CUTTING OF MULTI-LAYERED PRODUCTS IN FOOD INDUSTRY

V. GUTS, O. GUBENIA*

Abstract: *Most food products and some packaging materials are laminated, or have inclusions that are different structural and mechanical properties. Feature cutting multi-layer materials - increase efforts at resistance movement knife to approaching blotches. The technique of cutting research, conducted modeling the blade in multilayer products, conducted experimental research. In the results obtained a number of mathematical models of cutting in the form of second order differential equations that allow to determine the cutting force and speed of the blade in the product.*

Keywords*: cutting, food, packaging materials, multi-layer materials, force, mathematical modelling.*

Introduction.

The food cutting process used in the food industry may serve as a bypassing operation of division of raw material and semi-finished products to pieces of specified shape and size during formation, batching and milling. Cutting may be as a final operation of product making. The front look and the quality of product surface depend on the quality of its execution.

Foodstuff can be homogeneous (a sugar beet, meat without a bone, confectionery weights etc.), and also multilayered, or with impregnations [1,2,4]. Layers or impregnations are strongly connected with the basic volume of a product, but considerably differ the structurally-mechanical properties. For example, it are meat products which have layers from sinewy fabrics, a skin and bones. Vegetables which have a strong external cover.

And many packing materials which consist of layers (cardboard, paper, synthetic fiber, skin) which differ in structure.

The analyses of scientific papers showed that the methodologies for directly detecting the power of cutoff cutting is missing and don't let using the gained results during calculation and construction of cutting equipment.

For determination of cutting power we conducted math and physics modeling. This allowed to determine the main parameter of cutting process – the power of cutting in dependence with the blade speed in the product and mechanical property of the product.

2. Analytical research of the cutting

2.1. Modelling of cutting of homogeneous products.

Let's take a look at the mechanism of cutting process. Let's compose a differential equation which describes the blade movement in the product.

In case of cutting of a homogeneous product on edges forces operate:

- Cutting F_r
- Friction

$$G = C + k_1 V = C + k_1 \frac{dy}{dt} \tag{1}$$

- Inertia

$$P_i = ma = \frac{m\,d^2 y(t)}{dt^2} \tag{2}$$

C, k_1 - factors, which характеризируют a friction;
y, V, a – moving, speed and edge acceleration in the product.

Let's write the differential equation of movement of an edge in the product.

$$F_r + G + P_i = 0 \Rightarrow \tag{3}$$

$$F_r + (C + k_1 \frac{dy(t)}{dt}) + m\frac{d^2 y(t)}{dt^2} = 0$$

Having solved the equation (3), we receive the equation for definition of force of cutting depending on speed of the edge and properties of the product:

$$F_r = \frac{k_1 \frac{dy(t)}{dt} - e^{-\frac{k_1 \cdot t}{m}}(C + V_{oy} k_1) + C}{e^{-\frac{k_1 \cdot t}{m}} - 1} \tag{4}$$

Capacity of cutting:

$$N = F_{rm} \frac{dy(t)}{dt} \tag{5}$$

* *National University of Food Technologies, Kyiv, Ukraine,* e-*mail: goots@ukr.net*, *gubena@meta.ua*

F_{rm} the maximum force of cutting.

During cutting force and power of cutting equipment calculations it is necessary to know the specific power of cutting as relation to the power of cutting to the length of the cut L.

$$F_{sr} = F_r / L, \text{ Н/м} \quad (6)$$

Having experimental meanings of specific power of cutting the effort of cut off cutting by lamellate flat knife is being determined.

The detailed analysis of the equation (5,6) it is shown in works [1, 3].

To determine the cutting power with the usage of received math models we developed experimental rigging [*1*] (fig.1). It is simple by construction and safe while using. On the end of the dragonflies 2 blade 4 is placed. Blade during dragonflies falling cuts product 7, which is secured in the fixator 8. Blade speed and its reserve of kinetic energy is easily changed in the wide limits. For this the dragonflies is flinging from various angles, and the placement of load 3 is being changed.

Blade speed:

$$V = R\sqrt{2\frac{\sum P_i r_i}{J}(1-\cos\beta)} \quad (7)$$

P_i – weight of every detail of dragonflies, r_i – distance from the center of the weight of this detail to the axes of dragonflies; β – angle out of which dragonflies is hurling; R – dragonflies length; J – inertia moment of all dragonflies details.

The results of the modeling are undertaken to define the rational regimes of food products cutting. Cutting power is determined by formula (4). The specific cutting power F_{sr} to the blade length is calculated (5). The results are presented on the fig. 2 and 4.

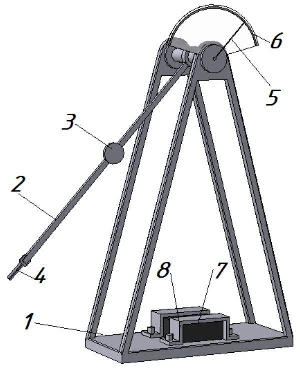


Fig. 1. The scheme of the device for cutting process research:
1 - plate; 2 - dragonflies; 3 - load; 4 - blade; 5 - pointing hand; 6 - scale; 7 - product; 8 – product fixator.

Reduction of the cutting force is happening at the expense of lessening of product deformation under blade edge under its high speeds. It's typical for all viscid, elastic and plastic products.

For comparatively tight and frail products continuous increasing of cutting force at blade speed growth is observed.

The results gained are valuable for determination of work regimes for cutting equipment. Usage of them in practice allows to lower the energy cutting costs, reduce deformation of products and increase the quality of the cuts.

The application of the results of modeling allow optimize the process for many food products. Besides determination of rational cutting regimes with the help of developed methodology it is possible to determine the consistency of the product. The consistency together with other indicators allows evaluate the product quality.

2.2. Modelling of cutting of non-uniform products.

Feature of cutting of non-uniform products which have impregnations or a cover, it is short-term an operating (instant) force, which operates at edge approach to the cover:

$$F_M = Be^{-bt} \quad (5)$$

The equation of movement of an edge for such products:

$$F_r + G + P_i + F_M = 0 \quad (6)$$

Change of instant force is shown on fig. 3. Graphically it is represented as quickly falling down dependence, time of its action 0 – t_1 it is much less movements of blade in a product.

The differential equation of movement of an blade:

$$F_r + (C + k_1\frac{dy(t)}{dt}) + m\frac{d^2y(t)}{dt^2} + Be^{-bt} = 0 \quad (7)$$

Having solved the equation, at entry conditions (t=0 => x (0 =0, V (0) =V_0) we receive value of moving (8), speeds of blade (9) in a product and force of cutting (10).

Change of force of cutting, if cover is presenting, was confirmed experimentally. According to the equation (4) it is received force of cutting of meat with a sinewy layer. The layer was on an input or an exit of an blade from a product. Force of cutting of separately sinewy layer is so small, that was not fixed by devices. But at cutting of meat with a layer average force of cutting increases at layer placing on an exit of an blade from a product (fig. 3).

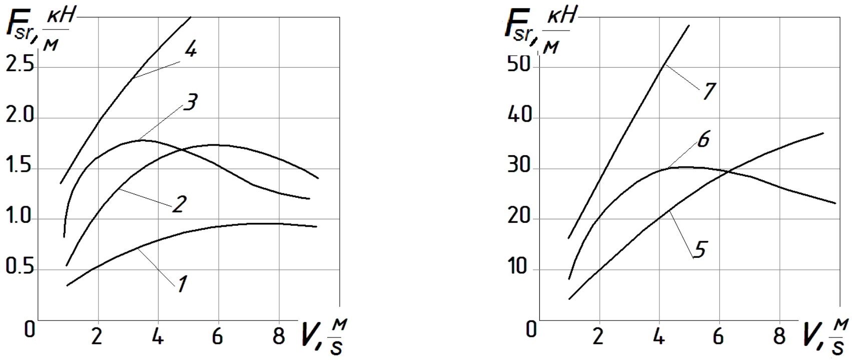
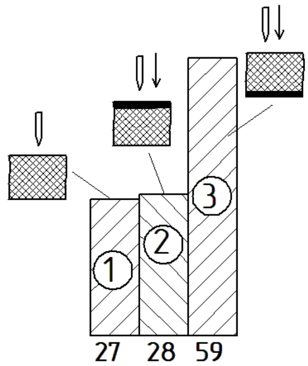


Fig. 2. Dependence of specific cutting power from the blade moving speed in the product during cut off cutting:
1 – crumb of hot bread; 2 – crumb of bread after cooling for 6 hours; 3 – cheese; 4 – sugar beet; 5 – scab bread; 6, 7 – meat (pork) under temperature 5° C and -5°C.



Specific force of cutting, kN/m

Fig. 3. Dependence of force of cutting of meat on placing of a sinewy layer:
1 – without the layer; 2 – the layer on an input in the product; 3 – the layer on exit of the blade from a product.

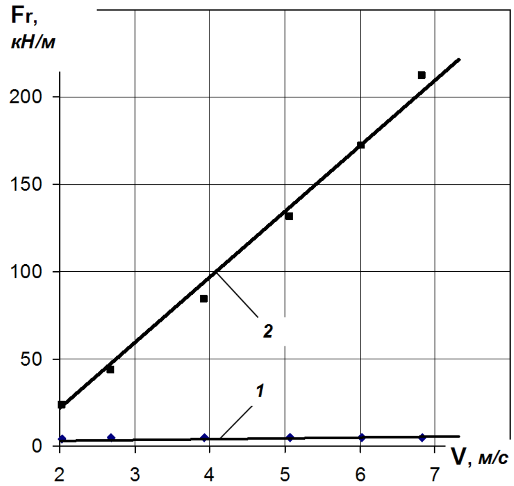


Fig. 4. Dependence of specific force of cutting of porous polyfoam on speed of cutting:
1 – a cover on an edge input in the product;
2 – on an exit of an edge from the product.

$$y(t) = \frac{m(1-e^{-\frac{k_1 t}{m}})(V_0 k_1 + C + F_r)}{k_1^2} + \frac{k_1\left(B\left(1-e^{(bt)}\right) + bt\left(C+F_p\right)\right) - mb(bt(C+F_r) + B(1-e^{-\frac{k_1 t}{m}}))}{(mb-k_1)k_1 b} \quad (8)$$

$$V(t) = \frac{e^{-\frac{k_1 t}{m}}(V_0 k_1 + C + F_r)}{k_1} + \frac{k_1\left(Bbe^{(-bt)} + b\left(C+F_p\right)\right) - mb(b(C+F_r) + \frac{Bk_1 e^{-\frac{k_1 t}{m}}}{m})}{(mb-k_1)k_1 b} \quad (9)$$

$$F_r = \frac{Vk_1mb - Vk_1^2 + e^{-\frac{k_1 t}{m}}(-V_0k_1mb + V_0k_1^2 - mbC + Bk_1) + k_1C - k_1Be^{(-bt)} - k_1C + Cbm}{e^{-\frac{k_1 t}{m}}(mb-k_1) + k_1 - mb} \quad (10)$$

Adequacy of the received models is confirmed and for not food product. For example, presence of a thin polymeric layer on a packing paper increases force of its cutting at 20-50 times under condition of film placing on an blade exit.

To receive exact results for foodstuff difficult as they do not possess constant properties. Therefore as a subject of researches of cutting multilayer materials we used a modelling body – porous polyfoam. The cover role is carried out pasted by a film. Polyfoam on the structure - an is viscous-elastic body, as well as the majority of foodstuff. Dependence of effort of its cutting on a cover arrangement (fig. 4) is received.

The cover arrangement on an exit of an edge from a product increases force of cutting in 50 times in relation to a case when the cover settles down on an edge input in a product or is absent. The work spent for cutting of directly cover, in this case is very small. But, if the cover is located on an edge exit, she creates resistance to product deformation at blade introduction. Thus on a lateral surface of an blade the big pressure operates, and there is a great strength of a friction.

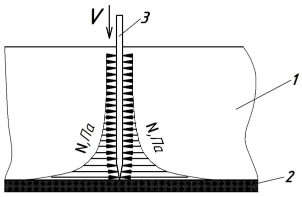


Fig. 5. Change of pressure N on a knife surface:1 – product; 2 – cover; 3 - blade

It is experimentally confirmed, that the greatest resistance to blade movement arises at its maximum approach to a cover. In case of cutting of a modeling body, this distance makes 0.5 – 1 mm. For example, average force of cutting of a modelling body at a thickness of polyfoam of 0.5 mm 82 kN/m, at a thickness have made of 2 mm - 83 kN/m, 20 mm – 85 kn/m (at speed of an edge of 5 m/s). Such law explains exponential dependence of instant force F_M on cutting time *t*.

On the basis of the aforesaid it is drawn a conclusion, that the product structure influences force of cutting. Presence of a cover and its arrangement on an exit of an edge from a product considerably increases force of cutting, therefore so to cut a product irrationally.

Let's consider rational ways of orientation of blade for various types of cutting of products with a cover .

At normal cutting the cover should be on an edge input in a product. Thus the knife easily cuts a cover, and further it does not interfere with product deformation.

The correct arrangement of a knife at cutting under a corner also allows to lower effort of cutting. In the beginning the cover, and behind it a product great bulk is cut.

At cutting by a disk knife under the scheme, if axis of rotation of a knife is placed over product, the cover in the beginning is cut. If the rotation axis is below a cover - there is an additional friction.

Similarly product orientation gets out at cutting tape teeth a knife. It is necessary to notice, that the increase in lateral loading at a knife surface leads to a curvature of a teeth and a deviation of a knife from a correct direction of movement. The product thus is considerably deformed.

Conclusions

1. Force of cutting of products with a cover or impregnations, and also quality of a surface of a cut depends on an arrangement of a cover concerning blade movement.
2. Mathematical models of movement of an blade in homogeneous and non-uniform products on structure. Models allow to define forces, rational modes and ways of cutting was received.
3. Performance of the resulted recommendations for choice orientations of the cutting tool at cutting multilayered products allow to provide high quality of cutting at low expenses of energy.

References

1. Gubenia O., Guts V. *Modeling of cutting of food products* / EcoAgroTourism. - 2010. - N1. – P. 67-71. [Romania]
2. С. Стефанов, Ч. Саздов. *Състояние и тенденции при производството на PET бутилки* / ХВП. № 6, 2009 [Bulgaria]
3. В. Гуць. А. Губеня. *Определение усилия резания продуктов с разными структурномеханическими свойствами* / Научни трудове на УХТ, том 57, свитък 2. – Пловдив – 2010. - С. 411-416. [Bulgaria]
4. Д. Господинов, С. Стефанов, В. Хаджийски. *Влияние контактной поверхности между слоями гофрированного картона на его механические свойства* / Упаковка. – 2011. - № 6. [Ukraine]