносно конструктивного, що забезпечує зменшення опору матеріалу та скорочення витрат енергії.

Ключові слова: *процес різання, різальне обладнання, ножі подрібнювачі, швидкість різання, кут загострення, пластично в'язкі матеріали, профіль різального краю ножа.*

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SEARCH OF THE RATIONAL PROFILE OF THE CUTTING EDGE OF THE KNIFE OF THE CUTTER OF PLASTIC VISCOUS MATERIALS

The article is dedicated to the study of the plastically sticky stuff cutting process and search of the profile for a cutting edge to comply with all the technical demands and supply efficacy and reduction of energy while cutting process. The dependence on a working and a constructive angle of the knife sharpening while sliding is calculated. There was calculated the appropriate profile of the cutting edge of the knife that supplies the reduce of the working angle of sharpening to constructive one. This provides the reducing strength of materials and energy consumption.

Key words: *cutting process, cutting machine, choppers, cutting speed, sharpening angle, plastically sticky stuff, profile of the cutting edge of the knife.*

Formulation of the problem. Cutting is one of the basic technological processes in food production. Look, quality and yield of the finished product depends specifically on this process. A variety of products are cut, both homogeneous and those with a complex multi-layered structure; viscous, plastic, hard and brittle materials; semi-finished products and finished products. The cutting process for each case has many differences. The main working body of cutting machines are knives [1]. They can be various: rotary, cylindrical, conical; round and disk, which are used mainly for cutting plastic and soft materials; flat, tape, which are working as a rule, according to the principle of pressure cutting or scissors; ribbon knives for cutting bread and other flour products while hot; sickle-shaped knives, which are used primarily for transverse cutting of bundle-like materials and for chopping fish, meat, vegetables during processing, as well as cutting wire (string), which in terms of cutting quality corresponds to knives with a blunt blade. In cutting equipment, plate and band knives with a serrated, wave-shaped cutting edge are most often used as working organs [2]. An important indicator of the process of grinding food raw materials is energy consumption during cutting [3]. Efficiency and energy consumption during the cutting process are directly affected by such a parameter of the chopper knife as the sharpening angle, which depends on the geometry of the blade, and therefore it is advisable to conduct research on finding the profile of the cutting edge of the knife, which will satisfy the cutting requirements, in particular, plastically viscous materials.

Analysis of recent research and publications. The analysis of domestic and foreign literature publications showed that there is enough material and research on finding the profile of the cutting edge of a knife and cutting modes of food products (confectionery, meat, vegetables, fish) [6] and dough, bakery products [7] at the appropriate equipment. Works [5], [8] research the movement regimes of the knife blade on a multilayer material. During the research of the cutting process it was established that the reduction of cutting forces is affected by the reduction of friction due to the high speed of sliding and up to 60% of the total energy is spent. In work [4] the impact of the power of the cutting process on the angle of inclination of the saws and the sharpening angles of the knife blade was studied. It was established that when tilting sawmills from 15^0 to 20^0 is optimal. In work [8], the process of hydrojet water-polymer processing of food products by cutting was investigated. The presented results made it possible to create equipment for universal water-polymer cutting in 3D mode. Having conducted an analysis of literary sources on the research of cutting modes of food products, we can conclude that along with traditional cutting methods, such methods as vibration cutting and water-polymer jet cutting are gaining popularity.

The goal of the work. The most important working body of cutting machines are chopper knives. They are used for grinding plastically viscous materials, dividing them into pieces, cubes, etc., or giving them a specific shape. The main parameter of the chopper knife that affects energy consumption is the sharpening angle, which is characterized by the geometry of the blade. The presented research is devoted to the search for the rational profile of the cutting edge of the knife of the shredder of plastically viscous materials.

The main research material. When grinding plastically viscous materials that contain connective tissue, up to 90-95% of the total cutting costs are accompanied by compression, shear, extrusion, mixing, friction, heating and other phenomena which are not directly related to the cutting process. The angle of sharpening the knife directly affects energy consumption. When cutting fibrous and plastic materials, it is better to choose the minimum sharpening angle, which ensures a decrease in material resistance and a decrease in energy consumption.

With a certain constructive angle of sharpening, the direct effect on the material is the kinematic angle of sharpening, which changes depending on the profile of the cutting edge and its position relative to the material. At the same time, sliding or pulling cutting occurs at a speed v_k, directed along this edge, at a feed speed v_n, which is directed perpendicular to the cutting edge (Figure 1).

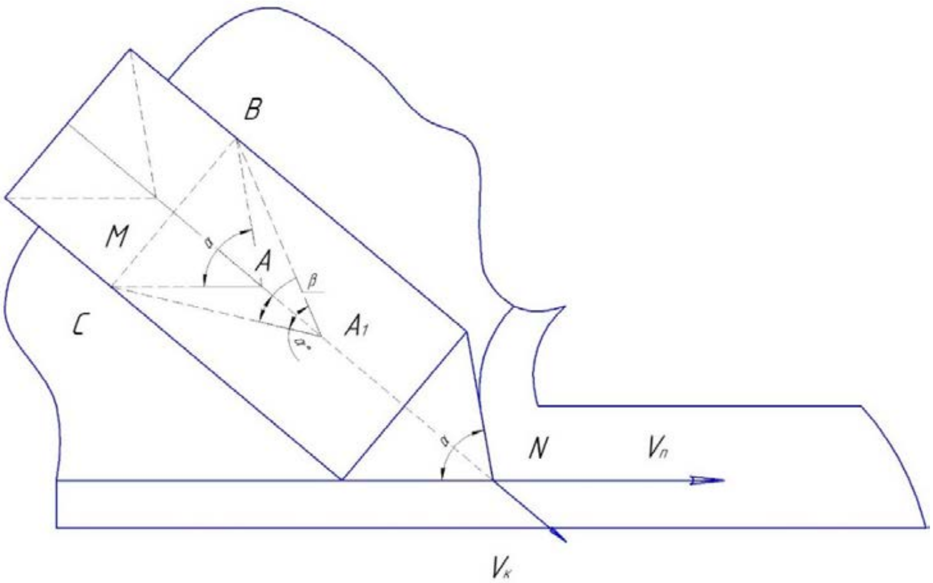

Figure 1. **Scheme of sliding cutting**

Let us consider the speed of the cutting parts of the material along both sides of the knife to be the same. Then, in the absence of sliding of the knife ($v_k = 0$), the path of the material along both faces of the knife consists of segments $AB = AC$. If the knife has a relative sliding speed v_k, then when moving along the cutting edge for a distance AA_1 the path of the cut parts of the material can be shown by the segment $A_1B = A_1C$, that is, cutting can be done not in the ABC plane, but in the A_1BC plane. If for a stationary knife the working sharpening angle α is equal to the constructive angle between the wedge faces, then when the knife slides, the sharpening angle will be equal to $\alpha_0 = BA_1C$.

The relationship between the working and constructive sharpening angles is expressed by the dependence:

$$sin\frac{\alpha_0}{2} = \frac{CB}{2A_1C} = \frac{2ACsin\frac{\alpha}{2}}{2\frac{AC}{sin\beta}} = sin\frac{\alpha}{2}sin\beta, \qquad (1)$$

where $\beta = arctg\frac{v_n}{v_k}$.

The best profile of the cutting edge of a rotating knife is considered to be a curve, the tangent to which coincides at each point with the tangent to the circle and passes through the point we will consider.

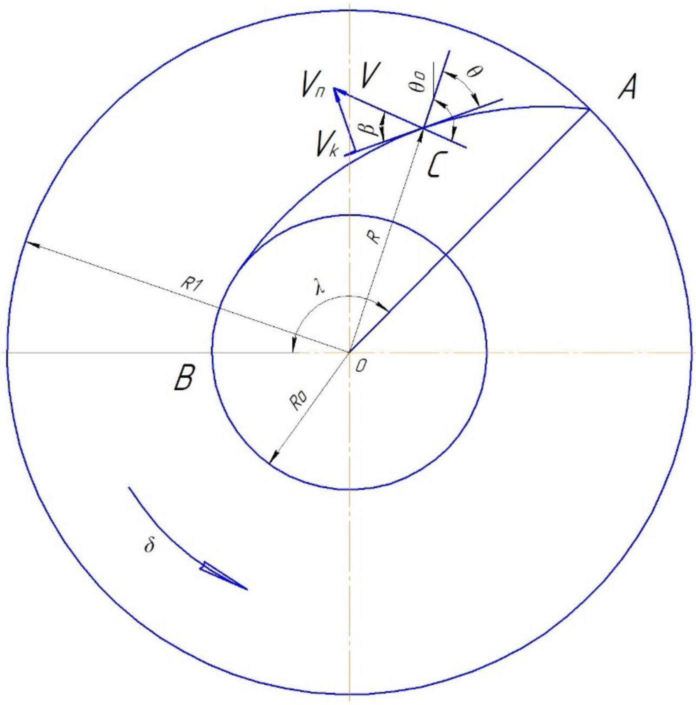

Figure 2. **Knife cutting edge profile**

Let us take an arbitrary profile of the cutting edge of the knife (Figure 2), rotating relative to the center O, and a polar coordinate system with the pole at the center O.

We select an arbitrary point C on the curve and enter the following notations: v is the linear speed vector of the knife at point C; v_k is the component of velocity v directed tangentially to the curve AB; v_n is the component of velocity v directed along the normal to the curve AB at point C; β is the angle formed between the velocity vector v and its component v_k; r is the radius of OC; θ is the angle formed by the direction of the vector OC and the positive direction to the curve AB at point C; θ_o is the angle formed by the direction of the vector OC and the positive direction of the tangent at point C to the circle with radius OC.

There should be drawn a line between the specified points A and B so that the sliding speed is maximum and constant. The practice of solving similar problems shows that the given problem can have a number of solutions and the optimal one can be determined using the theory of variational calculus.

To build the desired profile of the cutting edge of the knife, from all the curves that pass through the given points, we choose the curve $r = r(\lambda)$ where the functional is minimal:

$$F = \int_{\lambda_1}^{\lambda_2} (\theta_O - \theta) d\lambda, \tag{2}$$

where $\theta_O - \theta = \beta$.

The value θ is determined from the following equation

$$\theta = arctg(\frac{1}{r}\frac{dr}{d\lambda}), \tag{3}$$

where r – is the radius from the axis of rotation to the point of the blade under consideration.

Let's enter the notation

$$x = (\frac{1}{r}\frac{dr}{d\lambda}) \tag{4}$$

Let's expand the $arctgx$ function into a power series, for $x < 1$ we get:

$$arctgx = \frac{\pi}{2} - (x - \frac{x^3}{3} + \frac{x^5}{5} - \frac{x^7}{7} \dots) \tag{5}$$

Consider only such curves $r = r(\lambda)$, for which $x^2 \leq 1$. Then we leave the first two terms of the expansion in equation (5) and, taking into account equations (3) and (4), we obtain:

$$\theta = \frac{\pi}{2} - \frac{1}{r}\frac{dr}{d\lambda} \quad (6)$$

Substituting equation (6) into expression (2), taking into account that $\theta = \frac{\pi}{2}$:

$$F = \int_{\lambda_1}^{\lambda_2} (\frac{1}{r}\frac{dr}{d\lambda})^2 d\lambda \quad (7)$$

The Euler equation for the functional (7) will have the form:

$$\frac{d^2r}{d\lambda^2} - \frac{1}{r}\left(\frac{dr}{d\lambda}\right)^2 = 0 \quad (8)$$

The solution of equation (8) is the function:

$$r = C_1 e^{C_2 \lambda}, \quad (9)$$

where C_1 and C_2 are constant values that characterize the mechanical properties, blade geometry, cutting speed, etc.;

λ is the turning angle of the knife;

e is the base of the natural logarithm.

The calculations show that the profile of the cutting edge of the knife, which meets the requirements, is described by a segment of a logarithmic spiral.

Constant values C_1 and C_2 are found based on the design dimensions of the knife blade.

During the study, calculations of the kinematic cutting angle α_0 were carried out with a constructive sharpening angle from 10^0 to 90^0 (through 5^0) and a knife rotation angle from 135^0 to 240^0 (through 15^0). The results of the calculations are shown in Table 1. The calculations took into account that $r = 50$ mm, $\lambda_0 = 0$, $r_1 = 100$ mm, $\lambda = 135^0 ... 240^0$.

Table 1

Meanings of kinematic cutting angle α_0 were carried out with a constructive sharpening and a knife rotation

	α	λ							
		135^0	150^0	165^0	180^0	195^0	210^0	225^0	240^0
α_0, degrees	10^0	$2^0 48'$	$2^0 34'$	$2^0 20'$	$2^0 08'$	$1^0 59'$	$1^0 51'$	$1^0 44'$	$1^0 37'$
	15^0	$4^0 13'$	$3^0 51'$	$3^0 30'$	$3^0 13'$	$2^0 58'$	$2^0 48'$	$2^0 36'$	$2^0 26'$
	20^0	$5^0 37'$	$5^0 12'$	$4^0 40'$	$4^0 17'$	$3^0 58'$	$3^0 41'$	$3^0 27'$	$1^0 15'$
	25^0	7^0	$6^0 23'$	$5^0 49'$	$5^0 20'$	$4^0 57'$	$4^0 16'$	$4^0 18'$	$4^0 03'$
	30^0	$8^0 27'$	$7^0 38'$	$6^0 57'$	$6^0 23'$	$5^0 55'$	$5^0 30'$	$5^0 09'$	$4^0 50'$
	35^0	$9^0 43'$	$8^0 51'$	$8^0 04'$	$7^0 24'$	$6^0 51'$	$6^0 23'$	$5^0 59'$	$5^0 17'$
	40^0	$11^0 05'$	$10^0 06'$	$9^0 12'$	$8^0 27'$	$7^0 49'$	$7^0 17'$	$6^0 49'$	$6^0 24'$
	45^0	$12^0 25'$	$11^0 18'$	$10^0 17'$	$9^0 27'$	$8^0 45'$	$8^0 09'$	$7^0 18'$	$7^0 10'$
	50^0	$13^0 43'$	$12^0 29'$	$11^0 22'$	$10^0 27'$	$9^0 40'$	9^0	$8^0 26'$	$7^0 55^0$
	55^0	$14^0 59'$	$13^0 39'$	$12^0 26'$	$11^0 25'$	$10^0 14'$	$9^0 50'$	$9^0 12'$	$8^0 19^0$
	60^0	$16^0 15'$	$14^0 47'$	$13^0 28'$	$12^0 22'$	$11^0 27'$	$10^0 40'$	$9^0 58'$	$9^0 22^0$
	65^0	$17^0 28'$	$15^0 54'$	$14^0 39'$	$13^0 17'$	$12^0 18'$	$11^0 27'$	$10^0 43'$	$10^0 04^0$
	70^0	$18^0 39'$	$16^0 59'$	$15^0 27'$	$14^0 11'$	$13^0 08'$	$12^0 14'$	$11^0 27'$	$10^0 45^0$
	75^0	$19^0 49'$	$18^0 02'$	$16^0 25'$	$15^0 04'$	$13^0 57'$	12 59'	$12^0 15'$	$11^0 24^0$
	80^0	$20^0 56'$	$19^0 03'$	$17^0 20'$	$15^0 55'$	$14^0 44'$	$13^0 43'$	$12^0 50'$	$12^0 03^0$
	85^0	$22^0 01'$	$20^0 02'$	$18^0 14'$	$16^0 44'$	$15^0 29'$	$14^0 25'$	$13^0 29'$	$12^0 40^0$
	90^0	$23^0 03'$	$20^0 58'$	$19^{05}0'$	$17^0 31'$	$16^0 13'$	$15^0 06'$	$14^0 08'$	$13^0 16^0$

To study the results, graphs of the dependence of the angle of sharpening when sliding on the angle of rotation of the knife were plotted at different values of the working angle of sharpening with a stationary knife (Figure 3-9).

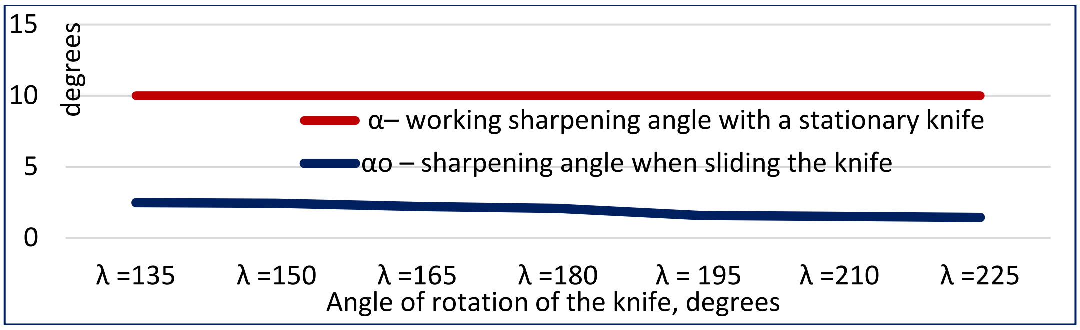

Figure 3. **The results of determining α_0 at the constructive sharpening angle 10^0**

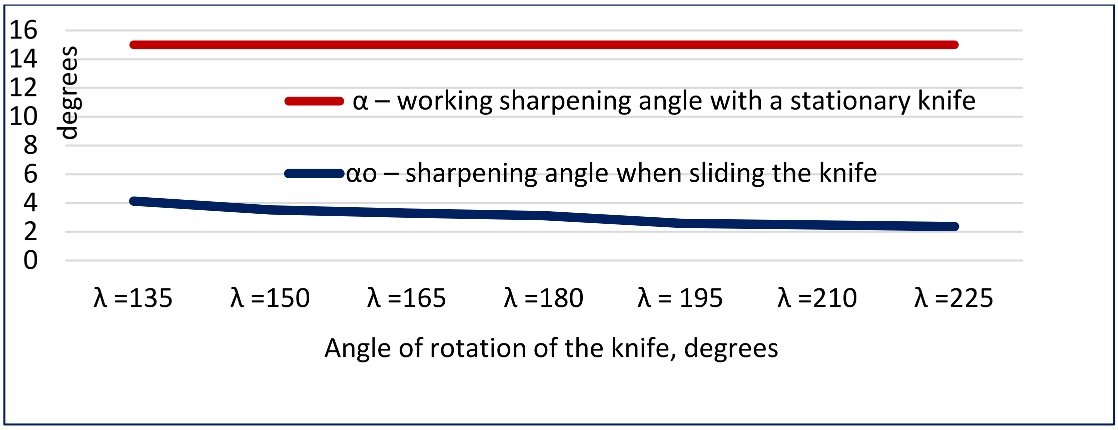

Figure 4. **The results of determining α_0 at the constructive sharpening angle 15^0**

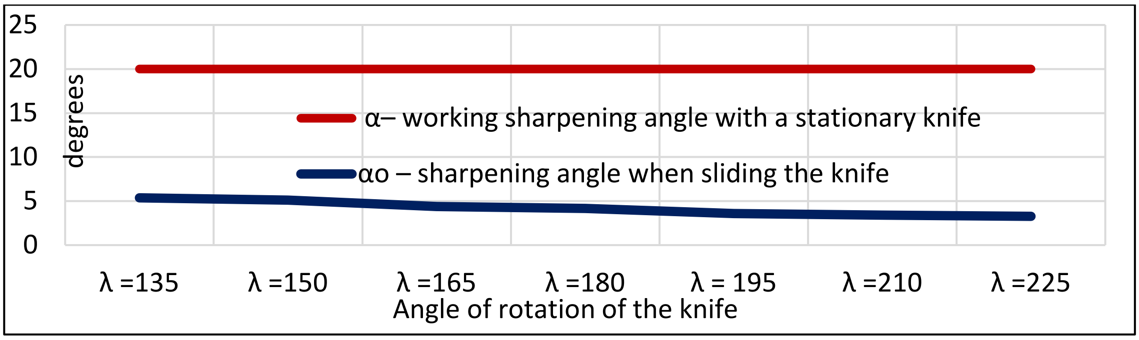

Figure 5. **The results of determining α_0 at the constructive sharpening angle 20^0**

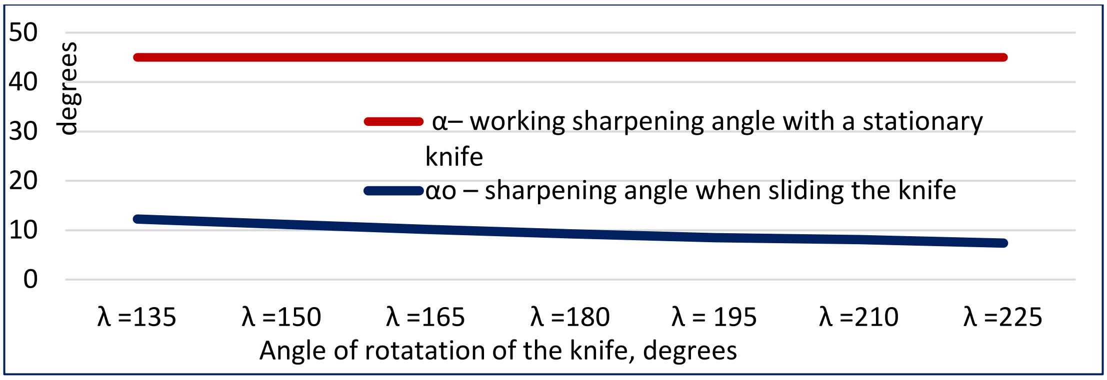

Figure 6. **The results of determining α_0 at the constructive sharpening angle 45^0**

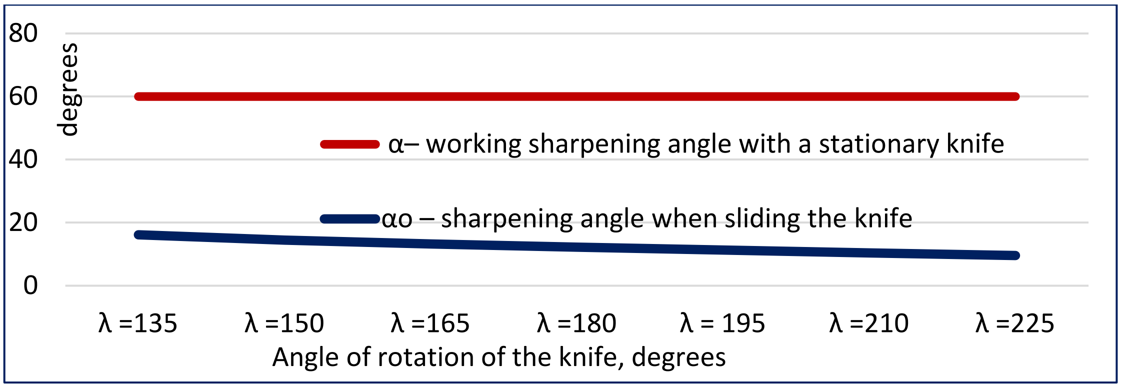

Figure 7. **The results of determining α_0 at the constructive sharpening angle 60^0**

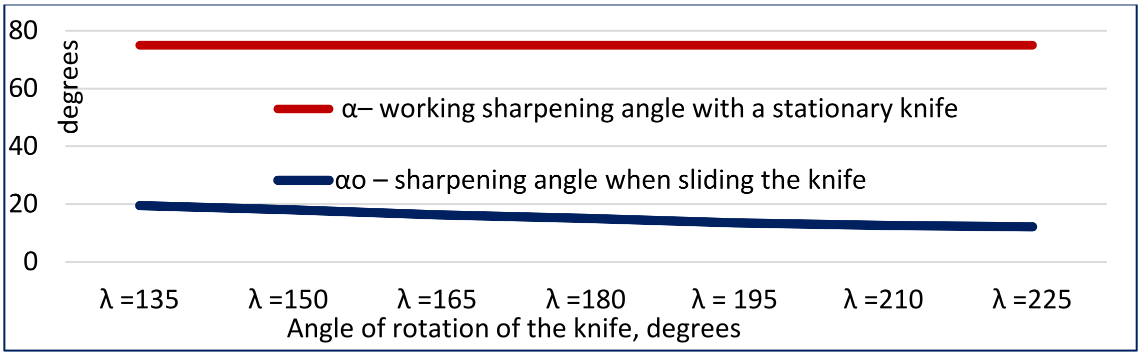

Figure 8. **The results of determining α_0 at the constructive sharpening angle 75^0**

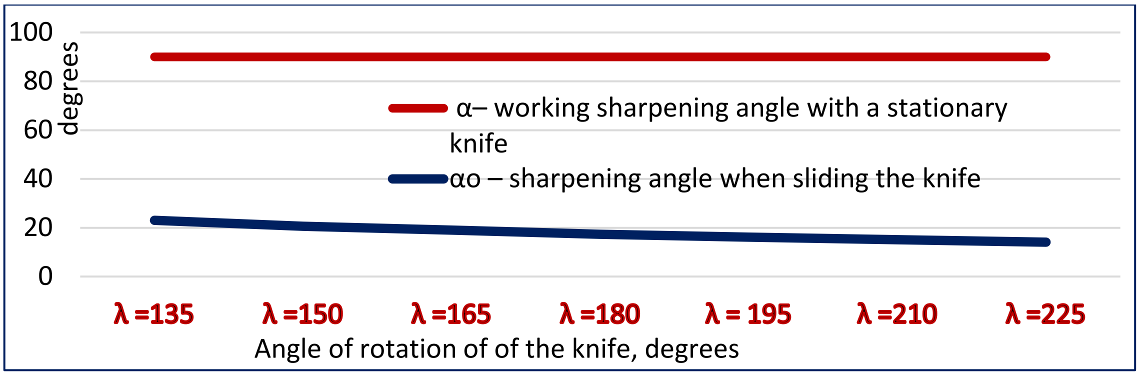

Figure 9. **The results of determining α_0 at the constructive sharpening angle 90^0**

Conclusion. The analysis of the results of research and calculations convincingly shows that when the profile of the cutting edge of the knife is described by a segment of a logarithmic spiral, the kinematic sharpening angle relative to the structural one decreases by 2-4 times, that ensures a decrease in material resistance and a decrease in energy consumption. Therefore, it is advisable to implement the profile of the cutting edge of the knife along a logarithmic spiral.

References

1. Research of Power Parameters of the Technological Process of Cutting Bakery Products / O.T. Velyka, S.E. Liaskovska, M. Petryk / Automation of Production Processes in Mechanical Engineering and Instrument Engineering. Vol. 55 (2021), Pp. 34-42. https://science.lpnu.ua/sites/default/files/journal-paper/2021/nov/25560/211352maket-34-42.pdf

2. Rational Modes of Cutting Food Products / V.S. Guts, O.O. Gubenia // Resource- and Energy-saving Technologies of Production and Packaging of Food Products are the Main Principles of its

Competitiveness: Materials of the II International Specialized Scientific and Practical Conference, September 11, 2013 – K. 2013, Pp. 36-38. http://dspace.nuft.edu.ua/jspui/handle/123456789/21243

3. Reduction of Energy Consumption When Cutting Visco-elastic Materials / A.V. Shaina, O.E. Melnyk // Improvement of Processes and Devices of Food Production. Vol. 35 (2017), Pp. 42-48. http://nbuv.gov.ua/UJRN/Otkhv_2017_35_8

4. Zaverbnyi A.R., Kodra U.V. Determination of Design Parameters of Machines for Cutting Bakery Products. // Bulletin of the Lviv Polytechnic National University. Optimization of Production Processes and Technical Control in Mechanical Engineering and Instrument Engineering. - 2018. - № 891. - Pp. 3-7. http://nbuv.gov.ua/UJRN/VNULPO_2018_891_3

5. Batrachenko Olexandr. Simulation of Influence of Constructive Parameters of Meat Bowl Cutterknives on Their Endurance at Alternative Oscillations // Lecture Notes on Data Engineering and Communications Technologies, 2023, 178, p. 363–385. https://doi.org/10.1007/978-3-031-35467-0_23

6. Viktor Goots, Oleksii Gubenia, Bogdan Lukianenko (2013), Modeling of cutting of multilayer materials, Journal of Food and Packaging Science, Technique and Technologies, No2, Pp. 294295.3. DOI: http://dspace.nuft.edu.ua/jspui/handle/123456789/21113

7. V. Guts, O. Gubenia, S. Stefanov, W. Hadjiiski (2010), Modelling of Food Product Cutting, 10th International Conference “Research and Development in Mechanical Industry - 2010”, Donji Milanovac, Serbia, 10-16 September 2010. Vol. 2. Pp. 1100-1105. http://dspace.nuft.edu.ua/jspui/handle/123456789/21118

8. Pogrebniak A.V. Study of the Process of Hydrojet Water-polymer Processing of Food Products by cutting // Scientific Bulletin of S.Z. Lviv National University of Veterinary Medicine and Biotechnology. Gzytsky Series: Food Technologies. 2017. Vol. 19. № 75. Pp. 134–139. http://nbuv.gov.ua/UJRN/nvlnuftech_2017_19_75_29