ANNALS of the ORADEA UNIVERSITY.

Fascicle of Management and Technological Engineering, Volume VII (XVII), 2008

SOME ASPECTS REGUARDING THE DEPENDENCE STUDY ON SOME VIBRATING MILL NET POWER AND ITS FILLING COEFFICIENT

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Key words: vibrating mill, milling zones, mill net power

ABSTRACT

This paper has confirmed a proportionality relationship between the mill's filling coefficient and the net power of some vibrating mill with balls. The established proportionality constant depends on the material to be grinded and on certain operational parameters of the mill.

1. Introduction

Both tumbling and vibrating mills with spherical milling bodies (balls) have milling zones where particles to be milled are trapped by colliding balls. The location of this zone depends on the mill type, so that in tumbling mills case this is located below, while the entire enclosure of a vibrating mill constitutes the grinding zone.

The necessary power to drive a vibrating mill includes several terms: a) the power dissipated by mechanical friction in power transmission elements; b) the power to drive the mill's chamber; c) the power dissipated in the mill charge. The present study focuses only the third category mentioned above.

In the vibrating mills design several relations expressing the relationship between mill power and its milling specific rate are used. All of them are empirical (experimentally established) and someone needs a lot of experience in using them. The specialists are proposing some more solid relation establishment based on mathematical expressions.

The paper [3] identifies a relation between the selection function (the milling specific rate) and the mill net power in the tumbling mill case. Although the previous papers, such as [1], [2] or [6], specified that between the two analyzed terms there is a proportionality constant depending on none of the operating parameters in the relation, it has been proved that it depends however on the mill's filling degree, φ.

2. Theoretical aspects

In a view to determine the power *P* dissipated in the mill charge, consisting in both grinding bodies and grinding material, the powder filling is assuming to be moving along with balls within the milling chamber, so that:

$$P = f_m \cdot P_b = \left[1 + \varepsilon_b \cdot U \cdot \frac{(1-\varepsilon_p)}{(1-\varepsilon_b)} \cdot \left(\frac{\rho_p}{\rho_b}\right)\right] \cdot P_b \tag{1}$$

The terms appearing are the following:
f_m - mass ratio of mill charge to milling balls, [-];
ε_b - void fraction of ball charge in a static mill, [-];
P_b - rate of energy given to balls, [ ];
U - fraction of static balls (grinding bodies) filled by powdered material to be grinded, [-];
ε_p - void fraction of powder charged, [-];
ρ_p - density of particle, [kg/m^3];
ρ_b - density of ball, [kg/m^3].

Starting from the f_m relation of definition, the expression (1) was reached:

$$f_m = \frac{M_b \cdot N_b + M_p}{M_b \cdot N_b} = 1 + \frac{M_p}{M_b \cdot N_b} \quad (2)$$

where M_b - mass of one ball, [kg];
N_b - number of balls charged, [-];
M_p - mass of powder charged, [kg].

Because

$$M_b \cdot N_b = V_M \cdot \varphi \cdot (1 - \varepsilon_b) \cdot \rho_b \quad (3)$$

$$M_p = V_M \cdot f_c \cdot (1 - \varepsilon_p) \cdot \rho_p \quad (4)$$

and

$$U = \frac{f_c}{\varphi \cdot \varepsilon_b} \quad (5)$$

so, the relation (1) results.

In the previous expressions the terms are:
V_M - mill volume, [m^3];
φ - mill filling coefficient (ratio of milling bodies volume to milling chamber volume), [-];
f_c - fractional volume filling by powder, [-].

Unlike tumbling ball mill, in the vibrating mill with balls the milling zone is the entire area where milling charge is disposed (figure 1). A horizontal vibrating mill, having circular oscillations with angular velocity ω_v and amplitude diameter D_v is presented. So, the mill's wall oscillates between the two dotted circles drawn in figure 1a and transfers kinetic energy by directly hitting balls within the two dotted circles.

Assume that the mill body vibrates only upward and downward for simplicity and the level of the mill charge is expressed by θ_{b0} as illustrated in figure 1. When this angle is less than the critical value $\theta_{b0} = \frac{\pi}{2}$ (or 50% of the mill volume), only the upward motion of the mill shall projects the mill charge upwards. When the angle θ_{b0} is greater than the critical value previous mentioned (figure 1,b), the mill charge is forced downwards instead of falling freely.

In a mill with circular vibrations, balls in the shaded regions *A* and *B* in figure 1 are subjected to the double action.

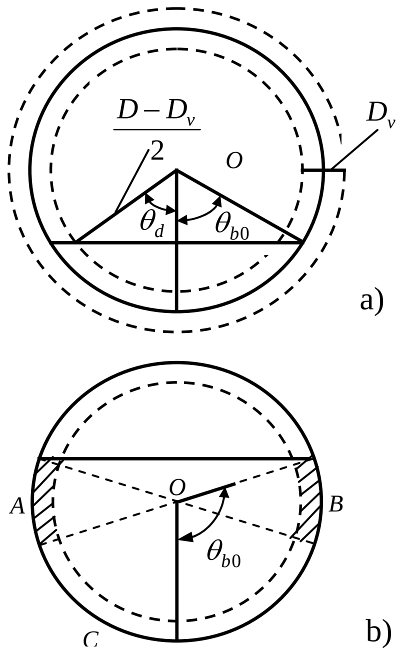

Figure 1. Vibrating mill with balls running
a) motion of vibrating mill; b) the double action region

The resultant power to the ball charge is given by:

$$P_b = (1+3f_d)\cdot N_d \cdot \left(\frac{1}{2}M_b \cdot v_s^2\right)\cdot\left(\frac{\omega_v}{2\pi}\right) \tag{6}$$

where: D - mill diameter, [m];

N_d - number of balls subjected to direct hit of wall, [-];

v_s - mean velocity of oscillating mill wall, [m/s];

f_d - ratio of balls subjected to double action to N_d balls, [-]:

$$f_d = \begin{cases} 0 & if \;\; \theta_{b0} \le \frac{\pi}{2} \\ 2-\left(\frac{\pi}{\theta_{b0}}\right) & if \;\; \theta_{b0} > \frac{\pi}{2} \end{cases} \tag{7}$$

N_d and v_s are specified according to:

$$\frac{N_d}{N_b} = 1 - \frac{f(\theta_d)}{f(\theta_{b0})}\left(1-\frac{D_v}{D}\right)^2 \tag{8}$$

$$v_s = \frac{D_v \omega_v}{\pi} \tag{9}$$

where

$$f(\theta) = \frac{2\theta - \sin 2\theta}{2\pi} \tag{10}$$

$$\cos\theta_d = \frac{\cos\theta_{b0}}{1-\frac{D_v}{D}} \tag{11}$$

Replacing the relations (6) and (9) in (1) we will obtain:

$$P = \left[\frac{(1+3f_d)\cdot\left(\frac{N_d}{N_b}\right)}{4\pi^3}\right]\cdot\left[f_m\cdot(M_b\cdot N_b)\right]\cdot D_v^2\cdot\omega_v^3 \tag{12}$$

where $[f_m\cdot(M_b\cdot N_b)]$ represents the total mass of charge (milling bodies and milling material).

The formula (12) is named NOMURA and TANAKA (1994) and is the only one that takes into consideration the shocks appearing between balls and the mill's wall.

The mill net power, *P*, is proportionate to $D_v^2\cdot\omega_v^3$ as in the ROSE's first formula (1961), see [5].

3. Results and comments

The numerical values used in calculus are presented in tables 1 and 2.

Table 1. Numerical values used in a vibrating mill calculus

D *[m]*	D_v *[m]*	ω_v *[s^{-1}]*	ε_p $[kg\cdot m^{-3}]$	ρ_p $[kg\cdot m^{-3}]$	*U*
0,2	0,004	157	0,4	0,27x10^4	1,0

Table 2. Numerical values used in a steel ball calculus

φ	ε_b $[kg\cdot m^{-3}]$	ρ_b $[kg\cdot m^{-3}]$
0,5	0,4	7800

In the vibrating mills case, the milling net power given by relation (12) is proportionate to $D_v^2\cdot\omega_v^3$. Rose and Sullivan formerly obtained a similar relation using dimensional analysis. Although the past literature offers some more other expressions for the mill net power, the specialty literature shows that the exponents 2 and 3 of the D_v and ω_v factors are accepted as medium values of calculus.

The graph plotted in figure 2 shows the dependence between the mill net power and its filling coefficient.

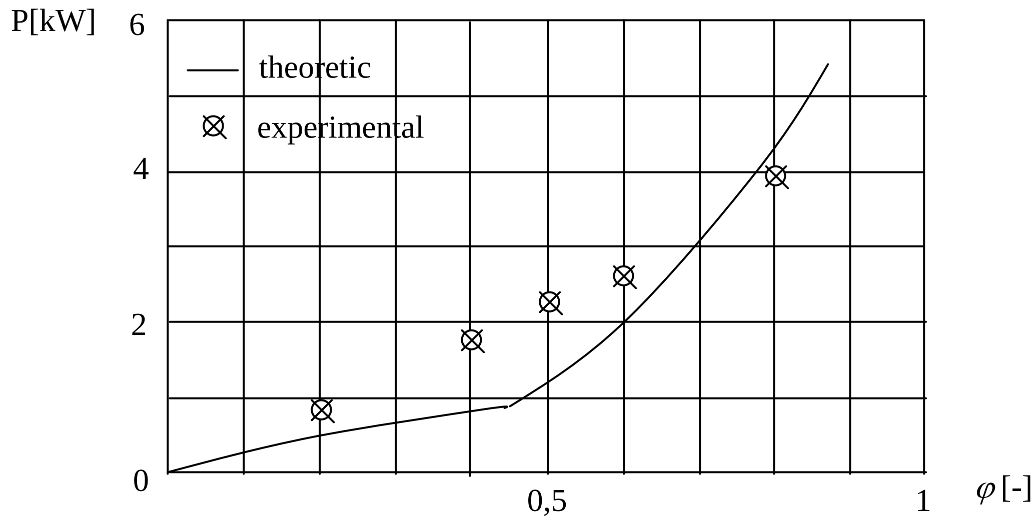

Figure 2 The dependence between mill net power of the vibrating mill and its filling coefficient

In some papers, such as [3], the mill grindability, defined with the so called selection function, appears in the ordinate. Same article points out that the mill grindability and the mill net power are similar when certain operating parameters are constant.

The experimental data corresponds to a vibrating mill with rotary chamber having the vibrations generator laterally mounted (GmbH Siebtechnic type) used by S.C. Ductil S.A. Buzău in order to obtain fine powders used in plain rods manufacture ($U = 1$).

The calculus reveals for φ ($\varphi = 0{,}412$) a so called critical value due to double action zones appearance $\left(\theta_{b0} = \frac{\pi}{2}\right)$.

In the theoretical variant of the graph, for $\varphi < 0{,}412$, the dependence between the mill net power and its filling coefficient has an approximate linear and slow breeder variation, while the variation is linear ascending, but the increase is more sudden for $\varphi > \varphi_{cr}$.

In the experimental variant, the graph shows a real linear dependence between those two studied terms.

4. Conclusions

This paper is materialized due to constant concern of its authors referring to some energy aspects that governs the vibrating mills running.

Reviewing all formulas for determining the vibrating mill running power in the past literature [5], the present paper focuses the superiority of NOMURA and TANAKA formula successfully used in these equipments design.

A comparative study between tumbling and vibrating mills will fallow up based exclusively on energy reasons.

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