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International Competition of Student Scientific Works

BLACK SEA SCIENCE 2021

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1. FOOD SCIENCE AND TECHNOLOGIES

INCREASING THE STRENGTH OF THE BOWL CUTTERKNIVES

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Abstract. *A necessary condition for the successful development of the food industry is the improvement of technological equipment in order to increase the efficiency of raw material processing and reduce operating costs. Implementation of these requirements is particularly relevant in the meat processing industry. One of the main types of meat processing equipment are bowl cutters. Many researchers have worked on the research and improvement of these machines. However, despite the achieved scientific results, in modern models of bowl cutters the strength of knives is insufficient, which leads to a significant reduction in the economic benefit of the use of these machines. In our opinion, the problem of increasing the strength of knives should be considered comprehensively. That is: increasing the static strength of the knife, increasing its fatigue strength, as well as increasing its vibration strength. The paper presents the results of research performed both experimentally and by numerical simulation. The values of pressures acting on the knife`s edge during cutting were set. The vibration strength of knives was studied and it was concluded that it needs to be improved. The fatigue strength of the bowl cutterknives was investigated. Based on the obtained results, a new method of strengthening knives is proposed, which allows to increase fatigue strength by 2.5 times. New designs of knives with high static strength have also been developed.*

Keywords: *bowl cutter, knives, strength, fatigue durability, experiment, numerical simulation, improvement.*

I. INTRODUCTION

About 70% of the operations of the technological process of making sausages and semi-finished meat products are minced meat production. These operations largely determine the quality and yield of the final product. Bowl cutters were and remain one of the main types of mincing equipment for meat processing plants.

The design of modern models of bowl cutters allows to use a number of modes of processing of food raw materials. These are grinding of boneless pieces of meat (fresh or frozen) to the state of minced meat or concentrated pellets, grinding of minced meat to the state of emulsion, mixing of prescription ingredients with simultaneous grinding and without it, vacuuming of raw materials and its heat treatment carried out simultaneously with grinding,saturation of raw materials with inert gas, freezing it with liquid nitrogen.

On the research and improvement of these machines worked such scientists as A. I. Peleev, V. M. Gorbatov, Yu. G. Sukhenko, V. Yu. Sukhenko, M. M. Klymenko, S. G. Yurkov, G. V. Bakunts, V. D. Kosoy, A. L. Zheludkov and other researchers.

However, despite the achieved scientific results, in modern models of bowl cutters the strength of knives is insufficient, which leads to a significant reduction in the economic benefit of usage of these machines.

II. LITERATURE ANALYSIS

Structurally, the bowl cutter is a machine of periodic action, processing and transporting raw materials in which occurs in the bowl 1 of the torus-shaped form [1]. Raw materials are crushed by rotating knives 4. Knives come in different designs and geometric shapes [1-3]. Some of them are shown in Fig. 1.

a) b)

Fig. 1.Types of bowl cutterknives: a) –ordinary; b) –perforated.

A significant problem for meat productions is the destruction of knives during operation [4-6]. On average, one or more knives are destroyed at a frequency of up to 3 times a year with a two-shift operation of the bowl cutter 16 hours a day. At the same time the knife (or severalknives) together with the processed raw materials (about 200-300 l) is lost, and also the bowl and a cover of a knife head of a bowl cutter are damaged – there are potholes of considerable length up to 6 mm deep. It should be noted that the cost of a set of 6 knives is currently up to 2000 € (knives from German manufacturers made of special corrosion-resistant steels).

Due to the destruction of at least one knife, the balance of the cutting head is disturbed, which leads to rapid failure of the bearings of the knife shaft. Deformation of the cutting head cover and deformation of the support shaft of this cover can also be observed.

During grinding, the cutting forces, the pressure from the raw material supplied by the grinder bowl and the centrifugal forces act on the knife. They lead to a complex stress-strain state of the knives, which is accompanied by the appearance of specific zones of stress concentration (Fig. 2) – near the mounting part of the knife and on its rear edge.

Fig. 2. Layout of stress concentration zones of the cutting knife: 1 – area near the mounting part of the knife, 2 – area on the back edge of the knife.

Knives perform up to 100 rotations per second. When entering the raw material, they bend under the pressure of cutting forces, and after leaving the raw material – unbend. In this case, we observe the oscillating process, which occurs with a frequency of up to 100 Hz. In our opinion, this, along with insufficient fatigue endurance, is one of the factors increasing the amount of knife breakage during the operation of modern high-speed bowl cutters.

Fatigue failure of knives can be caused by a number of reasons: insufficient static strength, insufficiently high allowable fatigue stresses of metal, insufficient fatigue endurance of metal, increased roughness of external surfaces, the presence of tensile stresses in surface layers after grinding and sharpening, corrosion and wear.

The problem of insufficient strength continues to be relevant for meat cutting knives and needs to find effective ways to solve it.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The aim of the work is to increase the strength of bowl cutterknives by substantiating ways to improve their stress-strain state and fatigue endurance.

To achieve this goal, the following tasks were set:

- to analyze the causes and consequences of the destruction of the cutting knives during workloads;
- to develop methods for studying the processes that occur during the interaction of cutting knives with raw meat during its processing;
- to identify patterns of influence of the parameters of interaction of knives with raw meat on their stress-strain state and the limit of fatigue endurance;
- to suggest ways to increase the strength and fatigue endurance of bowl cutterknives.

Objects of research: stress-strain state and fatigue endurance of bowl cutterknives.

Subject of research: regularities of influence of constructive and kinematic characteristics of bowl cutterkniveson their stress-strain state and fatigue endurance.

The experimental study of the fatigue strength of the samples, which are made using the technology of making bowl cutterknives, was carried out as follows.

The study of fatigue strength was carried out using a vibrationtesting machine VEDS-200A in Institute of Strength Problems of NASU named after G.S. Pisarenko (Fig. 3).

The influence of such methods of surface hardening as application of protective wear-resistant coating by pulse-plasma method and high-frequency mechanical forging was investigated.

The application of a protective wear-resistant coating was carried out at the installation "IMPULSE" of the laboratory of the Institute of Electric Welding named after E.O. Paton of the National Academy of Sciences of Ukraine. The design and appearance of the installation "Pulse 3/4" is shown in Fig. 4.

a) b)

Fig. 3. Testing the sample for fatigue on the vibrationtesting machine VEDS-200A: a) – deformations of the sample during oscillations; b) – fatigue cracks on the sample.

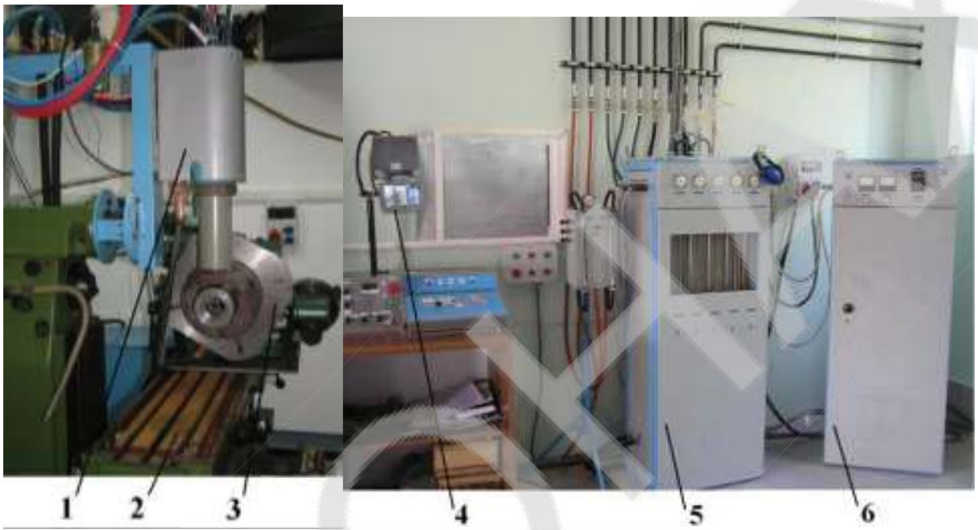


Fig. 4. Installation "IMPULSE 3/4" for pulse-plasma processing:

1 – detonation chamber; 2 – table of the milling machine; 3 – rotary faceplate with the drive; 4 – monitor for remote control of the processing; 5 – gas mixture preparation chamber; 6 – unit for generating electromagnetic discharge.

Hardening by high-frequency mechanical forging was carried out using the PWI-IPM installation of the Institute of Electric Welding named after E. A. Paton (Fig. 5).

Fig. 5. Installation for surface hardening by high-frequency mechanical forging

IV. RESULTS

4.1. The results of numerical simulation of the force impact of the raw material on the cutting knife

To determine the stress-strain state of the knives, first of all, it is necessary to determine the forces impact on them during operation. The magnitude of the force significantly depends on the cutting angle.

Numerical modeling of the hydrodynamics of raw materials during the movement of the knife was performed in the software package *FlowVision*. As a result of modeling, the distribution of fluid pressure during the frontal flow around the knife`s edge was determined. Visualization of preliminary results is shown in Fig. 6.

The results obtained by numerical simulation were approximated by the method of least squares, resulting in the following equation of multivalued regression:

$$P = -4,69 + 0,32 \cdot \beta + 0,0261 \cdot \upsilon + 0,0035 \cdot \eta , \qquad (4.1)$$

where P − pressure, MPa; β – knife sharpening angle, degrees;
υ–cutting speed, m/s; η – viscosity of raw materials Pa·s.

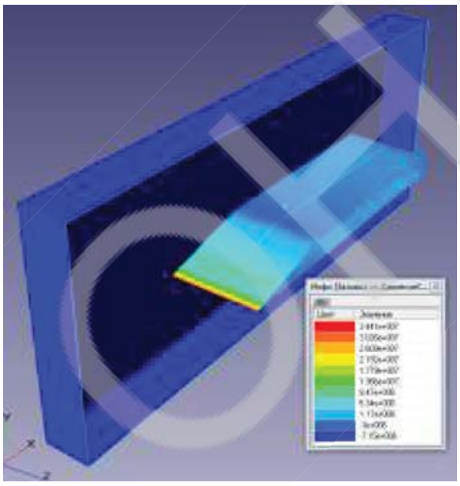


Fig. 6. Fluid pressure distribution during frontal flow around of knife (edge sharpening angleβ =14 degrees, cutting speedυ=200 m/s, viscosity of raw materials η =700 Pa·s)

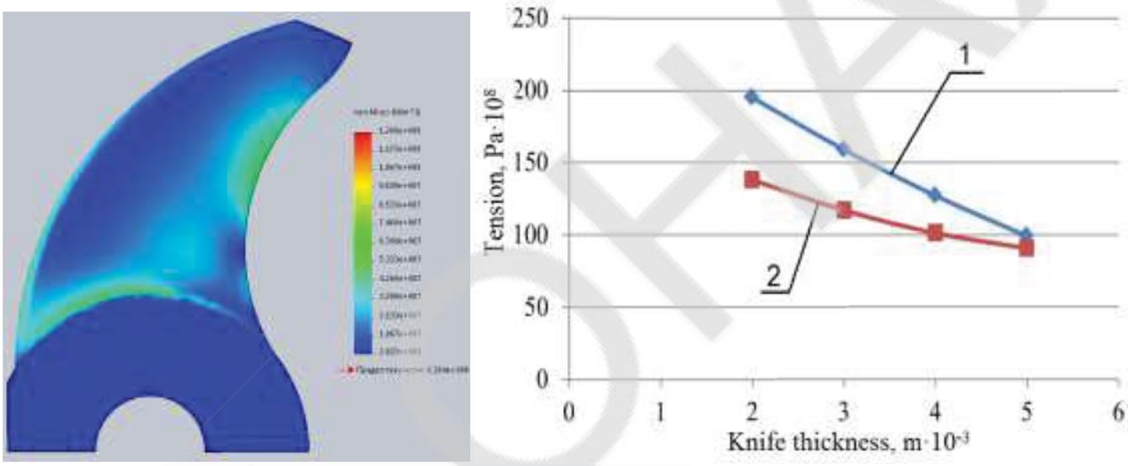
As follows from the simulation results, changing the angle of sharpening of the blade significantly affects the pressure acting on the surface of the knife`s blade. Thus, at a flow rate of 200 m/s, the pressure on the blade varies from 0.69 MPa to 13.66 MPa, respectively. In this case, the greater the viscosity of the flow of raw materials corresponds to a more significant increase in pressure with increasing angle of sharpening.

This indicates the need to take into account these design parameters when determining the conditions of force load of the cutter knives when calculating their strength.

4.2. Theoretical determination of the stress-strain state of knives under static load

The study of the static strength of the bowl cutterknives was carried out using numerical simulations. The data given in chapter 4.1 were used to determine the forces acting on the knife and on the side of the knives of Alpina, Seydelmann, Kilia, Laska, L5-FKB brands.

Stress determination was performed for two points, which are located in the most stressed areas of the knife (Fig. 2). The simulation results for the Alpina knife are shown in Fig. 7 (for other knives, the dependence of stresses on the thickness of the knife has a similar linear character). As follows from the data obtained, the dependence of stresses in the cutting knife on its thickness is linear for both of these points. This allows you to count on the possibility of a simple increase in the strength of the knives by increasing their thickness in the most stressful areas (zones 1 and 2 in accordance with Fig. 2).



a) b)

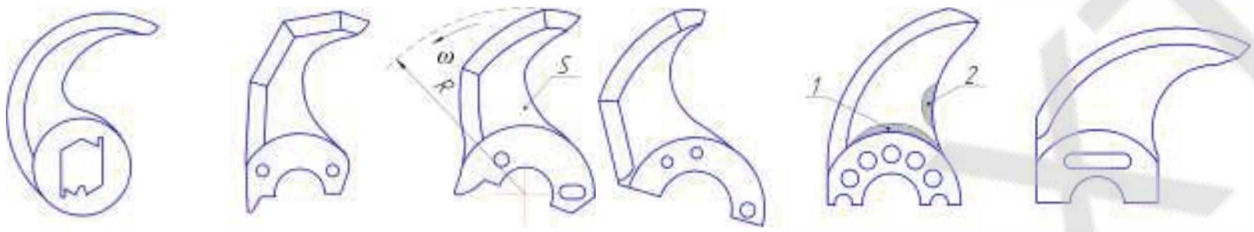
Fig. 7. Stress-strain state of Alpina knives: a) – visualization of stress-strain state, stress, Pa; b) – the dependence of the stresses in the knife of Alpina bowl cutter on its thickness: 1 – the area near the mounting part of the knife, 2 – the area on the back egde of the knife.

4.3.Numerical study of the frequencies of natural oscillations of knives and the influence of vibration loads on their stress-strain state

Performing up to 100 s^{-1} rotations and at the same time having periodic contact with the raw material the knife performs up to 100 oscillations per second due to deformation during cutting of the raw material. Given the relatively high frequency of oscillations of knives, their considerable length and small thickness, it is likely to assume that their operation may cause a resonance phenomenon, which is known to lead to a dramatic increase in body deformation and its destruction. The study of the parameters of the oscillations of the bowl cutter knives can provide an opportunity to determine rational ways to increase their strength, and hence durability.

The study of natural frequencies was performed by numerical mathematical modeling. 3D models were built for each type of knife, with a maximum radius of rotation of the perimeter points was 300 mm, and the thickness of the knife had three values, each of which was determined by the scale factor *k* (k_1=42,9; k_2=60; k_3=85,7).

The natural oscillation frequencies of 6 different types of knife designs (Fig. 8), which are most often used in modern models of bowl cutters, were studied. According to Fig. 8, the knives of the presented types belong to the bowl cutters of the following brands: type I – Seydelmann; type II and III – Laska; type IV – Kilia; type V – Alpina; type VI – L5-FCB.



a) b) c) d) e) f)

Fig. 8. Schemes of designs of knives which are most commonly used:a) – type I; b) – type II; c) – type III; d) – type IV; e) – type V; f) – type VI; R – the largest radius of rotation of the points of the knife; S is knife`s thickness; ω – the direction of rotation of the knife when cutting raw materials; 1, 2 – zones of occurrence of the greatest stresses in a knife body under static load

The scale factor *k* was calculated by expression:

$$k = \frac{R}{S}, \qquad (4.2)$$

where*R* – the largest radius of rotation of the points of the knife,mm;
S – the thickness of the knife, mm.

The values of *k* were determined according to [1], while the value of k_1 corresponding to the knives with the largest specific thickness, and the value of k_3 to the knives with the smallest specific thickness. In this case, for knives with *R*=300 mm, the values of the scale factor *k* corresponded to the following values of the thickness of the knife: when k_1=42,9 – *S*=7 mm; at k_2=60 – *S*=5 mm; at k_3 = 85.7 – S=3.5 mm.

Visualization of the obtained results (for some types of knives) is shown in Fig. 9. The obtained data were approximated by the method of least squares using thequadratic function:

$$\nu_{nat.1} = a + b \cdot k + c \cdot k^2 \qquad (4.3)$$

where $\nu_{nat.1}$ – the first natural frequency of the knife, Hz; *k* – scale factor; *a,b,c*– coefficients (determined according to table 4.1).

As follows from the obtained data, knives of all studied types, when used in modern high-speed bowl cutters, work in the range of frequencies close to resonance or can work in the resonance mode. At the same time, for knives of type I with reduced thickness, appearance of the first resonant frequency and approach to the second (48.9 Hz and 121.3 Hz, respectively) is observed, which indicates their extremely low vibration resistance.

To reflect the effect of vibration load of the knives on their stress-strain state, the concept of the coefficient of dynamism was used, which was determined by the expression:

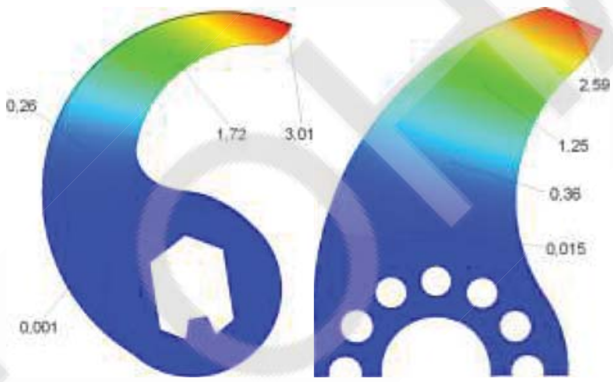
$$\beta = \frac{A}{x_{st.}} = \frac{1}{1 - \frac{\nu_{forc.}^{2}}{\nu_{nat.}^{2}}}, \qquad (4.4)$$

where$A$ – amplitude of forced oscillations; x_{st} – the deformation under static load of the knife;$\nu_{forc.}$ – frequency of forced oscillations of the knife, Hz; $\nu_{nat.}$ – natural oscillation frequency of the knife, Hz.

Table 4.1

Values of regression equation coefficients

Knife type	Coefficients`values			Knife type	Coefficients` values		
	a	b	c		a	b	c
I	213,665	-3,518	0,019	IV	390,166	-6,419	0,034
II	296,218	-4,880	0,026	V	410,421	-6,768	0,036
III	374,890	-6,180	0,033	VI	399,591	-6,573	0,035



a) b)

Fig. 9. The value of the relative displacements of the knives` sections: a) – knife type I when it reaches the first natural frequency of oscillation $\nu_{nat.1}$; b) – knife type VI when it reaches the first natural oscillation frequency $\nu_{nat.1}$

The coefficient of dynamism β indicates how much the amplitude of the forced oscillations is greater than the deformation of the body under the force of static load. When approaching the frequency of forced oscillations $\nu_{forc.}$ to the frequency of natural oscillations $\nu_{nat.}$ the value of the coefficient of dynamism β increases rapidly, which indicates a sharp increase in the deformation of the knife due to the action of vibration load.

Thus, the value of the coefficient of dynamism β allows to quantify how much the stress state of the body will change during the transition from static load state to vibration state.

Using the data in Table 4.1 and expression (4.4), the values of the coefficient of dynamism β were calculated for the most widely used frequency ranges of knives in modern bowl cutters. The calculated values are given in Table 4.2, where only the values that precede the achievement of the first natural oscillation frequency of the knives$v_{nat.1}$.

As follows from the results, the knives of all studied types when used in modern high-speed bowl cutters work in the range of oscillation frequencies close to resonance. For knives of all types made of their minimum specific thickness (*k*=85,7) the phenomenon of resonance in the range of working frequencies of rotation of knife heads of modern grinders (<6300 min^{-1}) is observed. For knives of type I resonance is observed forall values of the scale factor *k*, and at *k*=85,7 $v_{nat.1}$ minimum is 2934 min^{-1}. Type V and also type VI knivescan be considered the most rigid.

It is noteworthy that for knives types II-VI, even when performing at their maximum specific thickness (*k*=42,9), there is an increase in the coefficient of dynamism in the range of β=1,04-2,24, which causes a proportional increase in deformation and stresses that can be determined for knives under static loads.

In practice, this leads to a sharp increase in stresses in the areas of their greatest concentration, which can explain the breakage of the knives in these areas in accordance with Section I.

Table 4.2

Dynamism coefficient values β

Rotation frequency of knivesn_b,min^{-1}	Knife type								
	I			II			III		
	Scale factor*k*			Scale factor *k*			Scale factor *k*		
	42,9	60	85,7	42,9	60	85,7	42,9	60	85,7
2000	1,13	1,30	1,87	1,06	1,14	1,32	1,04	1,08	1,18
3000	1,36	2,07	-	1,16	1,37	2,20	1,09	1,20	1,52
4000	1,89	12,12	-	1,33	1,92	33,0	1,18	1,43	2,54
5000	3,82	-	-	1,62	3,96	-	1,32	1,88	19,14
6000	-	-	-	2,24	-	-	1,53	3,06	-
7000	-	-	-	4,06	-	-	1,89	11,9	-
Rotation frequency of knivesn_b,min^{-1}	Knife type								
	IV			V			VI		
	Scale factor *k*			Scale factor *k*			Scale factor *k*		
	42,9	60	85,7	42,9	60	85,7	42,9	60	85,7
2000	1,04	1,07	1,16	1,03	1,07	1,14	1,03	1,07	1,15
3000	1,09	1,18	1,46	1,08	1,16	1,4	1,08	1,17	1,43
4000	1,16	1,38	2,27	1,15	1,33	2,03	1,16	1,35	2,14
5000	1,28	1,75	7,98	1,25	1,64	4,86	1,27	1,69	5,99
6000	1,47	2,62	-	1,41	2,29	-	1,44	2,44	-
7000	1,76	6,35	-	1,65	4,27	-	1,70	5,07	-

The obtained results indicate the need to find effective ways to increase the vibration resistance of the bowl cutterknives, which would increase their strength without compromising the technological properties.

4.4.Experimental studies of the influence of processing technologies on the fatigue endurance of 65G steel samples (analog 66Mn4)

An experimental study of the fatigue strength of samples made using the technology for making meat cutting knives, as well as samples reinforced by pulse-plasma treatment and high-frequency mechanical forging (Fig. 10). High-frequency mechanical forging allows to increase the fatigue strength of steel 65G up to 2.5 times.

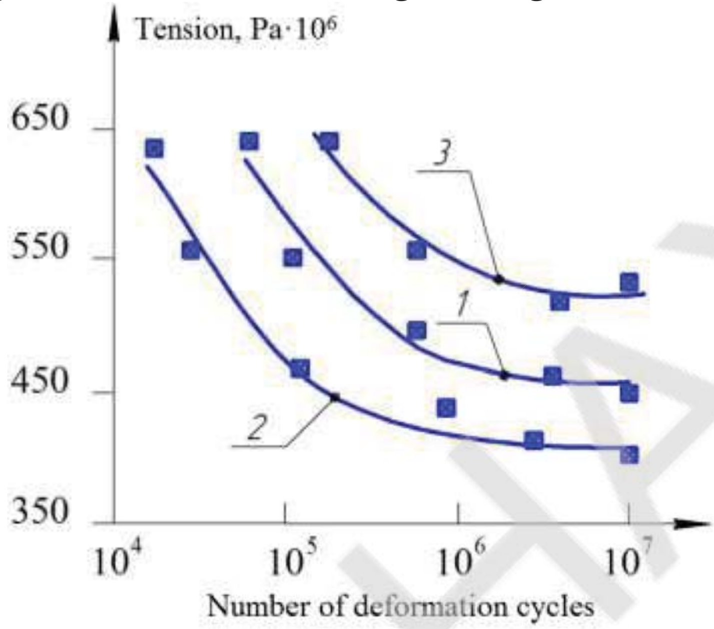


Fig. 10. Curves of fatigue of 65G steel samples: 1 – the usual sample; 2 – sample reinforced by high-frequency mechanical forging; 3 – strengthened by pulse-plasma processing sample

At the same time, pulse-plasma hardening reduces fatigue endurance by 3-3.5 times.

4.5. Numerical study of fatigue endurance of bowl cutterknives under alternating loads

In order to study the influence of the geometric shape of the cutting knife on fatigue failure resistance and to develop recommendations for rational design of the knives, a numerical modeling of their endurance under alternating loads was conducted.

Visualization of some results is shown in Fig. 11. As follows from them, the geometric shape significantly affects the durability of the cutting knives under alternating loads.

The lowest values of the endurance limit were shown by the following knives (according to Fig. 8): type III – $2{,}2 \cdot 10^4$ cycles; type II – $2{,}2 \cdot 10^4$ cycles; type I – $2{,}2 \cdot 10^4$ cycles. Knives of other brands have much higher durability: type V – $4{,}2 \cdot 10^5$ cycles; type IV – $1 \cdot 10^6$ cycles and above; type VI – $1 \cdot 10^6$ cycles and above. In this case, on average, knives of modern bowl cutters before disposal can work up to $2{,}3 \cdot 10^6$ cycles.

Thus, we can conclude that to ensure high endurance of the knives considering working on fatigue, it is advisable to produce the body of the knife of increased width and avoid the presence of sharp geometric transitions to eliminate stress concentrators. It will be useful to increase the thickness of the knife in the tensest parts of its body.

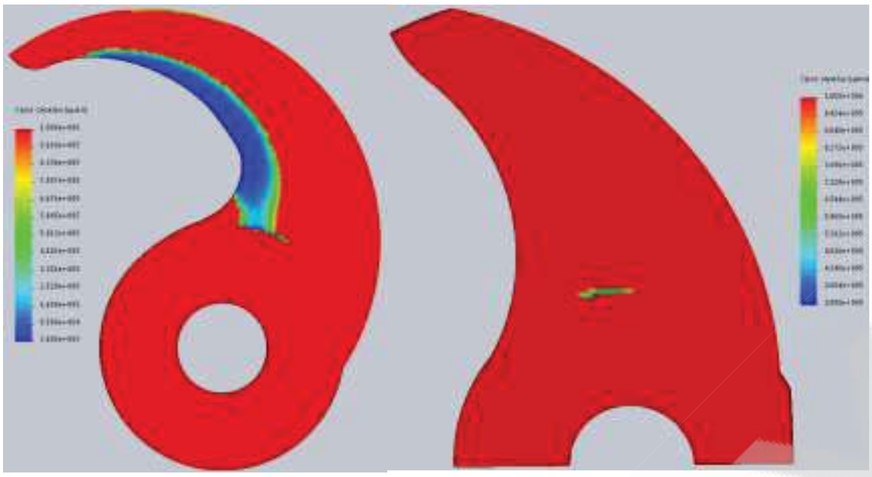


Fig. 11. The results of durability numerical simulation of cuttingknives at alternating loads (number of load cycles): a) –knife type I; b) – knife type V.

4.6. Development of new solutions to increase the strength of bowl cutterknives

Based on the obtained research results, we have developed a number of technical solutions to increase the strength of bowl cutterknives.

After analyzing the recommendations for improving the vibration strength of knives, a new way was proposed – a differentiated increase in the thickness of the knife (increasing the thickness in the rear, the tensest part of the knife, Fig. 12).

This ensures the simultaneous fulfillment of two known contradictory requirements for knives – low heating of raw materials due to the small thickness of the knifein the area of contact with raw materials and higher strength of the knife due to increased thickness in the rear, most tense part of the knife that does not contact raw materials. The design of the knife shown in Fig. 12 allows to increase its durability by 34% (fig. 13).

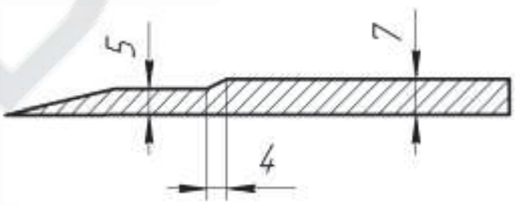
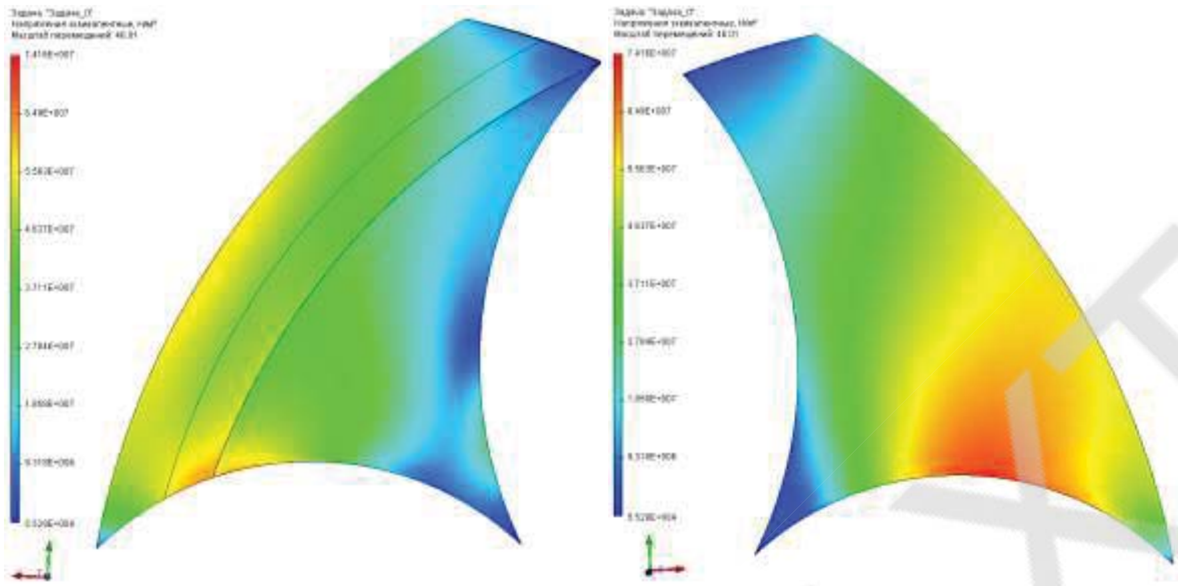


Fig. 12. Cross section of a knife of the developed design (with local thickening in a back part of a knife).

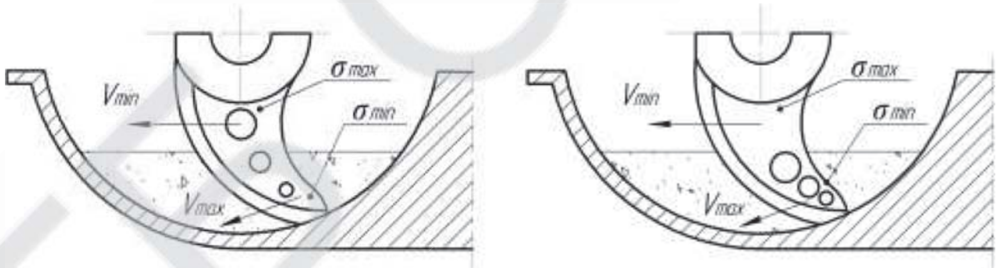
Also perforated bowl cutter knives are improved (fig. 14). The efficiency of perforation holes located near the mounting part of a conventional knife is insufficient due to the movement of this area with a minimum linear speed V_{min} (minimum cutting speed) in the upper part of the bowl cutter, which is not always filled with raw materials. At the same time, the holes near the mounting part of the knife significantly reduce its strength, because they are located in the tensest part of it (Fig. 14, a).



a) b)

Fig. 13. Visualization of the stress state of the knife of the proposed design (with local thickening in the back part of the knife): a) – the top side; b) – the bottom side.

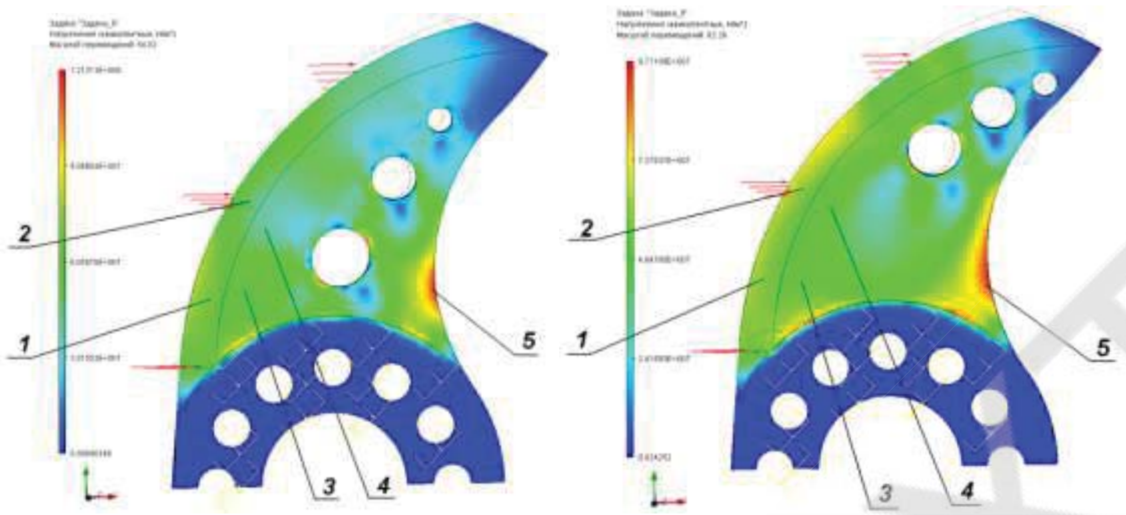
An improved design of a perforated knife is developed, the holes of which are located on the periphery of the body (Fig. 14, b). The strength of the knife of advanced design, with the thickening in the tensest part of it, became higher by 20% (Fig. 15). At the same time, the cutting ability of the knife is improved due to the more favorable location of the holes – they move in that part of the bowl, which is always loaded with raw materials, while moving with the highest linear velocities V_{max}.



a) b)

Fig. 14. Schemes of operation of perforated cutting knives: a) – ordinary; b) – improved; *V* – cutting speed; *σ* – tension.

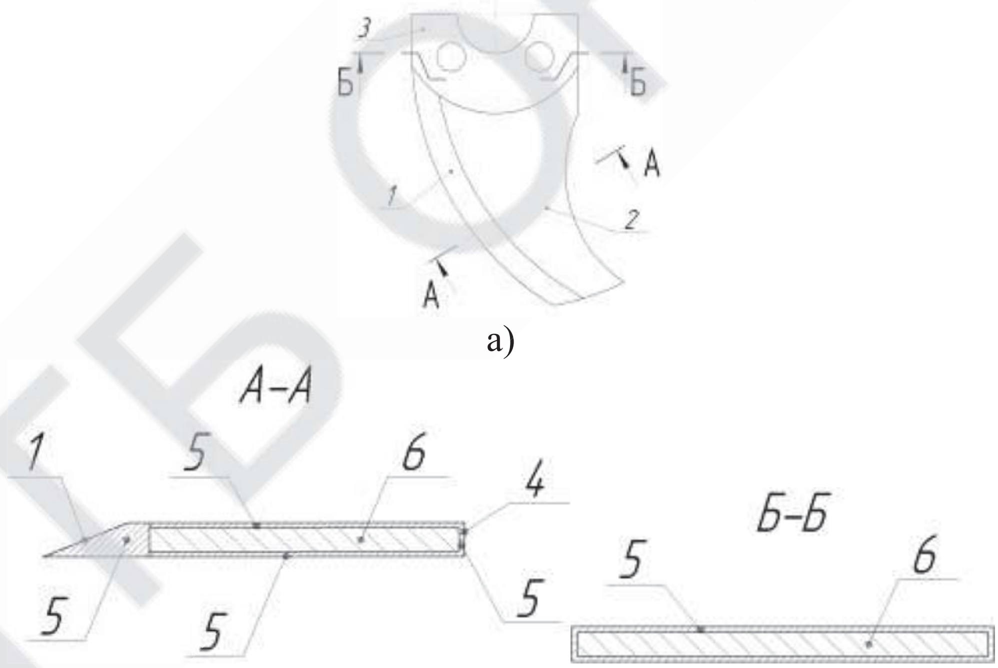
We have proposed a new way to strengthen the cutting knife, which allows you to increase its fatigue strength. Existing methods of heat treatment of knives are not able to meet a number of requirements for them, which in some sense contradict each other – high hardness of the knife (to ensure increased wear resistance of the knife, increased fatigue strength and improved corrosion resistance) and at the same time increased toughness of the knife body in order to improve the stability of the knife under shock loads.



a) b)

Fig. 15. Visualization of the stress state of the perforated knife: a) – Alpina manufacturer; b) – our developed design; 1-5 – stress measurement points.

In order to solve this problem, based on the results presented in chapter 4.4, a new way to strengthen the cutting knives was developed. It starts from annealing of the whole knife throughout depth, then follows normalization or improvement to hardness HB 200-350 throughout depth (fig. 16).



a)

b) c)

Fig. 16. The structure of the knife, strengthened by the developed method:
a) – general view of the knife; b) – cross section of the working part of the knife; c) – cross section of the mounting part of the knife; 1 – knife; 2 – working part; 3 – mounting part; 4 – rear edge; 5 – surface layers of the working part; 6 – core.

After that, the knife 1 is hardened throughout depth to a hardness of HRC_e 52-66 with appropriate tempering (for example, by means of induction hardening with high-frequency currents, plasma hardening, etc.). Then the surface hardening of other sections 4, 5 of the knife to a depth of 0.03-2 mm (high-frequency mechanical forging).

At the same time hardening of a knife 1 increases its wear resistance. Normalization or improvement of the core 6 of the mounting part 3 and the core 6 of the working part 2 of the knife increases its viscosity, which is favorable for the operating conditions of the knife during cutting (shock load).

Strengthening the surface layers 5 of the working part 2 of the knife increases the fatigue strength and corrosion resistance of these areas. Strengthening the surface layers 5 of the mounting part 3 increases their corrosion resistance and wear under fretting. As a result, it becomes possible to most effectively combine the operating properties of the bowl cutterknives in comparison with known analogues.

V. CONCLUSIONS

As a result of the performed researches the approach to increase the durability of bowl cutterknives due to a substantiation of ways of improvement of their stress-strain condition and fatigue endurance is offered. The most significant scientific results and conclusions of scientific work are as follows.

1. The analysis of the causes and consequences of the destruction of the cutting knives during operation is carried out. It is established that one of the main reasons for the destruction of knives is their insufficient vibration and fatigue strength, which is especially acute during the workloads of modern high-speed bowl cutters. The destruction of knives causes significant complex damage, which is characterized by the loss of a large volume of raw materials, expensive set of knives, failure of the bearings of the knife shaft, significant damage to the bowl and the cover of the knife head. It is important to comprehensively increase the strength of the cutting knives.

2. It was conducted a series of researches to select corresponding devices and the equipment for research and modeling of processes which occur during the interaction of working parts of bowl cutters with meat raw materials during its processing.

3. Numerical simulations have established the values of pressures acting on the cutting knives under different conditions of their workloads. The regularities of the influence of the knife sharpening angle, cutting speed and dynamic viscosity of the raw material on the pressure acting on the surface of the knife are revealed. The obtained results allow to take into account the influence of structural and technological factors of the process on the force load on the knife and, accordingly, to increase the accuracy of the calculation of knives for strength and fatigue endurance.

4. The static strength of the cutting knives was investigated by mathematical modeling using numerical methods. As follows from the obtained data, the dependence of the stresses in the cutting knife on its thickness is linear for both studied points. This allows you to count on the possibility of simply increasing the strength of the knives by increasing their thickness in the tensest areas.

5. Using mathematical modeling and numerical methods, it was found that cutting knives of all studied types used in modern high-speed machines operate in the range of oscillation frequencies close to resonant. Quantitative characteristics of the influence of vibration loads on the stress-strain state of knives are obtained. The results of research allow to increase the efficiency of finding ways to improve the vibration resistance of bowl cutterknives.

6. A set of full-scale and numerical experiments to identify the importance of the influence of structural and technological factors on the fatigue strength of cutting knives were conducted. Regularities of influence of technologies of strengthening of material and geometrical characteristics of knives on the limit of their fatigue endurance are revealed. A set of recommendations is proposed to increase the fatigue strength of knives.

7. Using the obtained research results, a set of constructive (a series of new constructions of bowl cutterknives) and technological solutions (a method of strengthening cuttingknives by high-frequency vibration riveting) was proposed and substantiated.

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