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Power calculation of grading device in desintegrator

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Abstract. This article describes the analytical method of measuring the secondary power consumption, necessitated by the installation of a grading device in the peripheral part of the grinding chamber in the desintegrator. There is a calculation model for defining the power input of the disintegrator increased by the extra power demand, required to rotate the grading device and to grind the material in the area between the external row of hammers and the grading device.

The work has determined the inertia moments of a cylindrical section of the grading device with armour plates. The processing capacity of the grading device is adjusted to the conveying capacity of the auger feeder. The grading device enables one to increase the concentration of particles in the peripheral part of the grinding chamber and the amount of interaction between particles and armour plates as well as the number of colliding particles. The perforated sections provide the output of the ground material with the proper size granules, which together with the effects of armour plates, improves the efficiency of grinding. The power demand to rotate the grading device does not exceed the admissible value.

1. Introduction

One of the disadvantages of desintegrators is low impact of particles collision and no grading in the peripheral part of the grinding chamber [1]. This drawback is caused by the fact that the first internal row of hammers decreases the processing capacity of the grinding chamber. As the material moves from the centre to the periphery in the grinding chamber, its volume increases while the particles concentration declines. Low concentration of particles leads to the lower collision of particles as well as lower interaction between particles and hammers faces. This results in low efficiency of the desintegrator and poor quality of the ground material. Therefore the authors have developed a new structure of the desintegrator that includes housing 1, discharge sleeve 2, hammers 3 and grading device rotating in the direction opposite to external row of hammers 4 (Fig. 1) [2].

Grading device 4 enables one to raise the concentration of particles in the peripheral part of the grinding chamber, and classifies particles before outputting them via discharge sleeve 2. Bigger size granules continue to move along the internal working face of the grading device and are ground until they pass through one of perforated sections 6.
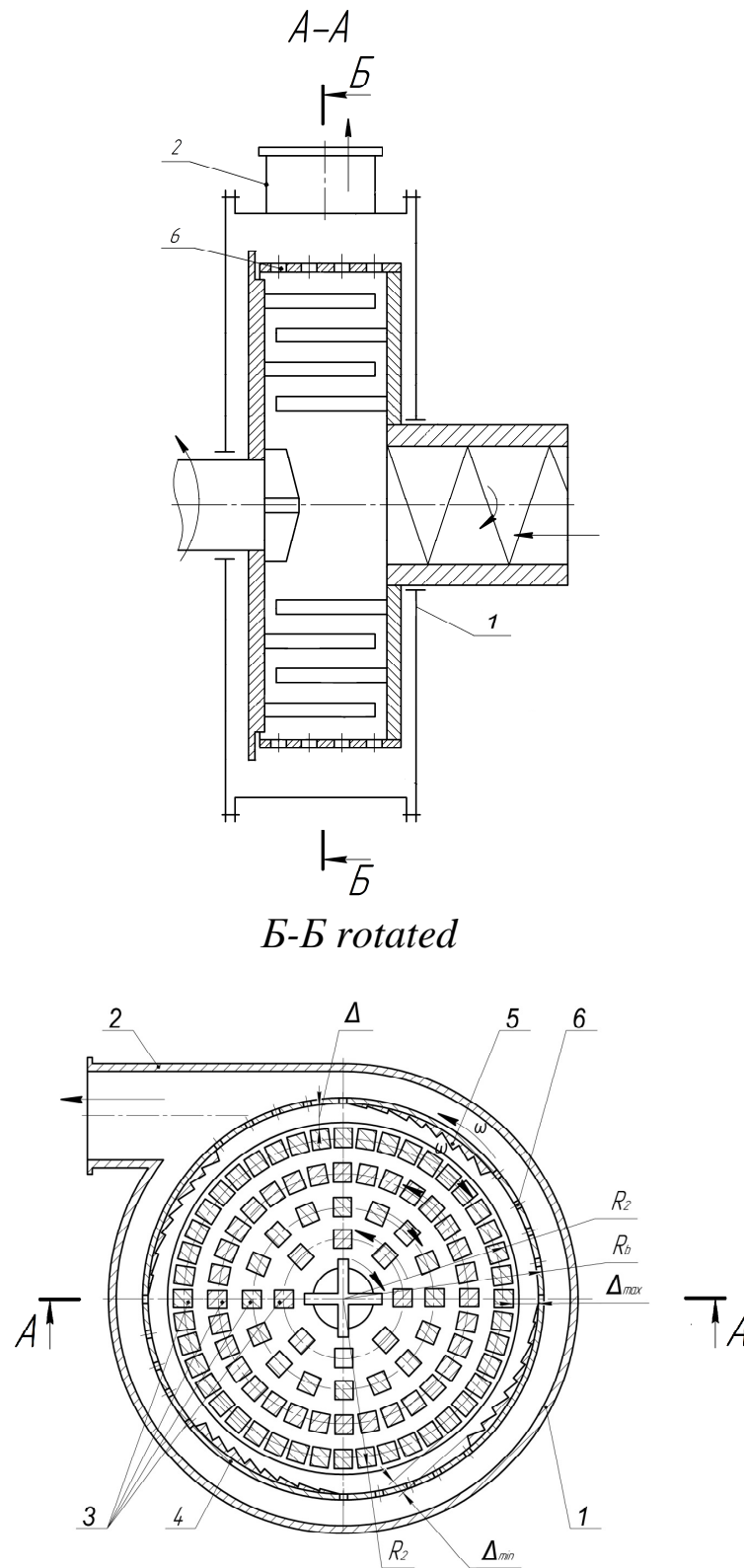
A–A

Б-Б rotated

Figure 1. Desintegrator 1 – housing; 2 – discharge sleeve; 3 – hammers; 4 – grading device; 5 – armour plates; 6 – perforated section.

The installation of grading device 4, containing tapered armour plates 5 and perforated sections 6,

in the grinding chamber of the desintegrator requires increasing power intake which is necessary to rotate grading device 4 with armour plates 5 and perforated sections 6 as well as to provide additional grinding and grading of the material. Thus the target value of power is the sum of the summands [3]:

$$P = P_1 + P_2, \tag{1}$$

where P1 – power demand for additional grinding of the material in the zone between the external row of hammers 3 and grading device 4;

P2 – power demand for rotation of grading device 4. The particles of the material moving in the area between the external row of hammers 3 and grading device 4 experience the intensive impact of transverse strain from the fast moving layer of granules near the external row of hammers 3 and contrarotating grading device 4. This has to result in partial destruction of granules due to the effects of tensile stress while passing the action zone of grading device 4.

The main part. It is logical to assume that in a given mode the mass of the material input from the external row of hammers 3, entering the action zone of grading device 4, is equal to the mass of the ground material output from grading device 4.

For one complete turn «T», the zone of additional grinding and grading produces the volume of the output ground material "Qy", equal to:

$$Q_y = \frac{S_0 \cdot (R_b - R_2)}{T}, \tag{2}$$

where S0 – the overall area of the perforation holes of sections 6 in the cylinder surface of the grading device 4;

Rb – the outside radius of the cylinder surface of grading device 4;

R2 – the swing of the external row of hammers 3.

Taking into account the fact that the time of a complete turn and the rotor frequency «ω» correlate:

$$T = \frac{2\pi}{\omega}, \tag{3}$$

then equation (3) looks like this:

$$Q_y = \frac{S_0 \cdot (R_b - R_2) \cdot \omega}{2 \cdot \pi}. \tag{4}$$

To match the functioning of the auger feeder (not shown in Fig. 1) and the conveying capacity of installed grading device 4, it is necessary to obtain the equality of expression (4) and the capacity of the auger feeder, equal to [4]:

$$Q_n = \psi \cdot \frac{\pi D_{on}^2}{4} \cdot \omega \cdot h, \tag{5}$$

where ψ – the volume efficiency of the cross-section area of the auger feeder;

Dоп – the optimum diameter of the auger feeder;

h – the step size of the auger feeder.

$$\frac{S_0 \cdot (R_b - R_2) \cdot \omega}{2 \cdot \pi} = \psi \cdot \frac{\pi \cdot D_{on}^2}{4} \cdot \omega \cdot h. \tag{6}$$

Resulting relation (6) can be considered as the equation in an unknown value. The solution of (6) in relation leads to:

$$S_0 = \frac{\pi^2}{2} \cdot \psi \cdot \frac{D_{on}^2 \cdot h}{R_b - R_2}. \tag{7}$$

To determine the transverse strain in the area of additional grinding, it is necessary to use the results of [5,6]:

$$\sigma = \frac{\mu \cdot \vartheta}{\Delta},$$ (8)

where μ – the pseudo viscous disintegration factor, equal to 2618 cPs;

ϑ – the rotary velocity of material particles near the surface of grading device 4;

Δ – the size of the opening between the radius of the external row of hammers 3 and the surface of grading device 4.
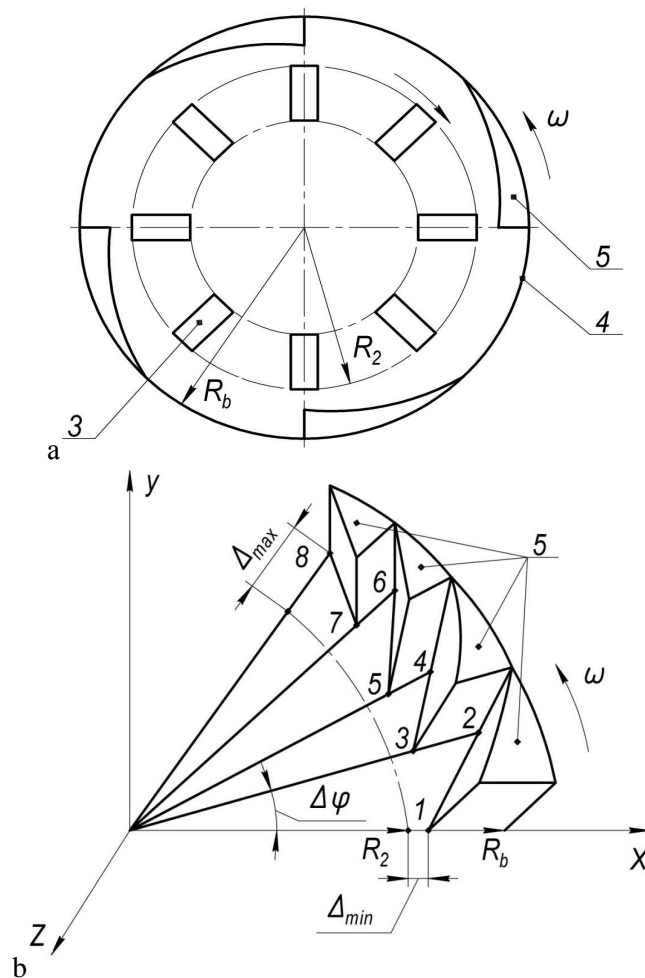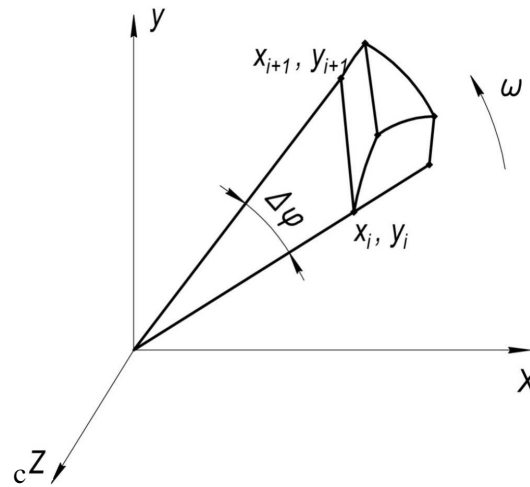
Figure 2. a) the layout of armour plates 5 in grading device 4 of the desintegrator; b) the calculation of the kinematic characteristics of the armour plate 5; c) the calculation of geometrical parameters of the highlighted section of armour plate 5

Solving equation (8) in relation with points 1 and 8 in Fig.2 b, as a result:

$$\sigma_{min} = \frac{\mu \cdot \vartheta_H}{\Delta_{max}}, \tag{9}$$

$$\sigma_{max} = \frac{\mu \cdot \vartheta_k}{\Delta_{min}}, \tag{10}$$

where ϑ_H – the initial rotary velocity of particles near the surface of grading device 4;

ϑ_k – the finite rotary velocity of particles near the surface of grading device 4;

Δ_{max} – the maximum size of the opening between the radius of the external row of hammers 3 and the surface of grading device 4;

Δ_{min} – the minimal size of the opening between the radius of the external row of hammers 3 and the surface of grading device 4.

The power demand, required for additional grinding in the action zone of grading device 4, is equal to:

$$P_1 = \Delta E \cdot \omega, \tag{11}$$

where ΔE – the changing kinetic energy of the particles flow in the action zone of four armour plates 5 of grading device 4.

$$\Delta E = 4 \cdot \Delta E_1, \tag{12}$$

where ΔE_1 – the changing kinetic energy of the particles flow in the action zone of one armour plate 5 of grading device 4;

$$\Delta E = \frac{m}{2}(v_k^2 - \vartheta_H^2), \tag{13}$$

where «m» – the mass of particles in the action zone of armour plate 5 of grading device 4 within one complete turn of the rotor;

$$m = Q_H \cdot \rho \cdot T, \tag{14}$$

where Q_H – the volume of the material in the opening between the external row of hammers 3 and the internal surface of the grading device 4;

ρ – the density of particles.

Substituting (4) and (3) makes expression (3) look as follows:

$$m = \frac{\pi^2}{2} \cdot \psi \cdot D_{on}^2 \cdot h \cdot \rho. \tag{15}$$

Taking into account the results of (9), (10) and (15), formula (13) turns into:

$$\Delta E_1 = \frac{\pi^2}{4} \psi D_{on}^2 \cdot h \cdot \rho \cdot \frac{1}{\mu^2} \left(\sigma_{max}^2 \Delta_{min}^2 - \sigma_{min}^2 \Delta_{max}^2 \right), \tag{16}$$

where σ_{max} – the maximum transverse strain;

σ_{min} – the minimum transverse strain.

Substituting (16) and (12) in (11) eventually results in:

$$P_1 = \frac{\pi^2 \psi}{\mu^2} D_{on}^2 \cdot h \cdot \rho \cdot \omega \cdot \left(\sigma_{max}^2 \Delta_{min}^2 - \sigma_{min}^2 \Delta_{max}^2 \right) \tag{17}$$

Therefore, resulting expression (17) determines the power demand, necessary to grind the material in the action zone of armour plates 5 of grading device 4.

For defining the power, which is required to rotate grading device 4 with armour plates 5 (Fig. 2), it is necessary to consider the geometry of armour plate 5, shown in Fig. 2b. The coordinate system is as given in Fig. 2b. Thus armour plate 5 consists of four elements with the same angular dimension (Fig. 2c). Using the calculation, presented in Fig.2b, the authors determine the coordinates of points from 1 to 8, taking into account the fact that the radial distance from the rotational centre of rotors to points 3, 5, 7 increases by the same distance mm. The points with even numbers 2, 4, 6, 8 have the same distance from the axis of rotation. It follows from the above said that in the two-dimensional cartesian reference system «xoy» (Fig. 2b), the coordinates of the points under study can be presented as:

$$x_{2n-1} = (R_2 + \Delta \cdot n) \cos((n-1) \cdot \Delta\varphi); \tag{18}$$
$$y_{2n-1} = (R_2 + \Delta \cdot n) \sin((n-1) \cdot \Delta\varphi),$$

$$x_{2n} = R_b \cdot \cos(n \cdot \Delta\varphi); \tag{19}$$
$$y_{2n} = R_b \cdot \sin(n \cdot \Delta\varphi),$$

where the index «n» can become n= 1,2,3,4.

Connection of points pairs (1,2); (3,4); (5,6); (7,8) represents direct lines with the equations that in the two-dimensional cartesian reference system «xoy» with the angular coefficient can look like:

$$y_n = K_n X_n + b_n. \tag{20}$$

In polar coordinate system (r,χ), the reference to the cartesian system is realised through:

$$\begin{cases} x = r \cos\chi, \\ y = r \sin\chi. \end{cases} \tag{21}$$

Using (21), the equation of direct lines (20) in the polar coordinate system looks:

$$r_n \sin\chi = K_n \cdot r_n \cdot \cos\chi + b_n. \tag{22}$$

Allowing (22) in relation with the value «rn»:

$$r_n = \frac{b_n}{\sin \chi - K_n \cdot \cos \chi}. \tag{23}$$

To obtain the coefficients «Kn»,«bn», it is necessary to apply (18) and (19).

Using (18) in relation with (20) results in the following:

$$(R_2 + \Delta \cdot n) \cdot \sin((n-1)\Delta\varphi) = K_n (R_2 + \Delta \cdot n) \cdot \cos((h-1)\cdot \Delta\varphi) + b_n. \tag{24}$$

In its turn, applying (19) to (20) leads to the following:

$$R_b \sin(n \cdot \Delta\varphi) = K_n \cdot R_b \cos(n \cdot \Delta\varphi) + b_4. \tag{25}$$

Resulting relations (24) and (25) represent the system of two linear equations in the unknown « K_n », « b_n ».

The solution of this equations' system results in the following expressions:

$$K_n = \frac{R_b \cdot \sin(n \cdot \Delta\varphi) - (R_2 + n \cdot \Delta) \cdot \sin((n-1) \cdot \Delta\varphi)}{R_b \cdot \cos(n \cdot \Delta\varphi) - (R_2 + n \cdot \Delta) \cdot \cos((n-1) \cdot \Delta\varphi)}, \tag{26}$$

$$b_n = \frac{R_b \cdot (R_2 + n \cdot \Delta) \cdot \sin(\Delta\varphi)}{R_b \cdot \cos(n \cdot \Delta\varphi) - (R_2 + n \cdot \Delta) \cdot \cos((n-1) \cdot \Delta\varphi)}. \tag{27}$$

Power demand « P_2 », which is required to rotate grading device 4 with armour plates 5, installed in the desintegrator, is defined as:

$$P_2 = E_{rot} \cdot \omega, \tag{28}$$

where E_{rot} – the kinetic energy of grading device 4 as a result of its rotation which is equal to [7]:

$$E_{rot} = \frac{M_0^2}{2I_0^2}, \tag{29}$$

where M_0 – the moment of impulse of grading device 4 with armour plates 5;

I_0 – the moment of inertia of grading device 4 with armour plates 5.

The moment of impulse can be found using the following expression [8, 9]:

$$M_0 = M_y \cdot \omega \cdot R_b^3, \tag{30}$$

where M_y – the mass of installed grading device 4 with armour plates 5.

According to the calculation in Fig.2a, the moment of inertia of installed grading device 4 with armour plates 5 can be defined with the help of:

$$I_0 = 4I_{б.n.} + 4I_{ц}, \tag{31}$$

where I_c – the moment of inertia of one cylinder section of installed grading device 4 with armour plates 5;

$I_{a.p.}$ – the moment of inertia of the section of armour plate 5 equal to:

$$I_{a.p.} = \sum_{n=1}^{4} I_n, \tag{32}$$

where I_n – the moment of inertia of the «n» section element of armour plate 5, which can be found from the following expression [10]:

$$I_n = \rho_m \int_0^z dz \int_{\varphi_n}^{\varphi_n + \Delta\varphi} \left(\int_{r_n}^{R_b} r^3 dr \right) d\chi, \tag{33}$$

where ρ_m – the density of the material which is used to make installed grading device 4 with armour plates 5:

$$\varphi_n = (n-1) \cdot \Delta\varphi. \tag{34}$$

Upon integration of (33) in relation with the variables «z» and «r», expression (33) acquires the following look:

$$I_n = \frac{\rho_m \cdot b}{4} \cdot \left[b_n^4 \int_{\varphi_n}^{\varphi_n + \Delta\varphi} \frac{d\chi}{(\sin\chi - K_n \cdot \cos\chi)^4} - R_b^4 \cdot \Delta\varphi \right]. \tag{35}$$

In its turn, the moment of inertia of one perforated cylinder section 6 of grading device 4 is equal to:

$$I_n = m_c \cdot R_b^2, \tag{36}$$

where m_c – the mass of one perforated cylinder section 6 of grading device 4, which is determined as:

$$m_c = \rho_m \int_0^b dz \int_0^{\pi/4} d\chi \int_{R_b - \Delta R}^{R_b} r dr, \tag{37}$$

where ΔR – the thickness of the cylinder surface of installed grading device 4.
The evaluation of the integral in formula (37) results in:

$$m_c = \frac{\pi}{8} \rho_m \cdot b \cdot \left(R_b^2 - (R_b - \Delta R)^2 \right). \tag{38}$$

Due to the fact that the thickness of the cylinder surface of installed grading device 4 is small, formula (38) can be presented as:

$$m_c \cong \frac{\pi}{4} \rho_m \cdot b \cdot R_b \cdot \Delta R. \tag{39}$$

Substituting (32), (36) with the account of (35),(39) in formula (31) leads to the following:

$$I_o = \rho_m \cdot b \left\{ \sum_{n=1}^4 \left(b_n^4 \int_{\varphi_n}^{\varphi_n + \Delta\varphi} \frac{d\chi}{(\sin\chi - K_n \cos\chi)^4} - R_b^4 \cdot \Delta\varphi \right) + \pi \cdot R_b^3 \cdot \Delta R \right\}. \tag{40}$$

Substituting (30) and (40) into (28) eventually results in:

$$P_2 = \frac{M_y^2 \cdot R_b^2 \cdot \omega^3}{2\rho m \cdot b \left\{ \sum_{n=1}^4 \left(\frac{b_n^4}{R_b^4} \cdot \int_{\varphi_n}^{\varphi_n + \Delta\varphi} \frac{d\chi}{(\sin\chi - K_n \cos\chi)^4} - \Delta\varphi \right) + \frac{\pi\Delta R}{R_b} \right\}}. \tag{41}$$

Substituting the resulting (17) and (41) into (1) enables one to obtain the following expression:

$$P = \frac{\pi^2 \psi}{\mu^2} \cdot D_{on}^2 \cdot h \cdot \rho \cdot \omega \left(\sigma_{max}^2 \Delta_{min}^2 - \sigma_{min}^2 \Delta_{max}^2 \right) +$$

$$+ \frac{M_y^2 \cdot R_b^2 \cdot \omega^3}{2\rho m \cdot b \left\{ \sum_{n=1}^4 \left(\frac{b_n^4}{R_b^4} \cdot \int_{\varphi_n}^{\varphi_n + \Delta\varphi} \frac{d\chi}{(\sin\chi - K_n \cos\chi)^4} - \Delta\varphi \right) + \frac{\pi\Delta R}{R_b} \right\}}. \tag{42}$$

Therefore, analytical method (42) enables one to calculate power input which is required to rotate

grading device 4 with armour plates 5 and perforated sections 6, as well as power demand for additional grinding and classifying the material. The power intake depends mostly on the geometrical parameters of the grinding chamber of the desintegrator.

2. Conclusion
Applying mathematical transformations, the authors have obtained the analytical model, enabling one to determine the additional power demand, caused by the installation of the grading device in the peripheral part of the grinding chamber in the desintegrator. The grading device improves the quality of the ground material via combining grinding and grading in the peripheral part. When calculating the power intake of the disintegrator, one takes into account the fact that extra power demand is necessary to rotate the grading device and to grind the additional material in the area between the external row of hammers and the grading device.

3. Summary
The resulting mathematical equations enable one to relate structural, technological and energy parameters of the desintegrator to the grading device.

When introducing a small amount of the aluminium oxide powder, the distance between the axes of the second-order dendrites and the average grain size reduces. This implies that a considerable part of the powder particles is effective crystallization centres. When increasing the nanopowder content, the structure starts coarsening relatively that, which was obtained using low powder concentrations. Introduction of the large quantity of the modifier leads to its coagulation and reduction of its influence on the structure.

4. Acknowledgments

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