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Durability of cutter assemblies and its causative factors

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Abstract: Cutter assemblies operate under stressful conditions: the knives are subjected to high dynamic loads, the cutter shaft rotates at a frequency of 5–100 s^{-1}, the electric driving motor of the cutter shaft overcomes high starting moments, the bed is subjected to significant static and dynamic loads, the food raw materials and humid atmospheric air in the production room is corrosive to the structural elements, etc. Under the influence of these factors, the cutter assemblies break down, which causes unregulated pauses in food raw materials processing and also requires high expenses for equipment repair. The aim of the paper was to study the durability of the main cutter assemblies and to establish its main determining factors. The presented numerical values of durability of cutter assemblies have been obtained as a result of the planned, warranty and post-warranty practical maintenance of cutters by the engineering team of GEA FOOD SOLUTIONS UKRAINE, LLC, the mechanical supervisor staff of Cherkassk Food Company, LLC and also as a result of scientific research of the processes that provide the operation of these machines and that were carried out at the Cherkassy State Technological University (the Ukraine). The components that operate under the most stressful conditions are knives, a cutter shaft and its bearing assemblies, and the electric driving motor of the cutter shaft. At the same time, the durability of most cutter assemblies is limited by the quality of operation of the cutter head and the durability of the knives. The expenses for the repair or replacement of cutter assemblies can amount to tens of thousands of euros (not including the losses caused by equipment downtime). By applying the appropriate technical solutions and cutter system operating rules, it is possible to significantly improve the durability of a cutter and reduce these expenses.

Keywords: Cutter, durability, repair, knives, fatigue strength, improvement

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INTRODUCTION

Cutters are used in the vast majority of processing lines for the production of sausages, canned meat and minced semi-finished products. The design of modern models of cutters makes it possible to implement a number of types and modes of food raw materials processing such as grinding boneless steaks (fresh or frozen) to the state of meal or mincemeat, grinding mincemeat to the state of emulsion, mixing formulation ingredients with simultaneous grinding or without it, vacuumizing raw materials and the heat treatment thereof, which is carried out simultaneously with grinding, the saturation of raw materials with inert gas, and freezing it with liquid nitrogen [1–6].

In order to provide the above processing types, a cutter is equipped with the appropriate assemblies, the main of which are: a cutter head several knife blocks each of which commonly contains 2 knives; the knives of a special geometric shape made of the appropriate steel grades and heat treated in the appropriate manner; a cutter shaft with bearing assemblies; an electric motor and the belt drive of the cutter shaft drive; a bowl; an electric bowl drive; a bed; an electric cabinet and control panel; a frequency converter, which is part of the cutter shaft drive.

Cutter assemblies usually operate, under stressful conditions: the knives are subjected to high dynamic loads, the cutter shaft rotates at a frequency of 5–100 s^{-1}, the electric drive motor of the cutter shaft overcomes high starting moments, the bed is subjected to significant static and dynamic loads, the food raw materials and humid atmospheric air in the production room are corrosive to the structural components of the cutter, etc. Under the influence of these factors, cutter assemblies break down from time to time, which causes unregulated pauses in food raw materials processing and also requires large expenses for equipment repair.

A systematic increase in the durability of cutter assemblies can reduce these negative effects. For this, it is necessary to study the durability of the main cutter assemblies and to establish the main factors that contribute both to a decrease and an increase in this durability.

There are no data on cutter durability in the known literary sources. The only exception is the publications [7–14] that highlight the wear resistance, static and fatigue strength of knives. A study of the durability of the main cutter assemblies is relevant.

The aim of the paper is to study the durability of the main cutter assemblies and to establish its main determining factors.

STUDY OBJECTS AND METHODS

The objects of the studies were GEA Cutmaster V vacuum cutters with 200, 325, 500 and 750-liter bowls; a Laska KR-200-2V vacuum cutter with a 200-liter bowl, a Laska KR-330-2V vacuum cutter with a 330-liter bowl, an atmospheric L5-FKB cutter with a 250-liter bowl, as well as their working bodies (knife heads, knives, bowls), drive components (motors, belt and gear drives, shafts, bearing assemblies and their seals), and electronic control elements.

The studied of GEA Cutmaster V cutters are installed at several meat processing plants in the Ukraine. The studied cutters Laska KR-200-2V, Laska KR-330-2V, and L5-FKB are installed at the meat-packing plant of Cherkassy Food Company, LLC (Cherkassy, the Ukraine).

The durability of the working bodies of cutters and the components of their drive was determined by the mechanical supervisor staff of Cherkassy Food Company, LLC during the planned works on equipment operation, as well as by the engineering team of GEA FOOD SOLUTIONS UKRAINE, LLC during the planned, warranty and post-warranty practical maintenance of cutters. At the same time, the actual operating time of the cutters, the conditions for their operation, the types of failures, their causes and the expenses for their elimination were specified.

The efficiency of cutter knives, their durability and ways to improve it was studied at the Cherkassy State Technological University (the Ukraine) using the following methods. The curvature radius of the cutting edges of the knives was determined using the hard copy proof method with an optical MBS-9 microscope. The pulse-plasma hardening of the cutting edges of the knives was carried out using IMPULS the insfallation of the laboratory of E.O. Paton Electric Welding Institute of the National Academy of Sciences of Ukraine. To determine the effect of pulse-plasma hardening on the microstructure of the surface layers, the corresponding metallographic specimens were made. The metal samples were subiected to grinding in several stages and chemical polishing in a 3% nitric acid solution for 5 s. The microstructure was studied using an optical Neophot-32 microscope. The microhardness of the hardened samples was measured using metallographic specimens with the help of an M-400 micro-hardness meter from LECO with a load of 50 g. The diffractometric studies of steel samples were carried out in order to identify the factors that provide the hardening of knife material after pulse-plasma treatment. A DRON-UM1 diffractometer, monochromatic Cu-Kα-radiation and the step scan method (35 kV, 25 mA, the exposure time at the point is 10 s, the pitch is 0.05°) were used. A graphite monocrystal set to a diffracted beam was used as a monochromate. The samples were studied in the plane of incidence of the X-ray beam as they were rotated. The hardness of the surface of the knives was measured using a TK-2M hardness tester (by Rockwell) and a Tsh-2 hardness tester (by Brinell). The roughness of the knife surface was measured using a TIME 3221 profilometer.

The strength and vibration resistance of the knives were studied by means of numerical simulation using a T-Flex Analysis software package. The determination of the necessary forces acting on a knife when being in contact with raw materials, as well as the study of hydrodynamics of raw materials during cutting, was carried out with the help of a special FlowVision software package. When studying the hydrodynamics of raw materials, a Sony FS700 digital video camera with high-speed video recording and the corresponding additional equipment (an Odyssey 7Q Convergent Design recorder, Sony SEL-18200 OSS lens and a 9.7" Lilliput 969 A/O/P video monitor) were also used.

The efficiency of raw materials processing using the advanced knife designs was studied by measuring the cutter productivity and energy consumption for the cutter shaft drive. The quality of the finished product was determined by organoleptic analysis in accordance with the current state standards.

RESULTS AND DISCUSSION

The raw material grinding process is carried out with a knife head. High demands are imposed on it as an assembly for imbalance exceeding the permissible value of which can result in a rapid failure of the bearings of the cutter shaft and the shaft itself. After each knife sharpening cycle (in practice-after each working shift), the static balancing of each knife block is performed. In this case, the design of knife blocks must also ensure the dynamic balancing of the knife head in order to eliminate the bending moments that caused by the unbalance of the individual blocks. Poor balancing significantly reduces the life-time of the front (on the knife head side) cutter shaft bearing and also increases the load on the shaft itself.

The knives are subjected to various impacts during operation. The factor the durability of knives is limited by most of all is the wear of their cutting edges. A sharpened knife has a cutting edge with a curvature radius of about 9 microns, which reaches 40–45 microns after one working shift. In the case of the average cutter utilization, the durability of knives is not above 2 months.

This is due to the high wear properties of meat raw materials, including the effect of its surfactants, as well as the sufficiently low allowance of knives for resharpening. The knives are sharpened along their front edge, which results in a decrease in the width of the knives, and consequently in a decrease in their strength. The knife resharpening allowance, which is regulated by the supporting documents from the manufacturer, is 8–15 mm for the knives of the cutters with a bowl volume of 200–330 liters. Thus, after a rather small number of cycles, a knife becomes unsuitable for further use and is discarded.

The cost of a set of 6 knives ranges for the present time from 200 € (domestic knives made of non-corrosion-resistant steels) to 2000 € (German knives made of special corrosion-resistant steels). Taking this into account, the increase in the wear resistance of cutter knives continues to be a relevant task. One of the ways to increase the wear resistance of knives is their surface hardening, for example, by pulse-plasma treatment, which allows us, according to the authors' studies, to increase the time between failures by 2.2 times. An increase in the microhardness of the surface from HV_{50} = 3700 MPa to HV_{50} = 11,000 MPa corresponds to this increase in the wear resistance of knives. It has been established that despite a rather high content of austenite, the hardness of the surface layers increases due to the phase hardening as a result of reversal α-γ transformations.

A significant problem for meat processors is the destruction of knives during operation. On average, one or more knives are destroyed at a frequency of up to 3 times a year in the case of two-shift cutter operation for 16 hours a day. At the same time, the knife (or several knives) itself and the raw material being processed (about 200–300 liters) are lost, and the bowl and the cutter head cover are damaged (there are potholes of considerable lengths up to 6 mm in depth). Fig. 1 shows the typical examples of such destructions, which are caused by the high linear velocities of knife parts (100–180 m/sec).

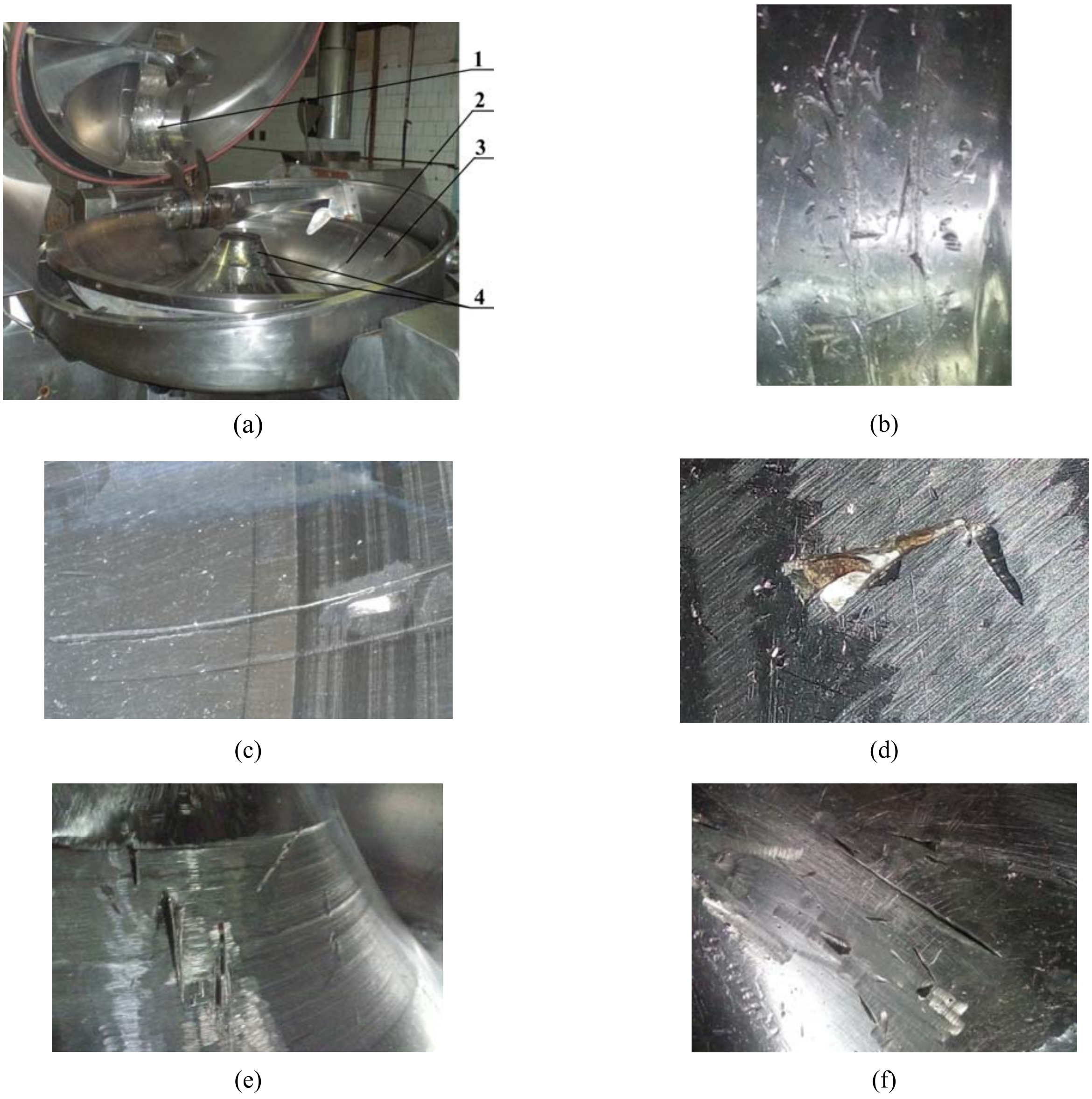


Fig. 1. Examples of damage to the construction elements of a Laska KR-330-2V cutter when the knives are destroyed during cutting: (a) general view of the cutter; (b) cover of the knife head (Pos. 1 in Fig. 1a); (c) periphery of the bowl (Pos. 2 in Fig. 1a); (d) periphery of the bowl (Pos. 3 in Fig. 1a); (e), (f) central cone of the bowl (Pos. 4 in Fig. 1a).

Due to the destruction of at least one knife, the balance of the knife head is violated, which results in the development of considerable dynamic forces that affect the cutter shaft and, as a consequence, in the rapid failure of cutter shaft bearings. There can also be the deformation of the knife head cover and the deformation of the support shaft of this cover.

When the knives are destroyed, the front and rear (the side of the knives and the motor side) cutter shaft bearings and the associated wear parts (seals, etc.) are replaced. In some cases, the cutter shaft can be replaced (if there is a further fast bearing failure after the bearings are replaced). The main sign of the need to replace the cutter shaft is an increase in vibration and noise during operation. In addition, the knife cover is levelled, the detected defects are welded (TIG) and polished.

The destruction of knives is caused by a wide range of things. These can be the causes by negligent cutter operation, in particular, by the bones or metal elements that get into the bowl of the cutter together with raw materials. The knife, when running against them, is subjected to great impact loads and is destroyed.

The other causes are due to the design and operation method of knives. During cutting, the cutting forces, the pressure from the raw material supplied by the cutter bowl, and the centrifugal forces act on the knife. They bring the knives to a complex stress-strain state which is followed by the appearance of characteristic stress concentration zones (Fig. 2a) – near the mounting part of the knife and on the back edge of the knife.

The knives make up to 100 revolutions per second. When entering the raw material, they bend under the action of cutting forces, and they unbend on leaving it. In this case, this refers to an oscillatory process which is carried out at a frequency of 100 Hz. The results of authors' studies [15] showed that the knives of modern cutters operate under conditions of the oscillations close to resonance (Fig. 2b). The dynamic factor reaches $\beta = 2.24$ for them, which indicates a proportional increase in the stresses in the knife precisely due to the specific impact of the oscillatory process. Along with insufficient fatigue strength, it is one of the factors of the increased incidence of knife destruction during the operation of modern high-speed cutters.

The authors have developed a new design of high-strength and highly efficient perforated knives. The efficiency of the holes that are located near the mounting part of the knife is insufficient due to the movement of this area with the minimum linear speed V_{min} (the minimum cutting speed) in the upper part of the cutter bowl that is not always filled with raw materials. At the same time, the holes near the mounting part of the knife significantly reduce its strength since they are located in the most stress-bearing part thereof. The improved design of a perforated knife provides the location of holes on the periphery of the body (Fig. 3b). The strength of the knife became higher by 20% in the most stress-bearing part thereof. At the same time, the grinding ability of the knife is improved due to the more advantageous location of the holesthey move in the part of the bowl that is always loaded with raw materials; moreover, they move with the highest linear velocities V_{max}.

As a result of the study of raw materials hydrodynamics during cutting, the authors have developed a technical solution that makes it possible to increase the strength of knives by several times. As is known, the following technical contradiction is fair for cutter knives: "The knife should be as thin as possible to minimize the heating of mincemeat when grinding and the knife should be as thick as possible to ensure its high strength." The heating of mincemeat causes a deterioration in the quality of sausages, and the destruction of the knife during rotation causes significant complex losses for a meat processing plant. As a result of the studies of raw materials hydrodynamics, it has been established that, in contrast to the known concepts (Fig. 4a), when flowing over the upper part of the knife profile, the flow of raw material, after moving along the blade rake, moves around the upper horizontal side of the knife with no contact to it (Fig. 4b). The new established knowledge have made it possible to propose a was differentiated increase in thickness of knives new way to increase their strength (Fig. 4b). At the same time, the above requirements are met at the same time-the low heating of raw materials (due to the small thickness of the blade in the raw material contact area), and the knife strength increased by more than 2.2 times (due to the increased thickness in the rear, the most stress-bearing, part of the knife that does not contact to the raw materials).

In modern cutters, the knives are fully loaded by the cutting power in a very short time interval–1/400 sec. In this case, it refers to shock-type load, and therefore the material of the knife must be adapted to such operating conditions, in particular, have sufficient viscosity.

This problem is solved by the choice of steel grades with a medium (steel 40X13, 50X14MoW) or high (65Mn steel) carbon content and the appropriate heat treatment of the most loaded knife areas (steel normalization or hardening).

One of the leaders in the production of cutting knives, the German company GW Steffens GmbH, produces them from the patented M92 steel. According to the manufacturer, it has the best combination of the following properties: a high wear resistance, high corrosion resistance, a high viscosity and fatigue strength. As shown by the chemical analysis of the material of these knives, the steel contains 0.7–0.9% of carbon, up to 1% of manganese, up to 1% of silicon, 1% of molybdenum, 15% of vanadium, 1% of niobium, and about 13% of chromium. The steel has a higher carbon content compared to 65Mn steel and at the same time the improved viscosity, corrosion resistance, and hardenability.

Different manufacturers of knives provide various thermal treatments thereof. Fig. 5 shows the results of the experimental measurement of hardness of foreign (a) and domestic (b) knife areas. As one can see from Fig. 3a, the knives manufactured by GW Steffens GmbH have a hardened working part (up to 56 HRC units) and a normalized mounting part (up to 20 HRC). Due to this, the improved ability to resist shock loads is provided for the area where the working and mounting parts of the knife are adjacent to each other (1 in Fig. 2).

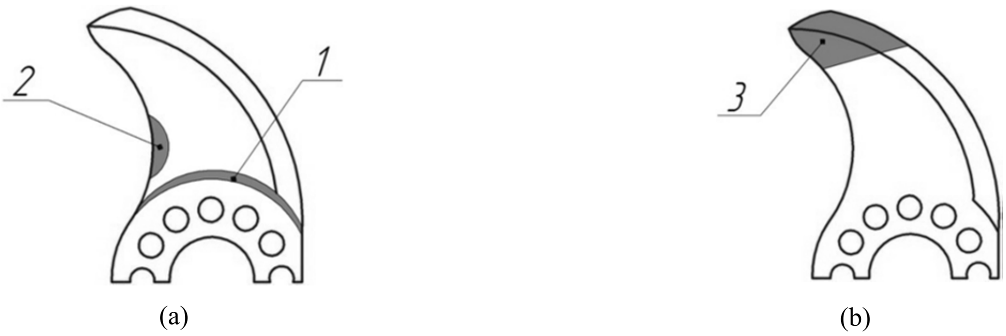


Fig. 2. Stress-strain state of knives: (a) stress concentration zones under static load (*1* – area near the mounting part of the knife, *2* – area on the back edge of the knife); (b) area of the maximum deformations *3* caused by the knife oscillations during cutting at frequencies close to resonant ones.

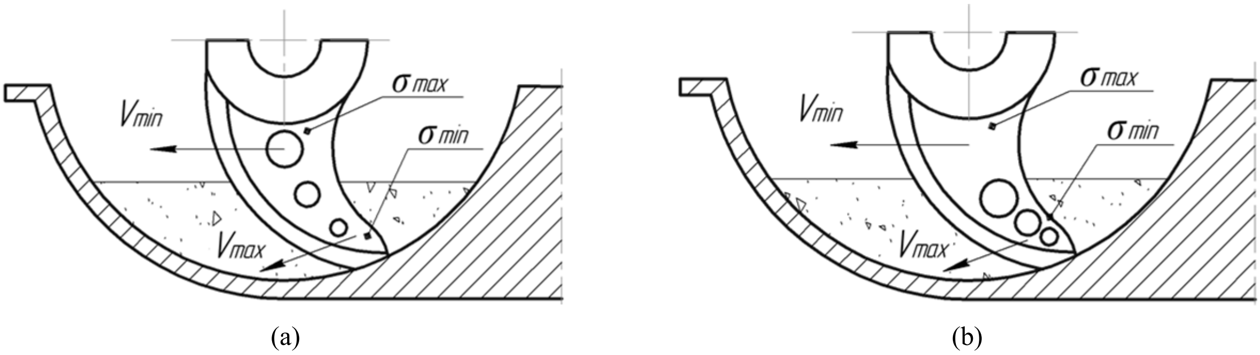


Fig. 3. Operation diagram of perforated cutter knives: (a) usual knife; (b) hardened knife.

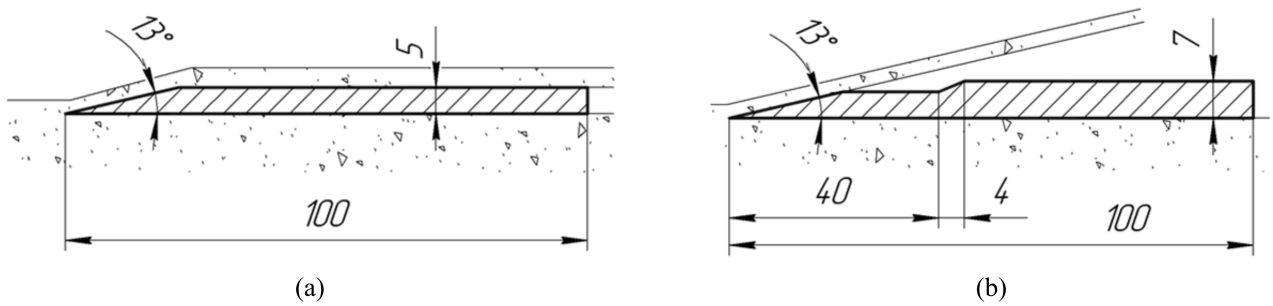


Fig. 4. Flow diagrams for raw materials and the cross-sections of cutter knives: (a) standard knife; (b) hardened knife.

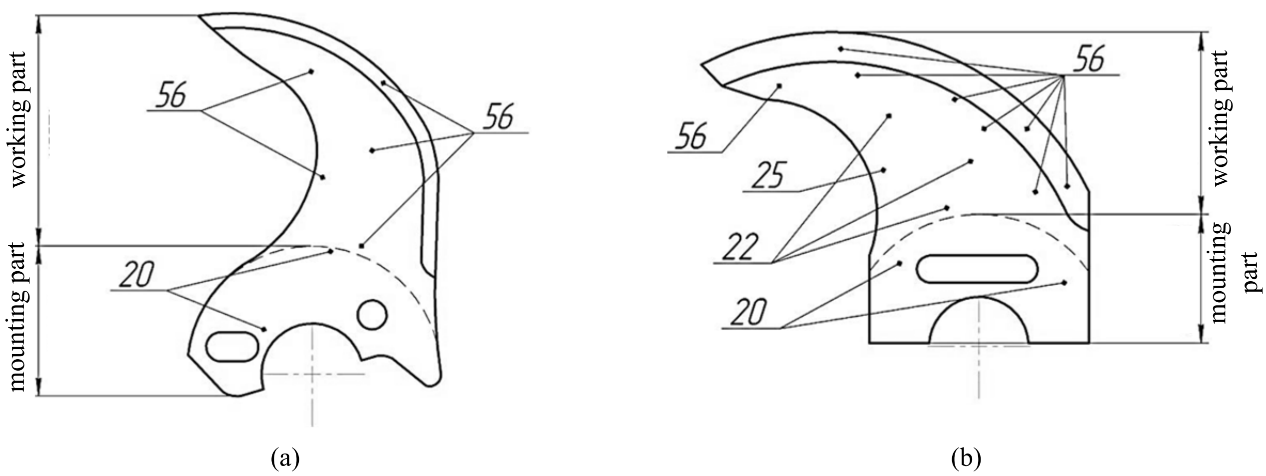


Fig. 5. Results of the experimental measurement of hardness of the knives of various manufacturers by Rockwell: (a) the knife of a Laska KR-330-2V cutter produced by the German company GW Steffens GmbH; (b) the domestic knife of an L5-FKB cutter.

The knives of L5-FKB and L5-FKM cutters manufactured in the Ukraine (Cherkassy) are heat-treated in the other way. The blade is hardened to a hardness of 56 HRC using high frequency currents, and the other parts of the knife remain normalized to a hardness of 20–25 HRC (Fig. 5b). This heat treatment method provides the high viscosity of the knife not only in the area where the working and mounting parts are adjacent to each other, but also at the stress concentration point on the back edge (4 in Fig. 6b).

However, as the results set forth below, show, such heat treatment methods do not provide adequate knife strength. Most of knife failures are caused by a fatigue failure. Fig. 6 shows a knife destroyed by fatigue stresses, as well as characteristic metal fracture zones.

The fatigue crack began to develop in the stress concentration zone 4 on the back edge of the knife at the point of the chamfer intended for mixing raw materials during the reverse rotation of the knife head. The metal has a fine crystalline structure here (zone 3 in Fig. 6b, c, d). The brittle fracture zone (zone 2 in Fig. 6b, c) has a coarse-grained structure. The fact that the fatigued area 3 is larger than the area of the brittle fracture zone 2 shows that the part has been destroyed by flexural strain and tensile stresses with the stresses reaching moderate values. A small amount 1 of the material taken off during resharpening (2.5 mm) should be noted especially. This indicates that the knife has run out less than half of its rated life before the breakage and its static strength has not reached a significantly reduced value due to the reduction of the width of the body.

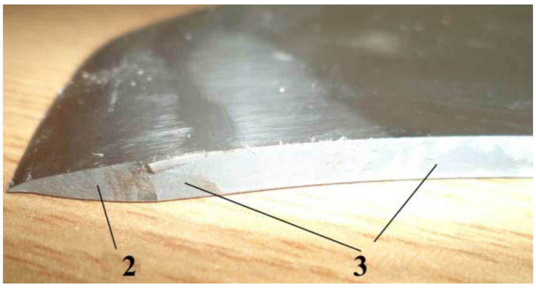
Fig. 7 shows a macrocrack that began to develop on the back edge of the knife of the L5-FKB cutter, the deepest part of the crack is in the stress concentration zone 2 (in accordance with Fig. 2a) on the back edge of the knife.

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

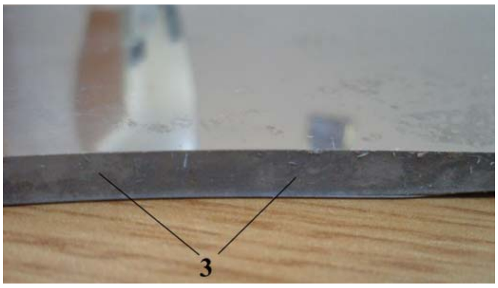
The measurement of surface roughness of the knives made in Germany and in the Ukraine (Fig. 8) made it possible to establish that the knives of the Laska KR-330-2V cutter produced by GW Steffens GmbH had a mounting surface with a roughness Ra = 0.708 μm and a working surface with a roughness Ra = 0.053 μm. The knives of the L5-FKB cutter had both a working and mounting part with a roughness Ra = 0.216 microns.

(a)

(b)

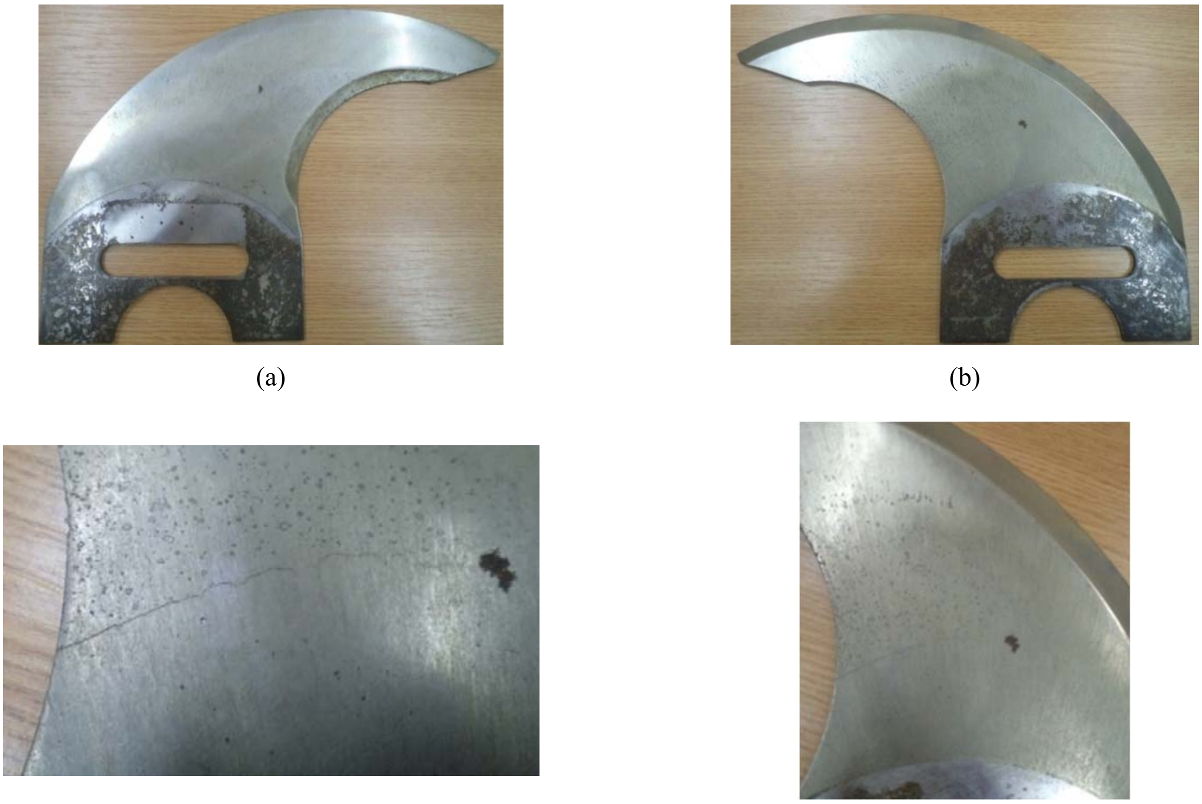


(c)



(d)

Fig. 6. Example of destruction of a knife of a GEA Cutmaster cutter with a bowl of 500 liters under the influence of fatigue stresses: (a) the general view of the knife from the side of the blade; (b) the general view of the knife from the side of the chamfer on the back edge; (c), (d) the characteristic knife fracture zones; *1* – the value of the metal taken off during resharpening; *2* – the area of coarse metal grains; *3* – the area of fine grains formed under the action of fatigue stresses; *4* – the place where the fatigue crack begins to develop.



(a) (b)

(c) (d)

Fig. 7. Fatigue macrocrack on the working surface of the knife body of the L5-FKB cutter: (a) the view of the knife from below, a chamfer on the back edge is shown; (b) the view of the knife from above; (c) the enlarged view of the area the fatigue macrocrack began to develop from; (d) the general view of the macrocrack.

(a) (b)

Fig. 8. Measurement of the roughness of the knife surface using a TIME 3221 profilometer: (a) the knife of the Laska KR-330-2V cutter; (b) the knife of the L5-FKB cutter.

The data obtained show that the working part of the German-made knife has been polished, while the working part of the Ukrainian-made knife has undergone a grinding operation as finishing. As a result, the L5-FKB knife has a 4-time higher roughness of the working surface, which causes 5–10% of its lower fatigue strength. The back edge of the Laska KR-330-2V knife has a high quality of processing, whereas the back edge of the L5-FKB knife has some significant jags, which is obviously also the source of fatigue cracks in the knife (Fig. 7).

The fatigue strength of the knives is significantly reduced by the fretting corrosion in the area 1 of the mounting part (Fig. 2a) due to the friction along the components of the knife block. In addition, the corrosive effect of the meat medium significantly decreases the fatigue strength due to damage to the surface layer. As known, the corrosive medium reduces the fatigue strength of structural steels by up to 87%, and corrosion resistant by up to 44%. The fatigue strength is also reduced by pre-corrosion (for example, when storing knives) by up to 35%.

The reduction of the risks of knife destruction can be provided by regular flaw detection for the presence of micro-and macrocracks in the repair and mechanical workshops of meat processing plants.

Such defectoscopy should be carried out every 2–3 knife sharpenings, but to date, little attention of production workers is paid to this aspect of cutter operation.

All the above confirms the high relevance of the problem of the insufficient fatigue strength of cutter knives, which requires effective ways to solve it. Given the above factors, it can be argued that none of the heat treatment diagrams shown in Fig. 3 fully meets the requirements for knife cutters. The metal in the areas 1 and 2 (according to Fig. 2a) should be sufficiently viscous to resist shock loads and sufficiently hard to resist fatigue failure and to increase corrosion resistance.

Based on the analysis of the requirements for the construction of cutters and the known methods for their heat treatment, the authors have developed a new way to harden knives. It lies in the fact (Fig. 9) that the whole knife is first annealed to the full depth, then it is normalized or hardened to HB200-350 to the full depth. Then, the blade 1 is hardened to the full depth to a hardness of HRC = 52-66 with the appropriate tempering (for example, by induction hardening with high frequency currents, plasma hardening, etc.). Then, sections 4 and 5 of the knife are face-hardened to a hardness of HRC = 52-66 to a depth of 0.03–2 mm (for example, using surface plastic deformation by means of high-frequency mechanical forging). Further on, all the surfaces of the knife, including the blade (1), the working part (2), the mounting part (3) and the back edge (4) intended for mixing raw materials, are polished. Polishing is carried out to a roughness at which the average height of microroughnesses of the surface is not above 1.0 μm.

At the same time, hardening the blade (1) increases its wear resistance. The normalization or hardening of the core (6) of the mounting part (3) and the working part (2) of the knife increases its viscosity, which is favorable for the operating conditions of the knife (a shock load). Hardening the surface layers (5) of the knife working part (2) increases the fatigue strength and corrosion resistance of these areas. The hardening of the surface layers (5) of the mounting part (3) increases their corrosion and wear resistance under fretting conditions. Polishing all the surfaces of the knife increases their fatigue strength and corrosion resistance. As a result, the most effective combination of working properties of the cutter knife in comparison with the known analogues becomes possible.

The cutter shaft system is one of the most critical assemblies of the cutter. Bearings is what fails most often (the durability is 12–24 months). They are replaced by two specialists, which causes the corresponding cost of repair work (the bearing replacement lasts for 10–16 hours, the average labor cost per one specialist is 25 euro/hour). The shaft sleeves and cover slides are also replaced (every 24–36 months). The wear parts of the cutter shaft (vacuum seals) are replaced every 6–12 months.

The cutter shaft itself breaks down far less often than the bearings do. This moment is noted for the destruction of the shaft or by the considerably reduced durability of the newly mounted bearings. The shaft is ordered from the manufacturer and is replaced by two specialists.

Both the bearings and the shaft fail for the same reasons, namely because of the high vibration of the knife shaft. Such vibration occurs when processing solid (frozen) raw materials, when using knives of an unregulated design, when one of the knives breaks down and the knife head is poorly balanced.

The decrease in vibration is enabled by a decrease in the outreach of the consoles l1 and l2 (Fig. 10), which is achieved by reducing the thickness and the number of knife blocks (l1), as well as by reducing the length of the pulley (l2) due to the transition from the use of V-belt transmission to the use a toothed gear.

L5-FKB and L5-FKM cutters have paired bearing assemblies (Fig. 10b) in contrast to foreign cutters (Fig. 10a). This results in an increase in the rigidity of the shaft (the load pattern of the shaft as a simple beam is replaced with the load pattern of a beam with two clamped ends) and, as a consequence, in a decrease in its maximum deflection by up to 4 times and an increase in the critical rotation speed by 1.16–1.52 times. As a result of this design of a cutter shaft system, the durability of the shaft and the bearings significantly increases.

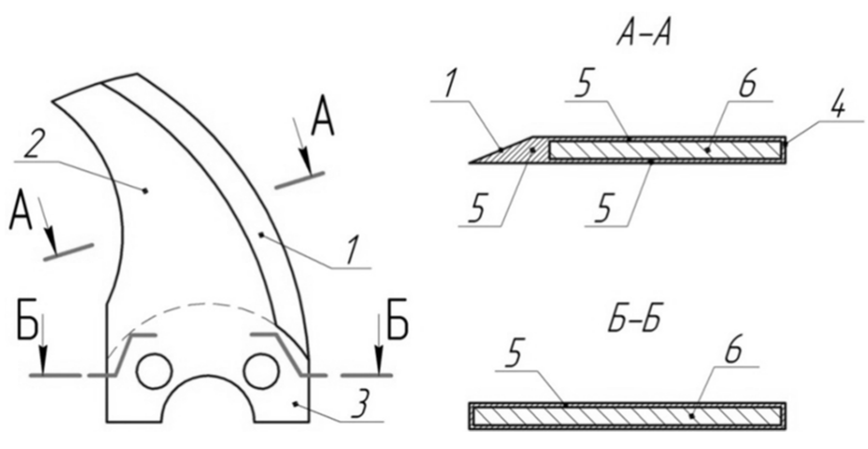
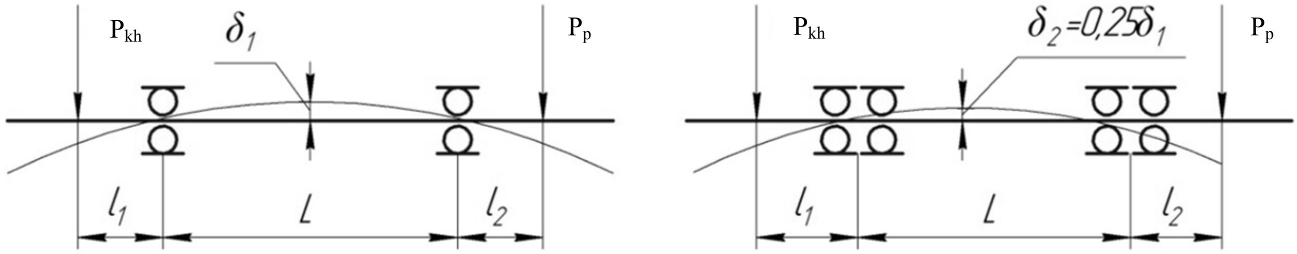


Fig. 9. Hardening pattern of the knife according to the developed method: *1* – knife blade; *2* – working part; *3* – mounting part; *4* – back edge; *5* – face-hardened layer with an increased hardness; *6* – normalized or improved layer with a reduced hardness.



(a) (b)

Fig. 10. Installation diagram of the knife shaft in the bearing assemblies: (a) of foreign cutters; (b) of domestic L5-FKB/FKM cutters. P_{kh} is the weight of the knife head; P_p is the gravity of the pulley; L is the distance between the bearing assemblies; l_1, l_2 are the lengths of the consoles; δ_1, δ_2 are the maximum deflections of the cutter shaft.

(a) (b)

Fig. 11. Diagram for the interaction of the knife with the raw materials: (a) with a straight blade located with the eccentricity *e*; (b) with a curved blade; *H* is the distance from the rotation axis of the knives to the raw materials in the cutter bowl.

As mentioned above, the vibration of the shaft is significantly determined by the design of knifes. The more curved the blade, the lower the vibration and vice versa-the more straight the knife blade, the higher the vibration. Fig. 11 shows two corresponding limiting cases. The maximum vibration will be noted when the knife blade is straight and located with the eccentricity e = h where h is the distance from the rotation axis of the knife to the raw materials in the cutter bowl (Fig. 11a). In this case, the load from the cutting forces on the knife will grow from 0 to max instantaneously, which will cause an increased shock load both on the shaft and the knife itself. When using highly curved blades (Fig. 11b), the load on the knife and the cutter shaft will grow gradually, which will reduce the vibration of the shaft.

Since the shape of the knife blades is determined by the type of the product being manufactured (knives with less curved blades are intended for non-structural sausage products, knives with more curved blades-for structural sausage products), then the contradiction between the requirements for the high quality of raw materials processing and low vibration loading of the knife and the cutter shaft is obvious. Relevant is the search for new design solutions for knives that can resolve this contradiction.

In order to reduce vibration during the operation of the cutter knife head, as well as to improve the efficiency of raw materials processing, the authors have developed two knife designs. The knife shown in Fig. 11 is intended for grinding the raw materials of structural sausage products (smoked, etc.). In contrast to standard knives, it has two areas of highly curved cutting edges (7 in Fig. 12). The knife has been designed as mounted on the supporting disc (1), there are grooves (6) for the passage of the raw materials discarded during cutting. Detachable blades (2) with cutting edges (7) are fixed on the body. A lock (5) is also provided for the fastenings (3), (4), (8), (9), (10). All the cutting edges of the presented knife are highly curved, in contrast to standard knives. This increases the smoothness of interaction of the knife with the raw materials and improves the quality of cutting the cooled raw materials used in the production of smoked sausages.

Fig. 13 presents a knife for cooked sausage products developed by the authors. Its design solutions are based on the new results of the studies of hydrodynamics and the quality of raw material processing during cutting. The knife has been made assemblable, the detachable blades (2) have a low metal consumption and prime cost. The design allows the following conflicting requirements to be successfully fulfilled: the increased curvature of the common cutting edge, the small cutting angle for grinding the connective tissue of meat raw materials (the angle α of the blade (2)), an increased cutting angle for the muscle tissue of meat raw materials (the angle β of the dispersing surface (5) of the overlay (4)). The use of such a knife reduces vibration when cutting, improves the processing of raw materials for cooked sausage products, and reduces the operating costs for cutting tools.

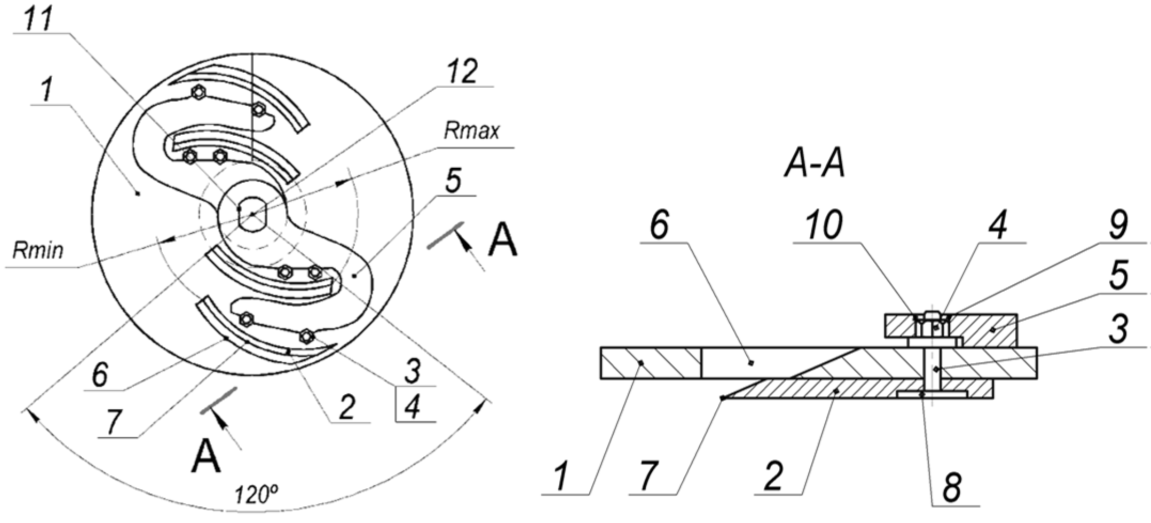


Fig. 12. Knife for structural sausage products: 1 – body; 2 – blade; 3 – bearing assembly; 4 – nut; 5 – lock; 6 – groove; 7 – cutting edge; 8 – bearing plate; 9, 10 – washers.

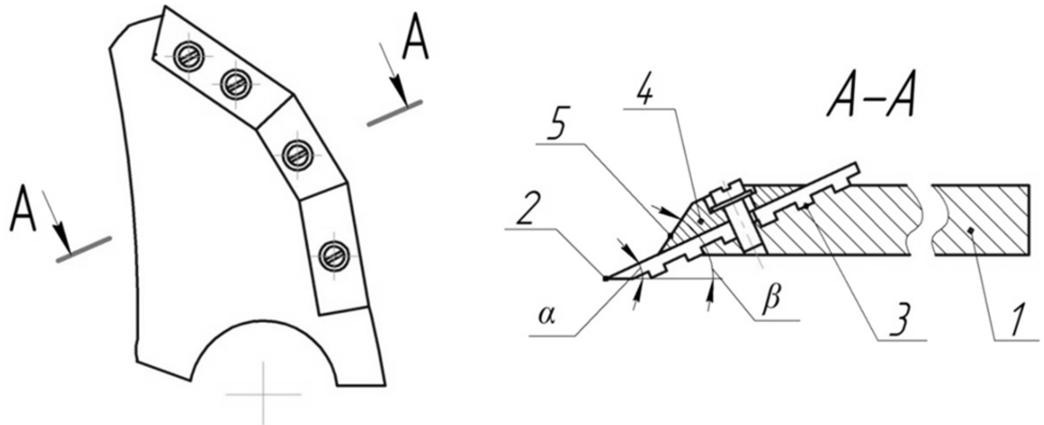
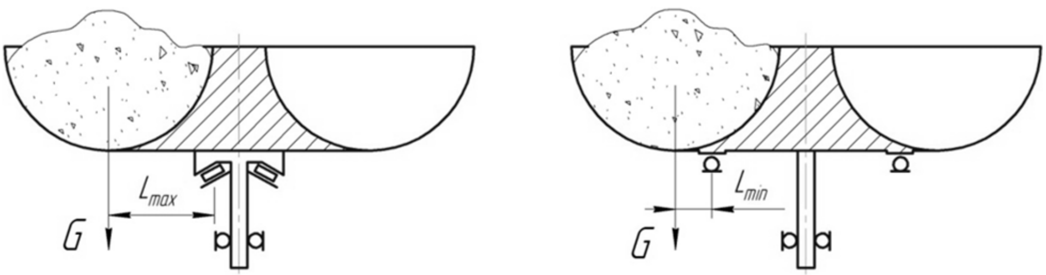


Fig. 13. Knife for cooked sausage products: 1 – body; 2 – blade; 3 – teeth; 4 – overlay; 5 – dispersing surface.



(a) (б)

Fig. 14. Origination of a bending moment from the weight of raw material when it is loaded into the bowl: (a) for a bowl with conventional bearing assemblies; (b) for the bowl of the cutters made by LaskaMaschinenfabrikGmbh with a thrust bearing with an increased diameter.

The durability of bearing assemblies of the bowl is quite high (24 months or more). Its reduction is mainly due to the slant of the bowl in the case of the asymmetrical arrangement of raw materials therein. This arrangement of raw material takes place when it is loaded into the bowl (Fig. 14) by means of a mechanical floor trolley lifter – the weight of raw material *G* acts at a distance *l* from the bearing assemblies, which results in the origination of a bending moment. In this case, the shaft bearings of the bowl work under worsened conditions and quickly fail. Some specialists of the Austrian company Laska Maschinenfabrik Gmbh have proposed the use of a thrust bearing of a considerably increased diameter and special design in the bowl supports (Fig. 14b). This makes it possible to significantly reduce the arm l_{min} in comparison with the bearing assemblies of a standard design (Fig. 14a), which significantly increases the durability of the bowl drive system. The bowl in CutMaster cutters made by GEA is mounted directly on the gear shaft, in this case, the durability of bearing assemblies is more than 9 years.

The cup itself wears out along the surface furthest from the rotation center during operation. Such wear out is caused by the effect of meat raw materials, which, when ground in the cutter head, acquires a high velocity in the direction of about 45° relative to the axis of the cutter shaft (the feed rate is close to the cutting speed, i.e. 70–150 m/s). Such wear out is intensified by the action of raw material surfactants. When the knives are destroyed, the bowl can sustain the most severe mechanical damage. Types of damage and repair are given above (see Fig. 1).

The durability of belt drive belts of the cutter shaft drive and the bowl drive (if a gear-motor is not used for the bowl drive) is 6–12 months. The duration value is determined, mainly, by the culture of operation of the belt drive (the tension of the belts with the appropriate force, preventing the ingress of chemically active substances on the belts, etc.).

Modern cutters use motors with a power from 30 to 320 kW and higher. The electric motor of the cutter shaft drive operates under rather severe conditions: high starting moments (in the absence of a frequency converter in the drive), high air humidity, frequent starts and stops (every 5–7 minutes), the insufficiently effective cooling in high-capacity cutters, etc.

The electric motor bearings are replaced on average every 36 months at a special plant. To this end, the electric motor is dismounted from the machine. The brushes of the electric motor are replaced every 12–24 months. An increase in the durability of the electric motor of the cutter shaft can be provided by the use of a frequency converter in the drive. It will ensure the smooth startings of the engine, by the effective forced cooling of the engine during operation (air or water cooling as in Seydelmann cutters), reduce the moisture condensation in the engine windings (for this purpose, the forced heating of the internal volume of the electric motor during down time is applied for Seydelmann cutters).

The electrical and electronic modules of the cutter, including the control panel, most often fail because of the high humidity in the room, due to the negligent operation of the cutter (the unauthorized actions of personnel during the sanitary treatment of the machine, or mechanical damage) and abnormal situations in the supply network of a meat processing plant. As a repair, the replacement of electrical or electronic components is used.

It should also be noted that the overhaul of a cutter under conditions of its operation is not provided at a meat processing plant. As the parts and assemblies wear out or fail, they are replaced with new ones, the replacement thereof is carried out at different times. If it is necessary to pick up a cutter from a meat processing plant, it reguires four workers (10–16 working hours), one specialist (about three working hours), at the same time, one or two fork lifters, a cargo crane, and a lorry (with a semitrailer) with a capacity of 20 tons should be used. Sometimes picking a cutter up is followed by the dismantling of the ceiling, or walls. The similar forces should also be used when returning the cutter back to the plant.

In general, it can be noted that a cutter remains one of the most important, in the technological sense, machines for making sausage products. The high demand for it in production and its high cost stipulate the increased demand for the durability of its assemblies. The components that operate under the most stressful conditions are knives, a cutter shaft and its bearing assemblies, and the electric driving motor of the cutter shaft. At the same time, the durability of most cutter assemblies is limited by the quality of operation of the cutter head and the durability of the knives.

CONCLUSIONS

The expenses for the repair or replacement of cutter assemblies can amount to tens of thousands of euros (not including the losses caused by equipment downtime). Applying the appropriate technical solutions and rules of operation of cutter systems can significantly increase the durability of a cutter and reduce these costs.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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