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Research paper

Ultrafine Grinding Process Calculation of Meat-Bone by-Product

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Abstract

This paper presents the method of calculating the cutting process of meat-bone by-products using rotary grinders. The cutting process is performed by cutting wheels and is counted according to the calculation of the cutting force, speed of cutting wheels, gap between the wheels and stress of the materials.

Keywords: *meat-bone, grinder, rotor, wheel, cutting process, gap, grinding angle*

1. Classification of meat grinders

In the meat industry one of the major energy-consuming processes is meat grinding process. Keeping the quality and yield of finished products is based on the study of rheological properties, technological parameters and the processes occurring in the grinding processes [1, 2].

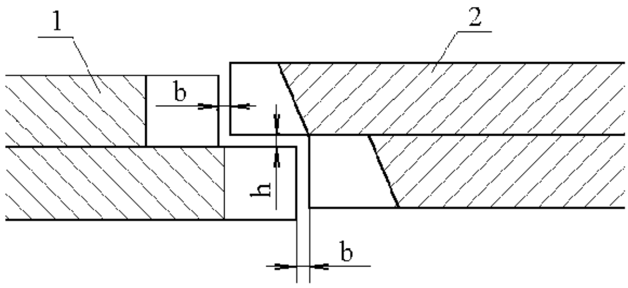
Depending on the grinding construction the ultrafine grinding machines classified as follows:

1. Multiknife grinders, where the set of knives with different shapes are mounted to the shaft inside the grinder.
2. Rotary grinders, where the grinding construction consists of static stator and rotating rotor.
3. Multidisk grinders, where the grinding construction consists of the set of disks with teeth or consequently installed screens with holes.
4. Cylinder grinders, which consist of rotating perforated cylinder with mounted knives [3, 4].

2. Rotary grinders

Rotary grinders are continuous running grinders with static stator and rotating rotor as a grinding mechanism. It is used for grinding dry or viscous materials. This type of grinder is widespread in the food industry because of the compactness and high performance [5].

The grinding angle rotating and stationary knives are 90° (Figure 1), while they are parallel to each other, which eliminates the regulation of the gap *b* between the end surfaces of movable and stationary knives. In addition, the gap increase between these surfaces leads to deterioration of the grinding process of raw materials. When conducting experiments with these knives, we obtained bone particles with a minimum size of 0.5 - 1 mm.



1- rotating knives, 2 – static knives
Figure 1: Knives with grinding angle 90°

Analyzing the operating experience of knives with an end surface of 90°, we can conclude that their main disadvantages are:

1. The absence of a change in the gap between the end surfaces, which makes it impossible to precisely adjust the particle size, moreover, during operation, the end surfaces of the moving and stationary knives wear out and, accordingly, increase the gap between them, which leads to deterioration of the grinding process and ultimately leads to to reduce the quality of the crushed raw materials.
2. The presence of only the process of crushing between the teeth of the cutting mechanism, which leads to the waste of energy.

These drawbacks reduce the throughput and cutting ability of the cutting mechanism and are the reason for the unstable operation of the grinder as a whole [6].

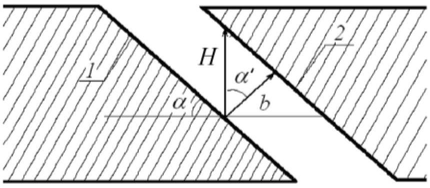
In order to eliminate these disadvantages, it is enough to change the angle of sharpening of the end surfaces of the knives. In this case, the angle of sharpening of the end surfaces should lie in the range from 0 to 90 º.

The gap can be calculated by equation:

$$b = H \cdot \cos\alpha \quad (1)$$

where: H – gap between the stationary and rotating knives;
b - gap between the end surfaces of knives;
α – grinding angle of the end surfaces of knives.

In this case, the angle α' will be equal to the angle of sharpening of the end surfaces of the rotating and stationary knives α, as an angle with mutually perpendicular sides in accordance with figure 2.



1 – end surface of rotating knife, 2 – end surface of static knife
Figure 2: Knives with grinding angle of the end surfaces 45º

If substitute values from the range from 0 to 90 º in formula 66, then it can be seen that the smaller the sharpening angle, the greater the gap between the end surfaces of the knives. Considering the above prerequisites, it can be assumed that the most rational angle of sharpening of the end surfaces of the rotating and static knives is the angle close to 45º. The gap between the end surfaces is calculated with the sufficient accuracy by the formula 2:

$$b = 0{,}7 \cdot h \quad (2)$$

3. Calculation the cutting process

When the knife rotates, the cutting force P acting on the bone particles can be determined by the formula 3 [7]:

$$P = 10 \cdot C_p a^x b^y v^n K_p \quad (3)$$

where, *Cv* - cutting coefficient
a - the width of a bone particle
b –the length of bone particle
v - cutting speed
Kp - coefficient taking into account the actual cutting conditions.

Based on the Carnot theorem, given that the weight of the knife is many times greater than the mass of a particle of bone, the speed of the knife after impact does not change.
Then the cutting speed is calculated by the following formulas 4 and 5 [8]:

$$\omega = \frac{\pi \cdot n}{30} \quad (4)$$

$$v = \omega \cdot R \quad (5)$$

where, *n* - the frequency of rotation of the knife
R- the radius of the knife

Consider the system of interaction of the movable and fixed knives with a particle of bone. When a bone hits between the knives, a shock is applied to the bone, leading to the destruction of a bone particle.
Defining the work performed by the knife, use the following formula 6 [9]:

$$W = J_c \cdot \delta_d \quad (6)$$

where, δ_d - movement at the point of impact C;
J_c - the moment of inertia of the knife.
The moment of inertia of the knife is determined by the formula 7:

$$J_c = \frac{M_k \cdot R^2}{2} \quad (7)$$

In this case, the potential energy of the elastic system will be equal to:

$$U = P \cdot (S + \delta) \quad (8)$$

where, *S* - is the path traveled by the tooth of the knife before impact;
δ - movement of the rod under the influence of force F on it.

Moving the rod is determined from the expression:

$$\delta_{cm} = \delta_1 + \delta_2 + \delta_3 \quad (9)$$

where, δ_{cm} - movement from a statically acting force F;
δ_1 - the shortening of the tooth axis from the action of the longitudinal force Phi is defined as:

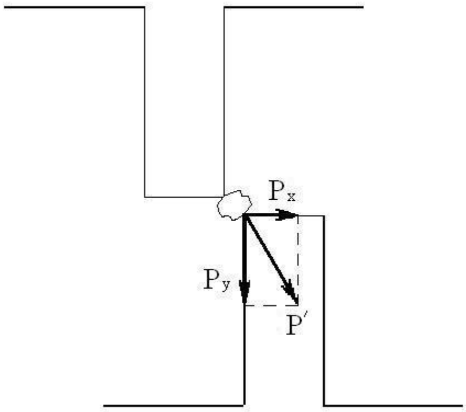


Figure 3: Diagram of the interaction of moving and stationary knives with a piece of bone

$$\delta_1 = P_y l / (E \cdot F_3) \quad (10)$$

F_3 - tooth cross-sectional area;
δ_2 - shortening of the rod axis due to its curvature;
δ_3 - movement of the point of impact due to the rotation of the section.

When the bottom end of the rod is embedded, when the force does not lie on the main axes of the beam, the displacement can be determined by the formula 11:

$$\delta_2 = \sqrt{\delta_x^2 + \delta_z^2} \quad (11)$$

The amount of tooth bending along the x and z axes is determined by the formulas 12 and 13:

$$\delta_x = \frac{P_x l^3}{3E \cdot J_z} \tag{12}$$

$$\delta_z = \frac{P_z l^3}{3E \cdot J_x} \tag{13}$$

where, l is the distance from the place of attachment to the point of force;
J_x, J_z - moments of inertia about the neutral axis.

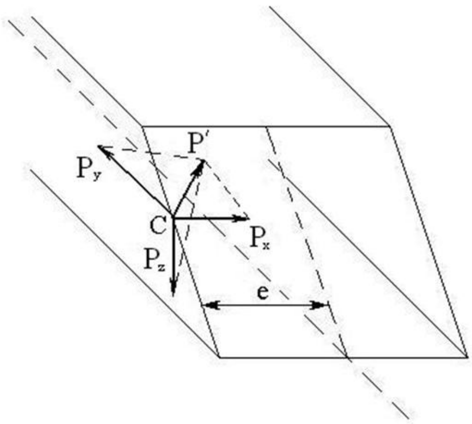


Figure 4: Forces acting on a knife

$$\delta_2 = \sqrt{\left(\frac{P_x l^3}{3E \cdot J_z}\right)^2 + \left(\frac{P_z l^3}{3E \cdot J_x}\right)^2} \tag{14}$$

Movement due to the rotation of the cross section is determined by the formula 15:

$$\delta_3 = \frac{P_y \cdot e^2 l}{(E \cdot J_x)} \tag{15}$$

Considering the displacement from the dynamic action of the load as a static displacement from the force $P = P' \cdot k_d$, we obtain the potential deformation energy of the elastic system as an expression:

$$U = \frac{1}{2} P \cdot \delta = \frac{1}{2} P' \cdot k_d \delta \tag{16}$$

where, k_d - is the dynamic coefficient.

Substituting the expression U in the equation (8) we get:

$$P \cdot (S + \delta) = \frac{1}{2} P' \cdot k_d \delta \tag{17}$$

or

$$2 \cdot (S + \delta) = k_d \delta \tag{18}$$

From equality (18) we get the following expression:

$$\delta^2 = 2\delta_{cm}(S + \delta) \tag{19}$$

Or

$$\delta^2 - 2\delta_{cm}\delta - 2\delta_{cm}S = 0 \tag{20}$$

From here

$$\delta = \delta_{cm} + \sqrt{\delta_{cm}^2 + 2\delta_{cm}S} \tag{21}$$

The traveled path S can be expressed by the ratio

$$S = \frac{2\pi R}{z} \tag{22}$$

where, R - is the radius of the knife;

z -is the number of teeth of the knife.

Then the formula can be represented by the expression:

$$\delta = \delta_{cm} + \sqrt{\delta_{cm}^2 + \frac{2\pi \cdot R\delta_{cm}}{z}} \tag{23}$$

Considering that $k_d = \frac{\delta}{\delta_{cm}}$, and also on the basis of formulas (56), (54), we obtain the following expression of the dynamic coefficient:

$$k_d = \frac{\delta}{\delta_{cm}} = 1 + \sqrt{1 + \frac{2\pi \cdot R}{z \cdot \delta_{cm}}} \tag{24}$$

Considering that:

$$\delta_{cm} = \delta_1 + \delta_2 + \delta_3 = \frac{P_y l}{E \cdot F} + \sqrt{\left(\frac{P_x l^3}{3E \cdot J_z}\right)^2 + \left(\frac{P_z l^3}{3E \cdot J_x}\right)^2} + \frac{P_y \cdot e^2 l}{E \cdot J_x} \tag{25}$$

the highest stress at impact is determined by the formula

$$\sigma = \sigma_{cm} \cdot k_d = \sigma_{cm}\left(1 + \sqrt{1 + \frac{2\pi \cdot R}{\frac{z \cdot P_y l}{E \cdot F_3} + z\sqrt{\left(\frac{P_x l^3}{3E \cdot J_z}\right)^2 + \left(\frac{P_z l^3}{3E \cdot J_x}\right)^2} + \frac{z \cdot P_y \cdot e^2 l}{E \cdot J_x}}}\right) \tag{26}$$

where, σ_{st} - static stress equal to the limiting stress of bone destruction.

4. Conclusion

Considering that this calculation was performed for one tooth while grinding one bone particle, we calculate the number of particles simultaneously ground by one tooth and the number of teeth simultaneously performing work. Since the direct calculation of these data seems impossible, the calculation will be performed using probability theory. At high grinding speeds, the repeatability of events will be quite high, which in turn gives a high percentage of calculation accuracy.

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