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# FUNDAMENTALS OF THE THEORY OF GRAIN GRINDING IN ROTARY MACHINES

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## ABSTRACT

In the flour milling industry, the degree of grain grinding and its particles in a roller mill is assessed by the extraction coefficient $k_i$, which is a function of the gap between the rollers $b$ and is expressed by the following exponential dependence:

$$k_i = Ae^{-Bb}$$

where $b$ is the gap between the rollers ($m$), $e$ is the base of natural logarithms, and $A$ and $B$ are coefficients depending on the structural and mechanical properties of the grain and the geometric and kinematic parameters of the rollers.

It has been established that the extraction coefficient is influenced by the initial size of the ground product particles when the roller gap remains unchanged. The value of $k_u$ is directly proportional to the coarseness of the initial material particles.

In the flour milling industry, grain is ground in machines with grooved or rough (smooth) roller surfaces. To intensify the grinding process and increase the efficiency of sieving machines in simple and dual-grade milling of wheat and rye, in addition to roller mills, beater machines are installed, designed for processing products after roller mills or upper sieve overflows. For the production of oat and corn flakes, as well as for separating the germ, roller mills (flakers) with smooth rollers operating at equal peripheral speeds are used.

The main working elements of the roller mill are cylindrical rollers of equal diameters, rotating around parallel axes in opposite directions, with different angular speeds.

Particle destruction occurs due to their compression and shear. Depending on the structural and mechanical properties of the particles and the ratio between the inter-roller gap $b$ and the size of the crushed particles $a$, destruction can occur either in a single pass between the rollers or multiple times, determining the degree of grain grinding. The working surface elements of mill rollers can be grooves applied by cutters to the surface, as well as micro-surface irregularities formed as a result of abrasive grinding or electro-spark processing. The characteristics of the working surfaces of rollers depend on the combination of requirements imposed on specific technological operations comprising the grain grinding process. In breaking systems, rollers with grooved surfaces are used, while in reduction systems, for grinding semolina and dunst, both rough and grooved rollers are used.

The productivity of a roller mill is the actual throughput achieved while maintaining the desired degree of grain grinding or intermediate milling products. The throughput of a working pair of grooved rollers can theoretically be determined by the formula:

$$Q = 3.6 \cdot \rho \cdot l(b+h)v_n \cdot \psi$$

where:

$\rho$ – density of the ground product (kg/m³), $l$ – roller length (m), $b$ – roller gap size (m), $h$ – groove height (m), for determining the throughput of smooth rollers in the formula, the value is $h = 0$, $y$ – volumetric filling coefficient of the zone, $v_p$ – average product speed in the grinding zone (m/s).

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The speed of movement of the product in the grinding zone can be considered, in the first approximation, equal to the half-sum of the peripheral speeds of the fast-rotating and slow-rotating rollers. However, in the grinding zone of smooth rollers, it is determined by the formulas:

$$v_n < \frac{2v_б}{i+1}\cos\alpha$$

$$v_n < \frac{2v_м}{i+1}$$

where:

$v_b$, $v_m$ – peripheral speeds of the fast-rotating and slow-rotating rollers (m/s), $i$ – degree of grinding, $a$ – angle of product capture by rollers (degrees).

The speed of grain in the grinding zone depends on the relative positioning of the roller grooves. As the ratio of the peripheral speeds of the rollers increases (with the speed of the fast-rotating roller remaining unchanged), the speed of movement of the grain in the grinding zone decreases. This fact suggests that product particles exit the grinding zone at different speeds. Fine fractions move in the inter-groove space of the 'fast' and 'slow' rollers at speeds equal to the speeds of these rollers, respectively. The remaining product particles move in the space of the inter-roller gap at a speed greater than the speed of the 'slow' roller but less than the speed of the 'fast' roller. Accordingly, the product speed (m/s) at the exit of the grinding zone is:

$$v_n = k_1 \cdot v_б + k_2 \cdot v_2(x) + k_3 \cdot v_м$$

where:

- $v_x$ is the product speed in the inter-roller gap (m/s),
- $k_1, k_2, k_3$ are coefficients indicating the portion of the product moving at the speeds of the 'fast' and 'slow' rollers and at the speed $v_x$.

The distribution of speeds in the gap space is conventionally assumed to be linear. Based on these assumptions, the following dependence is obtained:

$$v_n = k_1 \cdot v_б + k_2 \frac{v_б + v_м}{2} + k_3 \cdot v_м$$

The coefficients $k_1, k_2, k_3$ depend on the pitch $P$ of the grooves, their height h, the arrangement of the grooves, and the coefficient of filling of the inter-groove spaces (the cavities between the grooves) and are expressed by the following dependencies:

$$k_1 = \frac{0.432 \cdot P \cdot h \cdot l \cdot \psi_1 \cdot z_1 \cdot v_б}{Q_ф}$$

$$k_3 = \frac{0.432 \cdot P \cdot h \cdot l \cdot \psi_3 \cdot z_2 \cdot v_м}{Q_ф}$$

$$k_2 = 1 - k_1 - k_3$$

where:

- $z_1, z_2$ are the number of grooves per 1 cm of the roller circumference,

- $y_1, y_3$ are the coefficients of filling the inter-groove spaces of the 'fast' and 'slow' rollers, as well as the coefficient of filling the inter-roller gap zone,
- $Q_\varphi$ is the actual productivity of the roller mill (kg/day),
- $l$ is the roller length (m).

Experimental studies on the grinding process in roller mills with various combinations of groove arrangements show that the relative positioning of the grooves affects not only the grinding quality but also the productivity of the roller mill.

It is evident that the degree of product grinding depends, under equal conditions, on the number of impacts R_z of the grooves on the product during its residence time τ in the grinding zone, determined by the length of the processing path. The groove impact zone on the product corresponds to the arc length L of the circle:

$$L = \frac{\pi R \alpha}{180}$$

where:
- $R$ is the radius of the roller (m),
- $\alpha$ is the arc angle (degrees).

To determine the number of impacts by the grooves of the 'fast' roller on the product, the passage time of the product in the working zone must be known:

$$L = v_n \cdot \tau ,$$

where t$\tau$is the product passage time in the working zone (s).

During this time, the number of grooves $z$ of the 'fast' roller passing through the zone equals the number of impacts $R_z$:

$$R_z = (v_б - v_м) \cdot \tau \cdot z = \frac{v_б - v_м}{v_n} L \cdot z$$

Substituting $L$ from the previous formula and the value of $v_n$, after transformation, we obtain:

$$R_z = \frac{2\pi}{180} \cdot R \cdot z \cdot \frac{i-1}{A_i+1} \cdot \alpha$$

Assuming that the maximum angle α equals the friction angle $\varphi = arctgf$, we finally obtain:

$$R_z = \frac{2\pi}{180} \cdot R \cdot z \cdot \frac{i-1}{A_i+1} \cdot arctgf .$$

The equation shows that for rollers with a given number of grooves $z$ per 1 cm and at a constant differential, the number of impacts $R_z$ remains a constant value. Thus, $R_z$ can increase or decrease at constant $R$ and $z$ only by increasing or decreasing the speed ratio of the fast- and slow-rotating rollers (the differential of the inter-roller transmission) *i.*

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