Analysis of energy consumption during work of breadcutting machine

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Abstract. *In scientific and reference books there are no designed procedures to determine the drive power of cutting and feeding mechanisms of bread-cutting machines, with a bundle of tape serrated knives.*

Laying on the assaying of the scientific literature, critical parameters of process of cutting of bread are defined such as: rate of cutting and feeding, structurally - mechanical properties, force of cutting, cutting mode. Based on this data an analyze was conducted on the power of mechanisms of the bread-cutting machines, and it was developed a designing procedure of drive power of cutting and transportation mechanisms. The mathematical dependences which were determined allowed us to calculate drive power at known force and rate of cutting, to analyze and optimize expenditures of energy in the machine.

Results of probes could be used in calculation of the cutting equipment and when making a choice on the optimal parameters of work.

Keywords: energy consumption, bread, cutting

1. Introduction.

During operation of the bread-cutting machine with a bundle of tape serrated knives (Figure 1), power is used for the following processes:

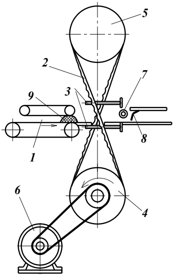

Figure 1. *Bread-cutting machine:*
1 - feeding mechanism; 2 - belt knives; 3 - guide rollers;, 4, 5 - drive and tensioning drums; 6 – drive; 7 – photosensor; 8 - moving mechanism sliced bread; 9 - bread.

1. Starting of a bundle of tape knives.
2. Starting of the conveyor for feeding of bread and pinch conveyor.
3. Starting auxiliary conveyors (the side pinch conveyors, the assign conveyor).

In the scientific and educational literature there are techniques which allow us to define capacity of drives of the bread-cutting machine and to analyze expenses of energy. However, number of modern scientific suggestions, allow us to define the expense of energy for work of the cutting machine. Among them it is necessary to note some results from the researches:

- data about structurally - mechanical properties of bread
- influence of speed of a knife on force of cutting of a grain crumb and crust.
- influence of speed of sliding of bread on lateral surfaces of a knife on a frictional force.
- rational speed of a knife at whom we will receive high quality of a cut under different conditions and modes of cutting

The purpose of the analytical research - analysis of energy costs in working cutting machine and development of methods for calculating bread cutting machines with toothed belt knives.

2. Materials and methods.

To define expenses of energy for work of the cutting machine results of scientific researches of process of cutting of bread are used [1, 2, 3, 4].

In developing the methodology for determining the power of the drive of cutting machine, data about the process of cutting bread was used, and power analysis was conducted for the individual elements of the cutting machine: feeding conveyor, clamping belts, cutting mechanism

To define the resistance to moving of conveyors and knives, moving between drum heads, the method for traction calculation and the theorem of Euler are used.

In order to analyze the friction between bread and a side face of knives data about the influence of the speed of the knife and the pressure of a friction is used. In case of movement of bread on a conveying tape at small speeds of sliding, it is accepted that a coefficient of friction is constant.

3. Results and discussion.

It is known that force of cutting of bread depends on the speed of the knife and the time of keeping of the bread after baking (figures 2, 3) [3]. By increasing the speed of an edge in a product, the force of cutting of a crumb increases. At speed about 5 m/s force of cutting reaches maximum (extremes on charts of the force of cutting), while at further increase of the speed force of cutting decreases. The greatest force of cutting of a crumb - when cutting bread right after baking.

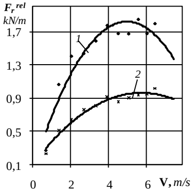

Figure 2. *Influence of the knife speed over the relative cutting effort of the bread core when time for stay of bread, h:*
1-0; 2-6.

Pressure of a friction between a side face of a knife and bread also depends on speed of the knife. With the increase of speed, the pressure of friction for bread crumb and crust increase. To define pressure of a friction *G, kPa*, it is possible to use the following equations [1].

For a crumb:

At $0 < \tau < 240$ *min*:

$$G = 133 + 0.003 \cdot \tau^2 - 0{,}97 \cdot \tau - 4.1 \cdot 10^{-5} \cdot N^2 + 0.447 \cdot N - 0.00104 \cdot \tau \cdot N + 12.4 \cdot V . \quad (1)$$

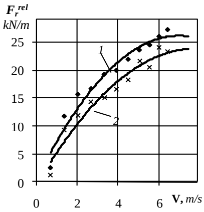

Figure 3. *Influence of the knife speed over the relative cutting effort of the bread cortex when time for preliminary stay of the bread,* ***h****:*
1-0; 3-from 6 to 48.

For a crust:

$$G = 98.56 - 0.0015\tau^2 + 0.60\tau + 0.14P + 31.9V, \quad (2)$$

where: τ - time of keeping of bread, minutes;

N - pressure of bread on the lateral area of a knife, *kPa*;

V - speed of sliding, *m/s*.

The equations is valid for such conditions:

range of speed V = 1-8 *m/s*;

pressure of bread on the side face of a knife of N = 400-2500 *Pa*;

time of keeping of bread τ = 0-240 *min*.

While calculating the pressure of a friction on a side face of a knife, it is necessary to know normal pressure of bread on a surface of a knife. It is determined using the formula:

$$N = Ex = E\frac{s}{B}, Pa, \qquad (3)$$

where: E - an elastic modulus of a product, *Pa*; x - relative deformation of a product; s-thickness of a knife, *mm*; B - a thickness of a piece of a product, *mm*.

It is necessary to know the elastic modulus as crumb, and crust.

Using of formula (3) is possible provided that in the product there is only elastic strain. Based on the literature it can be assumed that the elastic deformation occurs when the ratio of the thickness of the blade and a piece of the product is 1/10.

The coefficient of elasticity is defined according to the data [1] (Figure 4).

At the higher speeds of cutting, quality of the cut worsened: the cortex of bread is sanded smooth, and the crumb - crumbled. In work [1] the maximum speed was defined where there are no such types of defects. The speed is defined on Figure 5 depending on a normal surface load on the knife.

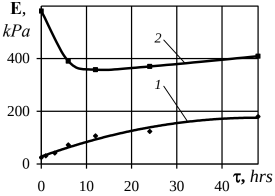

Figure 4. *Influence of time of keeping of bread on a coefficient of elasticity:*
1- bread crumb*; 2- bread cortex.*

As it had been specified, the load per unit area depends on a parity of thickness of a knife and a piece of the product.

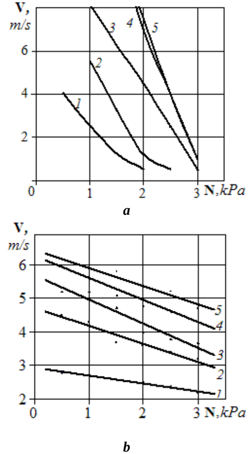

Figure 5. *Influence of specific batch on rate of a blade at whom quality of cutting decreased:*
a - the crumb crumble, b - the crust grind.
*Time of keeping of bread***,** *hour***:** *1-0; 2-1; 3-3; 4-6; 5-24.*

Definition of force and capacity of cutting.

Force of cutting of bread by a tape gear knife is defined by the formula:

$$F = F_l^{rel} \cdot \frac{V_n}{V_t} \cdot H, \qquad (4)$$

where: F_l^{rel} - specific force of cutting, N/m; V_n, V_t - rates of a knife and feeding of a product, *m/s*; H - height of a cut, *m*.

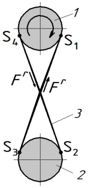

Figure 6. *The settlement scheme for definition of capacity of a drive of a package of tape knifes*
1, 2 - drive and tension drum heads; 3 - tape knife.

Definition of drive power of a bundle of tape knifes.

In order to define the capacity of a drive of pack of tape knives 3 (Figure 6) which move between drive (1) and tension (2) drum heads, we will make the settlement scheme and give on it characteristic points of contact with a tape knife.

Knowing force of cutting F, considering that the one tape knife cut a 2 pieces of bread, lets define a tension of a knife in characteristic points. We start with a point 1, in which tension of a knife is minimal. Let's designate a tension as S_1.

Tightness in a point 2:

$$S_2 = S_1 + F . \qquad (5)$$

Tension in a point 3:

$$S_3 = k \cdot S_2 = 1.06 \cdot (S_1 + F), \qquad (6)$$

where k - coefficient of resistance for a tension drum head

Tension in a point 4:

$$S_4 = S_3 + F = 1.06 \cdot (S_1 + F) + F \ . \qquad (7)$$

The tension in a point 4 also can be defined using the theorem of Euler:

$$S_4 = S_1 \cdot e^{f\alpha}, \qquad (8)$$

where f - a coefficient of friction of a knife on a drum head; for a friction of a steel on a steel at a coarseness of surfaces of 0.8 *mkm*, *f=0.13*.

α - angle of wrap of a drum a knife, usually α = 240 hailstones = 4.2 *rad.*

Then:

$$S_4 = S_1 \cdot e^{f\alpha} = 1.65 S_1 \ . \qquad (9)$$

Tension in a point 1 we will define from the equations (7) and (9):

$$1.06 \cdot (S_1 + F) + F = 1.65 S_1 \qquad (10)$$

$$S_1 = 3.49 \cdot F \qquad (11)$$

From the equation (9) and (11) we will define a tension in a point 4:

$$S_4 = 1.65 S_1 = 1.65 \cdot 3.49 \cdot F = 5.76 \cdot F \quad (11)$$

Let's define traction effort for one knife:

$$W = S_4 - S_1 + k \cdot (S_4 + S_1) = 5.76 \cdot F -$$
$$- 3.9 \cdot F + 0.04 \cdot (5.76 \cdot F - 3.9 \cdot F) = 2.58 \cdot F$$
(12)

Traction effort for a bundle of knifes:

$$W_\Sigma = n \cdot W = n \cdot 2.58 \cdot F \qquad (13)$$

Where n - number of working knives.

Capacity of a drive for a pack of knives:

$$Q = \frac{W_\Sigma \cdot V_n}{\eta} = \frac{n \cdot 2.58 \cdot F \cdot V_n}{\eta}, \quad W \qquad (14)$$

where: η - efficiency of a drive.

Definition of power mechanism of transportation bread to tape knives.

For definition of power of mechanism for transportation of bread to knives it is necessary to know resistance of bread to moving when cutting. Let's consider the scheme in Figure 7.

When cutting on bread, force of cutting F_Σ operated. It pressed bread to a bearer. Bread is being transported to the knife if force of feed of P is more than a frictional force of G.

Condition of feed of bread to a knife of a friction:

$$G = f \cdot F_\Sigma \ . \qquad (15)$$

Coefficient of friction between bread and a metal surface it is possible to accept f = 0.17.

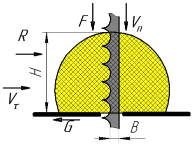

Figure 7.*The circuit of forces when cutting:*
F-force of cutting; G-friction force; R-force of feeding.
V_n - speed of a knife; V_τ - speed of feed

Bread is being transported because of the clamping pressure of the press conveyor 5 (Figure 8)

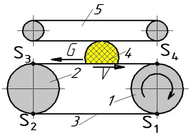

Figure 8.*The calculated circuit of the transporting conveyor.*
1, 2 - head and tension drums; 3 - ribbon; 4 - bread; 5 - pinch conveyor.

When driving the belt of feeding conveyor, we should note that there is force of resistance on the belt equal to the force of friction G.

Perform similar traction calculation.

$$S_2 \approx S_1 \quad (16)$$

$$S_3 = k \cdot S_1 \approx 1.06 \cdot S_1 \quad (17)$$

$$S_4 = S_3 + G = 1.06 \cdot S_1 + G \quad (18)$$

$$S_4 = S_1 \cdot e^{f\alpha} \quad (19)$$

f=0.17,

α - a corner of a grasp of a drum head a knife, α = 180 grad = 3.14 rad.

Then:

$$S_4 = S_1 \cdot e^{f\alpha} = 1.69 S_1. \quad (20)$$

Tension in a point 1 we will define from the equations (19) and (20):

$$1.06 \cdot S_1 + G = 1.69 \cdot S_1 \quad (21)$$

$$S_1 = 1.58 \cdot G = 1.58 \cdot f \cdot F_\Sigma \quad (22)$$

From the equation (20), (22) and (15) we will define a tension in a point 4:

$$S_4 = 1.69 S_1 = 1.69 \cdot 1.58 \cdot 0.17 \cdot F_\Sigma = = 2.68 \cdot G = 0.45 \cdot F_\Sigma \quad (23)$$

Let's define a tractive effort of a drum head:

$$W = S_4 - S_1 + k \cdot (S_4 + S_1) = 2.43 \cdot F_\Sigma. \quad (24)$$

Power of a drive for a package of knifes:

$$Q = \frac{W \cdot V}{\eta} = \frac{2.43 \cdot F_\Sigma \cdot V_\tau}{\eta}, \quad (26)$$

where: η - efficiency of a drive of the conveyor; V_τ - speed of transportation of bread, *m/s*.

Capacity of a drive of the clamping conveyor is equal to the capacity of a drive of the submit conveyor provided.

Procedure of payments of capacity of mechanisms of the cutting machine.

1. Determine the thickness of the crumb and crust
2. At the set speed of a knife and time of a seasoning define force of cutting of a crumb (Figure 2) and crusts (Figure 3).
3. On the formula 14 define power of a drive of the cutting mechanism.
4. On the formula 26 define power of a drive of mechanism of transportation

Example of use of results of researches.

Let's define capacity of drives of the cutting and transporting mechanisms of the cutting machine in the following circumstances:

Speed of a knife of V_n = 0.6 *m/s.*

Speed of mechanism of transportation of bread V_τ = 0.05 *m/s*

Quantity of working knifes - 11 (bread are cut on a 24 piece)

Dwell time after baking bread - 20 *min.*

Thickness of a crust - 3 *mm.*

Thickness of a crumb - 60 *mm.*

Force of cutting of a crumb - 1.8 *kN/m.*

Force of cutting of a crust - 25 *kN/m.*

Force of cutting for an one knife (the formula 4) F = 0.0028 *kN*.

Power of a drive of the cutting gear (the formula 14) - Q=530 *W.*

Power of a drive of the conveyor of feed (the formula 26) - Q=45 *W.*

Usually the power of a drive of the cutting gear is taken with factor of a stock 2-3. It is connected to the big frictional forces of bread and knives during start-up of the machine, and also for overcoming the forces of inertia at dispersal of a drum head.

Settlement power of a drive of mechanism of transportation is small compared to the cutting mechanism, and usually, considering power reserve, is considered within 200-300 W.

Conclusion

On the basis of the analysis of process of cutting of bread and the power analysis of mechanisms of breadcutting machine it is defined power of drives of cutting and transporting mechanisms.

The determined mathematical dependencies allowed to calculate capacity of a drive at known force and speed of cutting, to analyze and optimize expenses of energy in the machine.

The obtained results could be used during the designing of the cutting equipment, the analysis of expenses of energy and optimization of process of cutting.

The further research are demanded by the questions connected to a friction and a gripping power at cutting the corn by machines with a bundle of tape knives, and also the account of frictional forces when calculating the power.

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