Determining energy costs for milling solid matter in a ball mills

M. M.Kuznetsova [1],V.E. Ved [1], E.V. Krasnokutskiy [1], M.I. Satayev [2], A.A. Saipov [2], R.F. Altynbekov [2]
[1] National Technical University "Kharkiv Polytechnic Institute", 21 Frunze st., Kharkiv, 61002 Ukraine, e-mail: ved@kpi.kharkov.ua, tel. +38057 7076589; [2] M. Auezov South Kazakhstan State University, 5 avenue Tauke Khan, Shymkent, 160012 Kazakhstan.

In the theory of calculating milling energy costs the most known methods were suggested by Rittinger, Kirpichev and Kick, Bond and Rundquist. But none of them have wide practical application as they take into account only geometrical dimensions of the particles to be ground and the characteristics of the material regardless of the milling method and conditions. All this stands in the way of applying the known milling methods.

We suggest a method for calculating milling energy costs depending on the ratio of the impact and friction forces influence, as well as on the changes in the strength characteristics of the matter during milling.

The effective work used in milling consists of two components: work of impact (A_p) and work of attrition (A_{mp}).

The milling by attrition in a ball mill (according to Taggart) takes about 1.5-2% of the energy, respective of the part of the mass (volume) of the material to be ground. We suggest introducing an energy parameter p that characterizes a share of energy of milling by impact. Consequently the attrition energy share is (1-p). Let's assume that the milling stage – from the initial size of d to a size $d_к$, can be carried out in n stages. Then the energy required to fracture a particle of the material equals:

$$A_p = \frac{\sigma_{np}^2 k d^3}{2E} \sum_{i=0}^{n} p^i , \qquad (1)$$

where d – the size of the particles (a diameter of a circumscribed sphere of a polyhedron, which is the form that the particles tend to shape), k – coefficient of form, E – elastic modulus (Yung's modulus), Pa, σ_{np} – practical value of ultimate strength of the ground matter particles, Pa.

The work of the attrition force to grind (1-p) a portion of the matter for particles with the initial size of d equals:

$$A_{mp} = \frac{\sigma_m^2 k d^3}{2E}\left(1 - p^n\right), \qquad (2)$$

where σ_m – practical value of ultimate strength of the ground matter particles through compression for particles that is determined by Orowan-Kelly equation, Pa.

In order to establish the energy needed for milling in relation to the geometrical size of the particles to be ground, we have to determine the number of stages in each part of this process: The maximum milled extent of the matter is u that equals the ratio of the initial size of the particle to the final size d_k. With each stage every particle will split into a number of lumps. Hence we can claim that

$$a^n = \frac{d^3}{d_к^3} = u^3 . \qquad (3)$$

With the maximum value of a=2, we will now determine the number of stages necessary to get the necessary size of the particles that are milled:

$$n = \frac{3\lg u}{\lg 2} \approx 10\lg\frac{d}{d_K}. \qquad (4)$$

Thus the dependence of work needed for milling the mass of a matter m_M by the combination of impact and attrition on the initial and the final size of the particles, characteristics of the matter can be determined by the following expression:

$$A = \frac{m_M}{2\mathrm{E}\rho}\left(\sigma_{np}^2 \sum_{i=0}^{10\lg\frac{d}{d_\kappa}} p^i + \sigma_T^2\left(1 - p^{10\lg\frac{d}{d_\kappa}}\right)\right). \qquad (5)$$

For the first time there has been established the dependence of milling energy costs on the characteristics of the matter to be ground and the milling method in the form of an equation (5). The research also suggests a parameter p that allows setting the relationship of the influence of various milling methods on the milling process. It allowed comparing the energy needed for milling in relation to the shares of impact and attrition fracturing for processes with different dispersion level of the initial matter.