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THE GRINDING CHARGE OF ROTARY MILLS

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ABSTRACT

This paper presents the achievemens of grinding charge for the tube mills with balls.The author shows charactheristic size of grinding media charge: bulk density, porosity, filling degree. Regarding this last size,the author presents a way of its estimate,control and adjustment by measuring the level of charge. In the end,the way of establishing the material amount in the mill is presented,to achieve grinding in the best conditions(high fineness of grinding with small energy consumption).

1. Generalities

Different industries are using for grinding raw material and final products, exclusively rotary mills. For instance, in the cement industry, the raw used to produce cement clinker as well as the cement, is obtained by grinding in rotary mills.

These mills consist of a horizontal cylindrical drum partially filled with charge formed by free grinding media and first material. By drum rotation with a well specified revolution, the free grinding media (balls, cylpebs, etc), are drawn by this till a certain highness, whence they fall, striking the material. The grinding is produced as a result of the combined effect striking and friction.

The correct estimate of grinding charge (form and dimensions of the grinding media, loading specific charge of the drum, report between quantity of material and the quantity of grinding charge, etc), influence in a determining degree the efficiency of the mill work (grinding fineness, wear of grinding media, throughput of the mill, energy specific-consumption, noise produced by the mill, etc).

2. Grinding media

The grinding media used are, generally, balls and cylpebs. In compartments of coarse and medium grinding are used balls, and in that of fine grinding, balls or cylpebs. In any compartment, sizes of grinding media must be correlated with the size of the material. Between the balls are formed free spaces (emptiness). The porosity ε is determined by the relation

$$\varepsilon = \frac{V_{gol}}{V_{inc}} = \frac{V_{inc} - V_{cm}}{V_{inc}} = 1 - \frac{V_{cm}}{V_{inc}} = 1 - \frac{M_{cm}/\rho}{M_{inc}/\rho} = 1 - \frac{\rho_{cm}}{\rho} \qquad (1)$$

in which V_{gol} means the volume of emptiness, V_{inc} = the volume of charge, V_{cm} = grinding media or volume, M_{inc} = weight of the charge, M_{cm} = weight grinding media, ($M_{inc} \approx M_{cm}$), ρ = the density of the material of grinding media, ρ_{cm} = bulk density of grinding media.

Bulk density of grinding media can be determined (if ρ and ε are known), with the relation

$$\rho_{cm} = \rho(1-\varepsilon) \qquad (2)$$

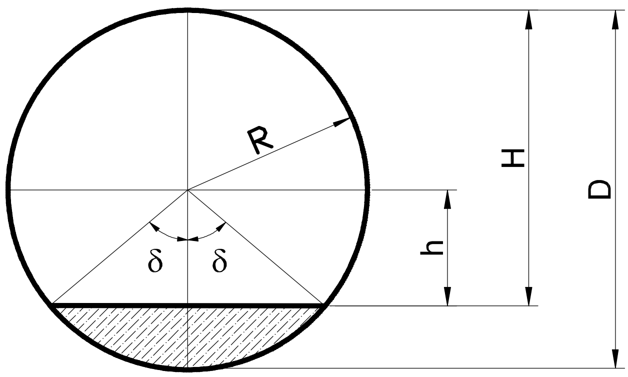
The relation (2) is useful also for the determination of the porosity ε, when ρ and ρ_{cm} are known.

For the complete use of free spaces between balls and the increasing throughput of the mill, the charge consists in a mixture of the balls of different sizes. Balls size distribution is established experimentally or using the usual dates obtained by exploitation of the balls mills [1,2].

The balls size distribution must allow replenished for wear of the grinding media with one or maximum two sizes of the balls. Usually, for replenished of the grinding media may consider the maximum media size. The positive influence of the mixture of charge media is obvious in the coarse and medium grinding, and very reduced in fine grinding compartment [5]. It is preferable to replace balls with cylpebs, which have the specific surface (surface aria of one ton grinding media) with 14.5% greater than the balls. [7]. This contribute to the augmentation of grinding by friction, what leads to a higher fineness of the material. In the same sense, is recommended to utilize in fine grinding compartment of a grinding media with small sizes (minipebs). [4].

3. Specific charge

The specific charge of the drum with grinding media is expressed by the report between the



volume of charge and the inside volume of the drum, or aria of cross section of the charge A_{inc} and aria of cross section of the drum A_t (fig.1) [5].

$$\varphi = \frac{V_{inc}}{V_t} = \frac{A_{inc}}{A_t} \qquad (3)$$

This parameter is usually expressed in percent

$$\varphi = \frac{V_{inc}}{V_t}100 = \frac{A_{inc}}{A_t}100 \ \% \qquad (4)$$

Fig.1. Scheme defining the specific charge

Practically, it is necessary to do the evaluation of the specific charge by parameters easy to measure. This parameter might be the distance H from top of the mil to the top of the charge (see fig.1).
The specific charge is expressed by the formula

$$\varphi = 112{,}5 - 125\frac{H}{D} \ \% \qquad (5)$$

which is more practical to evaluate the filling degree of the drum.
For an easier evaluation of the specific charge correlation (5) is presented in a digital form in table 1

Table 1.Digital form of function φ=f(H/D)

φ, %	5	10	15	20	25	30	35	40	45	50
H/D	0.903	0.844	0.792	0.746	0.701	0.660	0.619	0.578	0.539	0.50

Specific charge of rotary mills has the values φ= 0.20 … 0.50. But, one can observe that [5].

- for φ < 0.25, grinding media slip on mill lining (internal surface of the drum);
- for φ > 0.45, the trajectory of the falling balls are intersecting, and these are rushing against each other without damaging the material particles.

The research worker L. B. Levenson recommends for the level of the charge (see fig.1) h = 0.16 R [1,2] , what leads, using relation (5) to the value
φ = 40%.
Practically, one can observe that the specific charge is diminished from φ = 0.40 – 0.50 to φ = 0.20 – 0.25, producing an augmentation of the mill efficiency with 25 %.
Practically, the values of specific charge are [1, 6]:

φ= 0.25 – 0.38 for steel balls;
φ= 0.25 – 0.30 for cylpebs;
φ= 0.30 – 0.40 for silex balls.

At these values of specific charge and for values $\Psi = n/n_{cr}$ = 0.6 – 0.7 (n = mill speed, n_{cr} = critical speed of this, when grinding media do not fall, but they move solidary with the drum). The mill works in falling condition of cascade, and the grinding is achieved mainly by striking of the material by these. In conditions of higher values of the specific charge, the grinding is achieved mainly by friction [2].
It is necessary to correlate the specific charge with the mill speed.This is described by the relation [6]

$$\varphi = \frac{n\sqrt{D} - 16}{40} = \frac{\Psi \cdot n_{cr}\sqrt{D}}{40} = \frac{15\sqrt{2}\Psi - 8}{20} \quad (6)$$

where D is the inside diameter of the drum, and n represents mill speed measured in r.p.m.

$n_{cr} = \dfrac{30 \cdot \sqrt{2}}{\sqrt{D}}$ critical speed of the drum, r.p.m. (D expressed in m.).

For φ = 0.60 – 0.70 relation (6) leads to the values φ = 0.24 – 0.34, included in the field of values recommended. In multiple compartments mills (which usually work in open circuit), to obtain a natural circulation of the material, from the inlet to the outlet, the level of the charge from every compartment must be smaller with 10 mm, in comparison with the previous compartment [1,6]. So that, for a mill with three compartments, is recommended to realize the charge in this way [2] :

- compartment 1: φ= 0.30; d_b = 110 - 60 mm (d_b = diameter of balls);
- compartment 2: φ= 0.27; d_b = 60 - 35 mm;
- compartment 3: φ= 0.24; d_b = 30 - 20 mm.

In compartment 1 (coarse grinding), in which the material comes in, the grinding is mainly realized by striking, so that the balls with d_b = 100 – 110 mm must represent 25–30 % from the charge of this compartment. In compartment 2, (medium grinding), the grinding is realized by striking and friction, so that the balls with
d_b = 60, 50, 35 mm must be in equal quantities. In compartment 3, (fine grinding), the grinding is realized mainly by friction. It is necessary to use balls with d_b = 20 – 30 mm or cylpebs with d = 10 – 26 mm and l = 2d.
The inlet and the outlet of material in mills rotary drum is realized by tubular trunnion of the mill. It is necessary that the level of charge does not exceed the level of the inside surface of the tubular trunnion, otherwise the charge can get out of the mill (fig. 2).

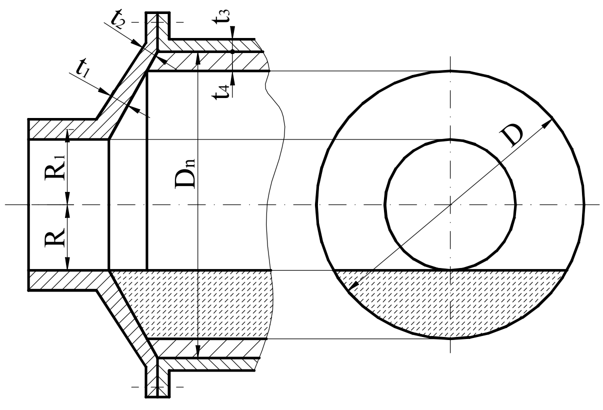


Fig.2. Scheme for determination of the tubular trunnion radius in the inlet.

In the design of a mill, can be used to determine the inside radius of the tubular trunnion,the formula [8]:

$$R = \frac{50-\varphi}{125}D \qquad (7)$$

where φ is expressed in %.

4. Control and adjustment of the specific charge

During the grinding process, grinding media as well as lining parts of the drum wear off, following specific phenomena (abrasion, oxidation, etc.). The value of the report between the wear of the grinding media and the wear of the lining parts is 4 – 10, especially in case of wet grinding where the specific, phenomena are more intense obviously, the wear of the grinding media depends of many factors, especially quality of the material and their thermal treatment, as well as the hardness and abrasive nature of the grinding material. The dry grinding of raw materials for cement (limestone, clay, marl), the wear of grinding media with hardness 350 – 400 Brinell is for big balls of 80 – 200 g/t (10 – 25 g/kWh) and for small balls and cylpebs of 35 – 120 g/t (3 – 10 g/kWh). The wear is much reduced for grinding media chromium alloyed steel, with hardness 600 – 700 Brinell [3].

The total wear of grinding media, during the cement clinker (balls of forging steel and hardened with 600 Brinell, and cylpebs by special iron) is of 162 – 308 g/t of cement (4.4 – 8.4 g/kWh) [2].

The presented values show a rapid wear of grinding media, which leads to the diminution of specific charge, with negative effects on grinding process. The throughput of the mill is reduced with 4 – 5 %, because of grinding media wear, even after several days of work.

Actual fact shows that the specific charge correctly adopted and compensation for wear of grinding media (bringing of the specific charge value to the initial size, by adding new grinding media), produces the increasing of the throughput of mill with 15 or even 30 % [1].

Taking in consideration the specified facts, it appears as necessary the control and adjustment of the specific charge of the drum with grinding media. For the mills with a single compartment we have good results to evaluate the specific charge by measuring the noise produced during the work, or by measuring the energy consumed by the mill. For the mills with many compartments, it is impossible to do that, because grinding media as well as specific charge are different from a compartment to another one. In this situation, the estimate of specific charge is done using the relation (5) [8].

The supplement of charge necessary to compensate the initial part lost by wear, during the grinding process, is determined as difference between the initial weight of the grinding media and the final weight of this.

The initial weight of the grinding media is determined by relation [8].

$$M_{cm,i} = \varphi_i \frac{\pi D^2}{4} L \rho_{cm} \quad \text{kg} \qquad (8)$$

where φ_i is the initial value of the specific charge ; D = inside diameter of the drum, m; L = the length of this, m; ρ_{cm} = bulk density of grinding media, kg/m^3. The initial level of the grinding media, distance H (fig.1) is determined by relation (5) or table 1, for the initial value φ_i of the specific charge.

After a period of work, the grinding media are worn, the level of grinding media is reduced and distance H increases, to the final value H_f . In this case, the charge volume has the value φ_f and is determined by relation (5) or by table 1 for the value of H/D ratio, corresponding to H_f level. The quantity of grinding media existent in the mill, in this situation, is:

$$M_{cm,f} = \varphi_f \frac{\pi D^2}{4} L \rho_{cm} \quad \text{kg} \qquad (9)$$

The weight of compensation charge is determined by relation [7,8].

$$\Delta M_{cm,f} = M_{cm,i} - M_{cm,f} = (\varphi_i - \varphi_f)\frac{\pi D^2}{4} L \rho_{cm}$$

$$= \frac{\varphi_i - \varphi_f}{\varphi_i} M_{cmi} \quad kg \qquad (10)$$

5. The quantity of material existent in mill

The material must be in such a quantity to fill every emptiness existent between grinding media [8].

The weight of material existing in mill is determined by relation

M_{mat} = V_{gol} ρ_{mat} = ε V_{inc} ρ_{mat}= $\varepsilon\varphi\frac{\pi D^2}{4}L\rho_{mat}$ kg (11)

where, besides the previously presented notations, ρ_{mat} is the bulk density of material, kg/m^3.

Relation (11) might have the form:

$$M_{mat}=\varphi\frac{\pi D^2}{4}L\rho_{cm}\frac{\rho_{mat}}{\rho_{cm}}(1-\frac{\rho_{cm}}{\rho})$$

$$=\varepsilon\frac{\rho_{mat}}{\rho_{cm}}M_{cm} \qquad (12)$$

or:

$$M_{mat} = k\cdot M_{cm} \qquad (13)$$

where:

$$k=\frac{\rho_{mat}}{\rho_{cm}}\left(1-\frac{\rho_{cm}}{\rho}\right)=\varepsilon\frac{\rho_{mat}}{\rho_{cm}} \qquad (14)$$

It results that between weight of grinding media and weight of material exists the ratio:

$$\frac{M_{cm}}{M_{mat}}=\frac{1}{k}=c. \qquad (15)$$

For an efficient use of grinding energy it is necessary that the ratio M_{cm}/M_{mat} has a certain value, which depends on concrete conditions of developing of the grinding process. This ratio also influences the fineness of material obtained by grinding (the value of this ratio must be the more so as the required grinding of the fineness material is higher.

To obtain a corresponding grinding fineness for a material cement (approximately 3200 cm^2/g Blaine) using in optimum way the grinding energy, it is necessary [2, 5]:

$$C = M_{cm}/M_{mat} >15$$

If the material fills the emptiness between grinding media, results:

M_{cm}/M_{mat} = 7, namely M_{mat} = 0.142 M_{cm} [5,8].

Generally, to obtain a maximum fineness in clinker grinding, for a minimum energy consumption, is recomanded [2]:

$$M_{cm}/M_{mat} = 8.1 ... 10.1.$$

6. Exemple of calculation

The first compartment of the rotary mill ф 2.6× 14.6m, with three compartments, for dry grinding of the raw material is calculated.

The mill is characterized by:

- inside diameter (useful) D = 2.5 m ;
- effective length of the first compartment L_1=3.5 m ;
- value for the specific charge of the first compartment $\varphi_1 = 0.30$;
- mill feed size: d = 25 mm

The density of the grinding media mixture for first compartment is determined by relation :

$$\rho_{cm} = \sum r_k \cdot \rho_{cmk}$$

(r_k = percentage of grinding media with k size; ρ_{cmk} = bulk density of these)

Resulted ρ_{cm1} = 4623 kg/m^3.

- Weight of grinding media for first compartment was calculated using relation (8). Resulted the value: $M_{cm,i} = 23828$ kg.

* Porosity of grinding media charge (rel. 2) resulted :

$$\varepsilon_1 = 1-\frac{\rho_{cm1}}{\rho} = 1-\frac{4623}{7850} = 0.411.$$

* To determinate the weight of the material was used relation (12) in which

ρ_{mat1} = 1300 kg/m^3.

Resulted the value: M_{mat1} = 2757 kg

* The ratio between weight of grinding media and weight of material resulted :

$$c=\frac{M_{cm}}{M_{mat}}=\frac{23828}{2757}=8{,}65$$

* We'll determine, to exemplify, charge of wear compensation of grinding media for the first compartment of the mill.

- The initial level of charge, for φ = 0.30 resulted from table 1 $(H/D)_i$ = 0.660, so H_i = 0.66 ·D = 0.66 ·2.5 = 1.65 m.
- After a time of work, because of balls wear, the distance (measured) H has the value Hf = 1.67m .
- Resulted (H/D)f $=\frac{1.67}{2.5}=0.668$, for wich corresponded (after table 1) a value of specific charge φ_f = 0.29.
- Weight of wear compensatio (relation 10) is :

$$\Delta M_{cm} = \frac{\varphi_i - \varphi_f}{\varphi_i} M_{cmi} =$$

$$= \frac{0.30 - 0.29}{0.30} \cdot 23828 = 794\,kg$$

- The charge is completed with balls of maximum diameter. One tonne of balls Φ90 contains 334 balls. So, to complete, will be used in the first compartment of the mill 0.794 $\times$ 334 = 265 balls.

7. Conclusions

The grinding charge of rotary mills has a high influence upon the grinding process. This influences by shape, dimensions and quality of grinding media, as well as by weight and its structure, fonctional parameters of the mill. The grinding fineness, the troughput of mill, specific consumption, metal consumption (grinding media + lining parts), etc. For that, the grinding charge must remain constant, as weight and as structure. In this situation, the reduction of grinding media weight must be compensated, adequately completing the charge, at well determined periods.

An other grinding charge parameter is represented by the report between grinding media weight and material weight. To realize the grinding fineness with a minimum energy consumption, this report must have well determined values.

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