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ANALYSIS OF CUTTING PROCESS OF PLANT MATERIAL

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Summary. an analysis of the cutting process of plant material was presented in the aspects of an influence of the geometrical and kinematical parameters as well as the properties of plant material on the quality of cutting.

Key words: cut, sharpness, edge geometry

INTRODUCTION

The cut of plant material is in many machines one of the main aspects of the technological process. Even with a use of an elementary edge it is a very complicated process. Under the pressure of knife edge there follows the crushing of material in the sphere of edge and next the cutting of fibril (in the case of fibril material), separation of the solid part, deviation from surface of the knife attack and deformation. The knife hits on its way on the resistance resulting from the mechanical properties of tissue and friction between the material and knife.

One way of the determination of the force in the cutting process is not to separate many components of forces (cutting) on the point of the component of force affixed to the edge [Czyżyk E. et.al., 1982]

The aim of this article is to present the research and general theory of cutting the plant material.

FORCE RESISTANCE OF CUTTING PLANT MATERIAL

Force resistance of knife movement during the cutting of plant material is often described by a general parameter – elementary resistance of cutting. This parameter is defined by the force accruing to length unity of the active cutting edge of the knife [Diakun and Tesmer, 1986].

According to Goriaczkin [Goriaczkin, 1936] the elementary normal resistance of cutting is given by the formula:

$$q = \frac{1}{b_1}\sqrt[3]{\frac{c_o}{s_1}} - [\frac{N}{m}] \tag{1}$$

whenever the value of the elementary normal resistance is determined:

$$S_n = \sqrt[3]{\frac{c_o}{s_1}} \tag{2}$$

where:

b_1 – the length of point of contact edge with product,
s_1 – the way of edge slide,
c_o – constant, characterized by the hardness of the product.

A large influence on normal and tangential cutting force is exerted by the angle of edge and angle of gradient of the leading edge [Zastępmpowski M. and Bochat M. 2005]. The own research [Niedziółka and Szymanek, 2003] and Figla and Frontczaka [Figiel and Frontczak, 2000 and 2001] showed, that the least value of cutting force occured at edge angle of 20° and angle of gradient at 30°.

The value of cutting resistance in the anisotropic material is dependant on the position to cutting area [Ajayi and Clarke, 1989] and the edge thickness [Żuk, 1998]. To reduce the resistance of cutting stalk material knives with nicked edge are used [Pawlicki, 1996].

Goriaczkin [Goriaczkin, 1936] found a significant difference between normal (the normal movement of edge S_n) and kinetic cutting (the movement of edge in two reciprocally direction – normal $_n$ and tangential S_t). The comparison of these two kinds of cutting showed that in the second case the reduction of necessary force P_n, is characteristic of the cutting process. It is caused by the tangential movement of edge S_t in the cutting material.

The notion of coefficient of slide *E* introduced by Goriaczkin, which presents the relation tangential V_t to normal V_n component of edge speed, showed the size of estimation result of a sliding edge in the cutting process.

$$\varepsilon = -\frac{V_t}{V_n} = -tg\tau \tag{3}$$

The angle between the direction of edge speed *V* and its normal component V_n was termed by Goriaczkin as angle of sliding.

The movement of sliding takes part in the process of cutting. This is interpreted so that even a carefully made edge has irregular space ledges which are dipped in material like sawtooth. The particles of material are seized by an uneven edge that tries to pull it behind. Between particles the stretch tension is formed instead of the compression tension, which happens at normal cutting.

Goriaczkin in research of a theoretical reason of the effect of decline of normal pressure edge for material realized the similarity of the cutting process slide to movement of substance on slopping surface under action of normal forces. His analysis concluded that by cutting with slide a part of friction force is transferred from normal directions – parting material. As a result of this the edge goes easier through the mass of material.

Another researcher [Kanafojski and Karwowski, 1980, Kośmicki Z., 1996] reported that by cutting with slide the material of large cutting area showed a decrease in resistance to cutting as a result of change of action direction in the friction force of the side knife. At normal cutting the resultant of resistance *W* is an algebraic sum; identically directed component of deformation resistance parting material and friction resistance side knife. However at cutting with slide the component W_l is an algebraic sum of the mentioned forces because their components are not lying on one right line.

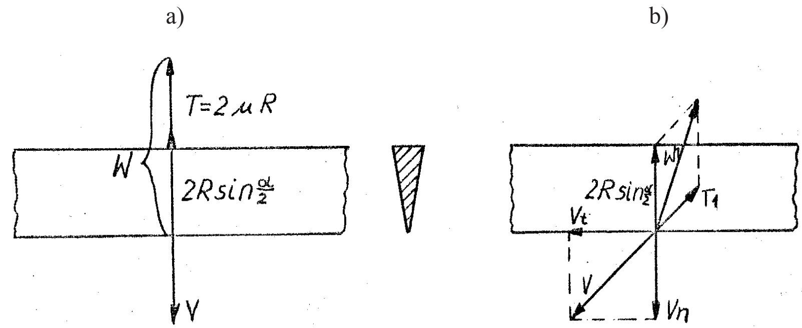

Fig. 1. The resultant of resistance (W i W_1) at : *a)* normal cutting, *b)* cutting with slide

Zeligowski [Zeligowski, 1940] in his work developed the theory of cutting edge, that allows for a wider study of the physical basis of technological cutting process. In slide cutting he indicated two kinds of cutting: the cutting with lengthwise movement and with slide. In the first case the direction of normal resultant force P_n and P_t is the component of cutting forces $P = \sqrt{P_n^2 + P_t^2}$ up to final direction $S = \sqrt{S_n^2 + S_t^2}$ of the movement of edge. In the second case this force area is not up to it and an angle is created in between (Fig. 2.)

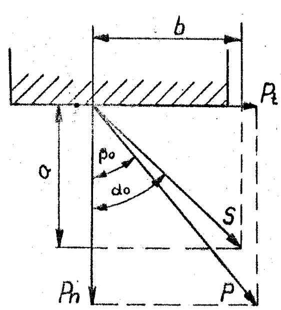

Fig. 2. Distribution of forces and resultant directions S of the knife movement

As a result of anisotropy build of most of the materials in the cutting process the value of this angle incessantly changes so that kinds of slide cutting can cross one to another. Zeligowski declares that the decrease of P_n force necessary to begin the cutting of the P_t force increases in size so that the resultant has an approximately constant value $P = \sqrt{P_n^2 + P_t^2}$. At some change, the relation of P_n to P_t changing direction S of the edge movement is more or less compatible with the change of edge direction P. The β_o is in the range of. In the case of equality of the angles there is no slide of edge to plant material but only its displacement in edge direction. The new destination is the base of value b/a, namely the coefficient of lengthwise displacement cutting surface of material. Zeligowski gives the following formula;

$$\frac{tg\alpha_o - tg\beta_o}{tg\alpha_o} \tag{4}$$

This expression showed that a large influence of slide movement on the cutting process can appear only at a particular value of angle .

In the cutting process two stages can be indicated: of material crushing by edge and direct cutting. The primary cutting resistance after initial material crushing and relation between forces is shown in Fig. 3.

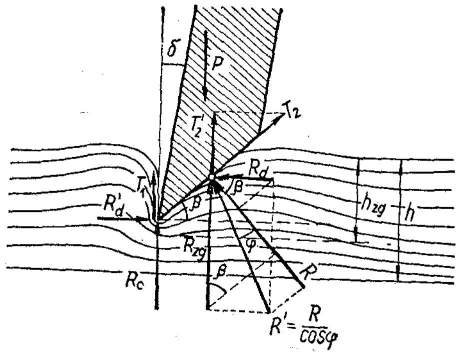

Fig. 3. The forces acting on a knife in initial cutting of the material of thickness *h*: T_1 – the friction force of knife edge by material, T_2 – the friction force of affixed surface, R_c – the material reaction at cutting, R_{zg} – the reaction at edge pressure to material, h_{zg} – the thickness of layer crushing by edge, h – the thickness of material before cutting, β – the contiguous angle of edge, δ – the inclination angle [Bochat and Grzonkowski, 2005]

To reduce the friction of frontal knife surface at cutting section plane it is placed at an angle. The summary pressure force of the edge is:

$$P = \Delta\sigma_c + \frac{E}{2}\cdot\frac{h_{zg}^2}{h}[tg\beta + \mu\sin^2\beta + \mu^{'}(\mu + \cos^2\beta)] \tag{5}$$

In this expression only the first component showed the useful force which is needed to realize proper cutting.

For a variety of the plant material the value of can be set only by experiment.

$$\sigma_c = -\frac{Rc}{\Delta} \tag{6}$$

where:
R_c – the reaction of material to its cutting,
Δ – the surface of edge.

The value of tension at cutting is not only dependant on material but also on sharpness of the edge. The second component determines all idle resistancy. It is proportional to the square of initially crushing of the edge knife. Reznik [Reznik, 1970] in his researches showed that the value h_{zg} increases proportionally to the value *h* and its efficiency is higher at compacter and thinner surface of the material under knife.

The researches of Kanafojski and Karwowski [Kanafojski and Karwowski, 1972] [Kanafojski and Karwowski, 1972], Diakona and Tesmera [Diakun and Tesmer, 1986], Żuk [Żuk, 1998] and [Niedziółka and Szymanek 2004] showed the reduction of mean cutting resistance along with an increase in its speed. This is interpreted that in plant material as plasticity – elasticity substance the speed of transmission of the tension in depth layer is low. As a result of this when the knife hits with a large force then the tension in material arises closer to the edge. The acceleration and the inertion of particular layers of material increases. As a result the value of force P increases and at the same time there is an increase in the coefficient of useful work η_c.

$$\eta_c = -\frac{A}{A+A'} \tag{7}$$

where:
A' – work of crushing,
A – work of cutting.

The role of cutting speed decreases when the beat of knife encounters a previously crushed layer.

The research of cutting plant material showed that the coefficient is η_c near to unity at the speed of knife 35 – 40 m/s [Reznik, 1970].

THE SHARPNESS OF EDGE

In the cutting process an important role is played by sharpness of edge which is characterized by geometrical parameters of its curb. There is no uniform opinion what belongs to it accept for sharpness indicator. There are a lot of grounded points of view but all of them are based on the conjecture that in circuit of edge profile can be written the circle. The working edge, which is even slightly blunt, has a ragged curb of cylindrical surface. The most researchers propose to estimate the sharpness of edge by diameter of the circle δ_1 written in the circuit of its profile [Reznik, 1970]. The others accept for an indicator the chord of an arch δ_2 which is formed by contact of the circle with edge (Fig. 4).

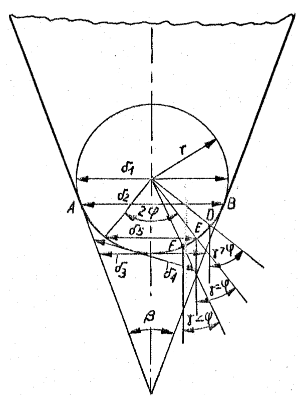

Fig. 4. The parameters of curb edge

Goriaczkin [Goriaczkin, 1936] defined the edge sharpness by leg δ_3 which is tangential to the written circle. There is normal to bisectrix of sharpened angle β and is limited by two straight lines being an extension of edge bevel. The sharpness of asymmetrical consumed edge is measured by leg δ_4 which is tangential to the written circle and is normal to the line of the less wasted bevel. Zeligowski [Zeligowski, 1940] is confident that the sharpness of knife edge by chord δ_5 which is formed through the cutting angle, is equal to friction angels 2φ, in the written circle edge. The geometrical parameter of the edge profile, which is accepted for indicator of its sharpness, should be estimated by two points of view:

- the role which it plays in the physical destruction process of material,
- the possibility of the sufficiently precise measurement of the parameters by methods that are practically attainable.

Table 1 shows the parameters value of the edge sharpness.

Table 1. The parameters value of edge sharpness [Zeligowski, 1940]

Parameters of edge profile	Angle °β	Value of parameter in μm at r = 50 μm
$\delta_1 = 2r$		100
$\delta_2 = 2r\cos\frac{\beta}{2}$	30	96,59
$\delta_3 = 2r\frac{l-\sin\frac{\beta}{2}}{\cos\frac{\beta}{2}}$		96,70
$\delta_4 = r(l+tg)\frac{90-\beta}{2}$		78,87
$\delta_5 = 2r\sin\varphi$	$\varphi = 42$	66,90

The difference in the parameters value does not exceed 30 -35%, so all of them are characterized by the sharpness of edge. However the rightness is not the same. The parameters δ_2, δ_3, δ_4 are not only dependant on radius but on the angle of sharpness.

On the basis of Table 1 and Fig. 5 we can determine that at two edges of equal radius this edge will be sharper, the angle sharpness of which is blunter.

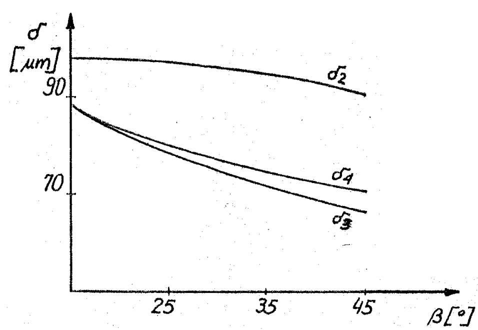

Fig. 5. The knife sharpness parameters δ_2, δ_3, δ_4 dependence of angle β

At increase of the sharpness angle β the force, which is useful to cutting, is decreased while the edge ability to cut is increased [Kanafojski and Karwowski, 1972]. It denies the logic and does not allow to consider the edge sharpness as independant parameter which defines the contact surface of curb and it is formed in the material destroying tension which is conditioning the cutting process.

Sieow [Sieow, 1971] behind Zeligowski states that this surface should be considered as the part of edge curb which is able to put pressure on the cutting material with the sum of forces acting in the area of displacement of cutting point of edge. As a result, beating of the knife without slide of the edge should press the layer of material whose thickness is equal to chord δ_5. The angle γ between normal to surface of curb and the directions of the edge movement in free point *G* is smaller than the friction angle. In the point *E* of cross-cut the arch and chord δ_5 have the angle $\gamma = \varphi$. Reznik [Reznik, 1970] thinks that in the range of this arch there is no slide of material at curb and it appears in free point of *b* where the angle $\gamma > \varphi$. In this case the curb of edge should not undergo destruction while just this part of edge is most destroying. This two departures from reality testify that the physical bases of the cutting process are very complicated. It is not possible to explain the material destruction at its crush by the edge.

The slide of the material of the curb edge is even in the range of arch 2φ.

All curbs of edge take part in the cutting process of material and there are no grounds to accept for sharpness the parameter δ_5 only for this reason that in its range the destroying crush arises. It is also not acceptable in this case because during penetrating the anisotropic material of edge the coefficient of friction and related with it the angle is changing all the time. At accepting the parameters of sharpness $\delta_5 = 2r^3 \sin\varphi$ there should be considered the constant parameters of edge for the variable size.

The estimation of sharpness helps to determine radius *r* or diameter $\delta_1 = 2r$ in the cycle which is written in the profile of its curb as correct and practically acceptable. The diameter depends neither on β angle nor the coefficient of friction μ of the material. It is important that for all considerations the indicators of sharpness of the size knife δ_1 is the most accessible to practical designation.

CONCLUSION

It results that in the cutting process the elementary value of resistance at plant material cutting depends on geometrical parameters (speed of dipping the knife into material, speed of sliding the edge) and on parameters which are characterized by the condition of the material (consistency). The influence of these parameters causes that for specific material the elementary value of cutting resistance is given in determined limits.

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