STUDY THE HARDNESS AND FIRMNESS INDEXES OF THIN LAMELLATE KNIVES

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ABSTRACT

The article covers technological stability of thin lamellar knives in terms of accuracy in size and shape of cut blanks, identifies main reasons for the deviation of the cutting edge from the cutting plane, structural diagram of lateral deviation of lamellar knife and experimental setup have been developed.
Keywords: static stability, diagram of technological efforts, thin lamellar knife, cutting edge, inertia forces, knife tension, strain transducer, knife stability.

INTRODUCTION

Accuracy of the dimensions obtained during cutting blanks is determined by ability of cutting body to resist the loads acting on it during operation, which is assessed by its rigidity and stability. Rigidity is characterized by the deflection of knife under the action of lateral force, stability is the ability of knife to maintain a flat shape of blade curvature under the action of cutting and feeding forces.

Static and dynamic stability should be distinguished when studying the work of cutting bodies. Static stability is estimated by the value of critical force at which the blade web loses its flat shape and bulges to the side. Dynamic stability is determined by conditions of occurrence under the influence of variable loads in the process of cutting resonant parametric oscillations of lamellar knife, in which it loses the ability to resist cutting and feed forces, and maintaining the straightness of the cut becomes impossible.

MAIN PART

Diagram of technological forces arising when cutting food half-finished product with a lamellar knife located at γ angle to the vertical and moving at U_1 speed is shown in Fig. 1. Material to be processed is fed horizontally at U_2 speed. The total cutting effort $R=R_1+R_2$ is deflected from the normal to the blade nn by the cutting friction angle $\mu=arctgR_1/R_2$ [3]. Feed effort vector R_2 is decomposed into R_2' and R_2'' components.

$$R_2 = R\frac{\cos\mu}{\cos\tau} \qquad (1)$$

From OR_1R triangle by sine theorem:

$$R_1 = R\frac{\sin(\gamma-\mu)}{\cos\gamma}; \qquad (2)$$

In the opposite direction the following vector acts

$$R_2'' = R_2 \sin\gamma = R\,\mathrm{tg}\gamma\cos\mu \qquad (3)$$

At vertical arrangement of knife in the cutting machine or device, the formulas for normal and tangential components of the total cutting effort will be obtained as a special case, taking $\gamma=0$

$$R_1 = R\sin\mu;\quad R_2 = R\cos\mu; \qquad (4)$$

Thin lamellar knife can work only if tensile forces N are applied to its blade (Fig. 2), which impart the necessary stability (rigidity) to the cutting edge. Tangent component R_1 practically does not affect the stress state of the blade, because $R_1 \ll N$. Possible loss of stability and deviation of the cutting edge from the cutting plane occur under the action of forces R_2 and R_3. Normal component of the total cutting force acts in the plane of greatest rigidity of lamellar knife and produces its bend in this plane. The blade of knife is in a stable state under the action of this force until its value reaches a critical value, at which the blade loses the stability of its flat bend and bulges to the side. The rigidity of the lamellar knife becomes equal to zero at a loss of stability.

If $R_2 > P_{кр}$, then there is a walk of cutting edge in the form of oscillatory movement of its blade in the plane of least rigidity.

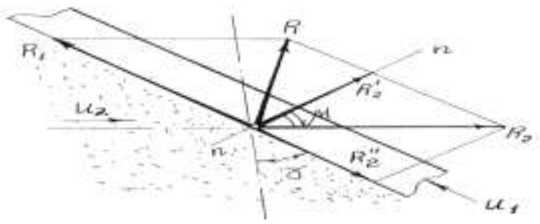

Fig. 1. Diagram of technological efforts arising during sliding cutting of food half-finished product with lamellar knife

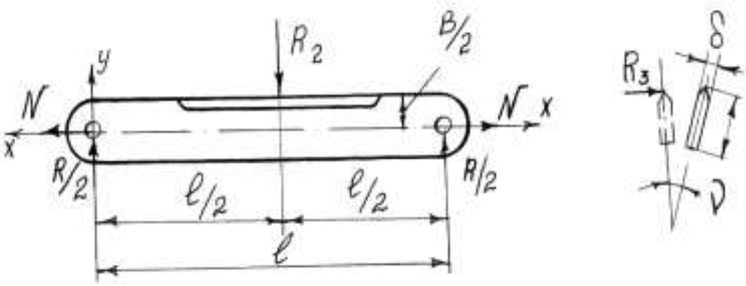

Fig. 2. Scheme of applying efforts to thin lamellar knife when calculating the stability of cutting edge

To determine the critical force $P_{кр}$, upon reaching which there is a loss of stability of pre-stretched strip, the following formula can be used [2.5]:

$$P_{кр} = \frac{\pi^2 N}{1}\left(\frac{R}{12} + \frac{G\delta^3}{3N}\right) \quad (5)$$

where: G is modulus of elasticity of knife material during torsion.
When using this calculation scheme, we will assume as an assumption that normal component R_2, acting under normal cutting conditions as uniformly distributed load, is concentrated and applied in the center of the span l. The lateral effort R_3 is caused by different cutting conditions along the edge of blade due to the unstable taper angle, possible curvature of the cutting edge, and different roughness of the chamfer surfaces. This is due to inaccuracies in formation of cutting edges, i.e. crumble and twists of blades, bluish and other grinding defects [1].
In total, all these reasons give very low values of the lateral component of R_3, in particular, significantly inferior to the value of R_2, but it should be noted that the direction of action of R_3 coincides with plane of least rigidity of a thin lamellar knife. This leads to a high sensitivity of the cutting tool to the action of this component of the cutting force.
In the process of operation, lamellar knives, in addition to effect of cutting and feed efforts, static loads from the tension of the cutting elements, also experience significant inertial loads due to the reciprocating movement of working bodies and depending on the parameters of cutting mechanism drive and the mass of the knife frames. Inertial loads cause vibrations of the body and components of machine, and reduce its durability and accuracy of processing of raw materials. These loads are highly dependent on the cutting conditions.
The main feature of cutting modes with lamellar knives is their variable movement speed U_1, conditioned to the reciprocating movement of cutting tool, and the constant feed speed of half-finished product. Such technological cutting process can be represented as consisting of 2 movements:
a) progressive movement of material at a feed speed: $x = U_2 \cdot \tau$.
b) reciprocating movement of the knife:

$$y = r(1-\cos a) \quad (6)$$

where r is the radius of crank, a is the current angle of crank rotation.
In this case, we assume that the ratio of r to the length of connecting rod is sufficiently small.
Summation of these two displacements in stationary coordinate system gives a complex resulting movement along sinusoid with absolute speed:

$$U = \sqrt{\left(\frac{dx}{d\tau}\right)^2 + \left(\frac{dy}{d\tau}\right)^2} = \sqrt{U_1^2 + U_2^2} = \sqrt{r^2\omega^2 \sin\omega\tau + U_2^2} \quad (7)$$

where ω is crank angular velocity, s^{-1}
Neglecting part of the mass of the connecting rod, the inertia force of the working body with lamellar knives can be determined by the formula:

$$P_u = -ma, \quad (8)$$

where m is the mass of reciprocating-translational moving parts of the cutting machine or device; a is lamellar knife acceleration.

The drive of cutting mechanisms of most designs of machines with lamellar knives is carried out according to the scheme of the central crank mechanism. In this case, the amount of acceleration is determined by the well-known formula:

$$a = \omega^2 r(\cos\alpha + \lambda\cos2\alpha) \quad (9)$$

Substituting formula (9) into (8) we have:

$$P_u = -m\omega^2 r(\cos\alpha + \lambda\cos2\alpha) \quad (10)$$

If we denote ($-m\omega^2 r$) by C, then formula (10) can be shown as:

$$P_u = C(\cos\alpha + \lambda\cos2\alpha) = C\cos\alpha+\lambda C\cos2\alpha) = P_{uI}+P_{uII} \quad (11)$$

Thus, the force of inertia P_u of cutting device with lamellar knives can be represented as the sum of inertial forces of the first and second orders, which vary according to the harmonic law depending on the angle of rotation of the crankshaft, and is primarily determined by the speed of rotation of the crankshaft , mass and size of knife stroke. The forces of inertia reach a maximum at the extreme points of movement of the lamellar knives due to their intense transverse-bending-torsional vibrations. At the same moment, the normal component R_2 also reaches its maximum, since μ=0 and R_2=R. Inertia forces do not directly affect the blade knives, i.e. are not technological efforts, but act on their attachment points and the cutting body of the machine as a whole. With its insufficient rigidity under the action of inertial forces, dynamic deformations of the fastening appear which reduce the tension forces of the lamellar knives and thereby reduce their rigidity. The largest lateral deviations of the cutting edge are possible when resonance conditions occur, i.e. in the case when the frequency of natural vibrations of the knife $w_н$ coincides with the frequency of forced vibrations w or the frequency of reciprocating movement of working body of the cutting machine: $\omega_н = \omega$.

Hence, it can be seen that the ability of the knife to resist the action of lateral forces, estimated by the value of rigidity j, under which we understand the ratio of the concentrated lateral force R_3 applied to the cutting edge of the knife perpendicular to the blade, to the value of deflection of the knife in the direction of the force action, will differ significantly depending on the cutting conditions used.

The need for experimental verification and refinement of the existing methods for determining $P_{кр}$ and $j_н$ is justified by the peculiarities of fastening the blade knives in the knife frame, their relatively small thicknesses, and special sharpening. In the general case, the rigidity of the lamellar knife was determined from the expression.

$$j = \frac{R_3}{y}; \quad (12)$$

If in this case R_2=0, then the calculated value corresponds to the initial rigidity $j_н$. If R_2 - 0 and $R_2<P_{кр}$, then this characteristic is the working rigidity $j_р$.

The stability of the knife was characterized by the value of the critical force $P_{кр}$. Under the critical force, we mean the ultimate load acting in the plane of the greatest rigidity of the knife, upon reaching which the knife loses the stability of the flat form of bending [4].

Empirically, a nonlinear dependence y=f(R_3) has been established, which is primarily due to the displacement of the point of application of the load relative to the longitudinal axis of lamellar knife and the points of its attachment. To unify all experiments in this series, a constant lateral deviation of the cutting edge y = 1 mm was chosen, which corresponded to different values of R_3, depending on the initial parameters of the knife (thickness and width of the blade, length, magnitude and eccentricity of the tension efforts). Thus, in each experiment of this series, after reaching y = 1 mm, the value of the force R_3 was fixed.

Experimental dependence of initial rigidity of lamellar knife on the tension force N for different thickness of the working bodyδ is shown on Fig. 4. As can be seen from the graph, tension is more effective in terms of increasing the rigidity of knives with a minimum thickness. If we approximate the experimental curves up to the intersection with the ordinate axis, then it can be noted that knives with a thickness of δ≥0.5 mm have a certain initial rigidity in the absence of tension. This is true for knives with a length l=250 mm and a blade width B=15 mm.

Hence, it can be seen that finding the experimental dependence j=f(l) at N=0 allows to objectively determine the geometric characteristics of the cutting tool corresponding to the concept of "thin lamellar knives". In this series of experiments, the tension mechanism (Fig. 3) was not used. Knives, the thickness d of which varied in the range 0.2 - 1.6 mm, and the length l was 50 - 380 mm were studied; web width B = 15 mm.

Obtained experimental dependences of this series of experiments (at B = 15 mm) are shown in Fig. 4. Hence, it can be seen that at N = 0, the initial rigidity of lamellar knives noticeably decreases with increase in their length. This is especially true for δ ≥ 0.6 mm.

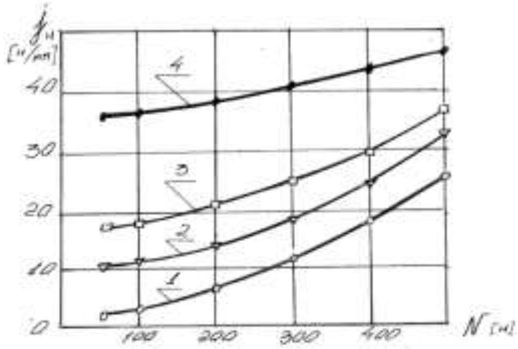

Fig. 3. Effect of tension on the initial rigidity of the lamellar knives 1- δ = 0.2 mm; 2- δ = 0.6 mm; 3- δ = 0.8 mm; 4- δ = 1.6 mm.

If we introduce into consideration the value of the normalized rigidity j_0, i.e. the minimum allowable value of this characteristic (Fig. 5), then it is obvious that the parts of the curves below the line j_0 = const. correspond to those lamellar knives, whose operation, according to the conditions of ensuring a stable cut surface without tension, is impossible. Thus, the corresponding geometric characteristics of the cutting tool correspond to the concept we have introduced "thin lamellar knives".

For the cases of cutting bread, rusks, macaroni, flour confectionery products, the value of j_0 should be taken equal to 35–45 N/mm. From this it can be seen that almost all knives with a thickness of δ<1.0 mm need tension. Experiments have shown that the working rigidity decreases with an increase in R_2 (Fig. 5).

These data confirm the accepted assumption about the dependence $j_p=f(R_2)$ in the form of parabola $j_p=AR_2+B$.

To determine the working rigidity of a lamellar knife, it is necessary, in addition to the initial rigidity, to know the stability of the knife, characterized by the value of the critical force $P_{кр}$

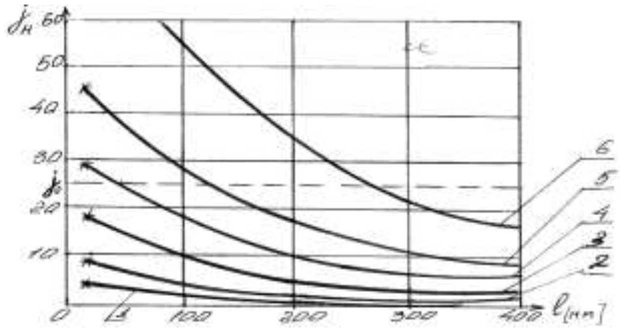

Fig. 4. Dependence of initial rigidity on the length of lamellar knife
1– δ = 0.2 mm; 2– δ = 0.4 mm; 3– δ = 0.6 mm;
4– δ = 0.8 mm; 5– δ = 1.0 mm; 6– δ = 1.6 mm.

Justification of the choice of the normalized rigidity j_0 is a difficult task, since a complex of hard-to-account factors indicated above determines this value.

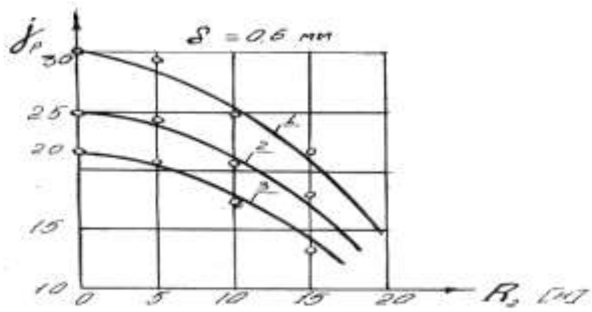

Fig. 5. Dependence of the operational rigidity of lamellar knife (δ=0.6мм) from the value of R_2.
1) N=400 H; 2) N =300 H; 3) N =200 H.

CONCLUSIONS

Technological reliability of thin lamellar knives in terms of dimensional accuracy and shape of cut blanks depends on the rigidity and stability of the cutting tool. The main reasons for deviations of the cutting edge from the cutting plane are revealed. Methodology has been developed, measurements of critical force $P_{кр}$, initial $j_н$ and working $j_р$ rigidity of thin lamellar knives have been carried out. The calculations and experiments carried out have shown that the thickness δ is the most significant factor influencing the operational rigidity and stability

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