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SPECIFYING THE PARAMETERS OF FLOW ASPIRATION IN THE TUBE MILL

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ABSTRACT

The aspiration pipe of cement mills was previously viewed by the industrial enterprises of building materials primarily as a process of reducing the emission of dust from the loading space in the neck of the mill shop and reduce airborne dust in the grinding part. The works of different authors have shown that the efficient mode of aspiration intensifies the mill work and the right choice of aspiration, the de-dusting units reduces the return of the discharged dust. These studies have not been completed yet. In this paper we will consider the analytical form of the expressions determines the resultant velocity components and the aspiration flow in the first chamber of the tube mill rotated with the drum mill. It was established that the helical pitch of the aspiration flow in the chamber is inversely proportional to the volumetric flow rate of the air mass and directly proportional to the speed of the drum. The grinding bodies decrease the oscillation amplitude of masses aspiration by the increasing of the load factor of camera. The analytical dependences allow defining the rational modes of aspiration and required air flow.

Keywords: tube mill, aspiration, travelling speed, cement.

INTRODUCTION

In the production of building materials it is necessary to fine grinding of raw component [1]. Fine grinding of materials is carried out in various grinding operations of the grinding aggregates: spherical, rod, tube, roller, roller pendulum, paddle-type mill, mine, vibration, jet mills, grinding mills [2, 3].

The ball drum mills are widely spread among the grinding units: in Russia their share is about 95%, abroad - 80%.

The cement factories in Russia and in the CIS countries have adopted different technological systems of grinding materials. The choosing one or another of them depends on the production scheme, size distribution of the product and other conditions. The clinker grinding with additives used primarily ball tube mills with capacity up to (50 ÷ 100) m/h or more [4]. The aspiration system of the grinding circuit tube mills allow to remove the dust particles of air flow direction, to make the additional drying of the material and thus to intensify the grinding process [5, 6].

The aspiration tube in the ball mill (tube ball mill) removes fine particles of the material which in turn can significantly reduce the aggregation process of the ground particles; they stick to the grinding balls and to lining [7]. Rationally chosen aspiration mode significantly enhances the efficiency of the grinding material in the mill [8].

The lack of the rational regime of mill aspiration leads to its steaming, grinding material build up on the lining and grinding media and thus poor performance and the specific energy consumption [9, 10].

The tube mill with the suction mode causes a number of problems [11] the solution of which is an urgent task. The process of air masses movement in the chambers of the tube mill has not been currently studied enough.

The number of works were devoted to the mathematical description of the aspiration process of tube mills [12, 13], the main drawback of which is a phenomenological approach to the description of the process. In this work we'll offer the mathematical description of the aspiration of the first chamber of the mill with waterfall mode.

RESULTS AND DISCUSSIONS

The main parameter of the directional air flow is its speed.

We carry out a description of the velocity field of the air flow which is formed in the first chamber in the tube ball mill with the waterfall regime motion of grinding bodies. We'll consider a three-dimensional model of the grinding machine.

Aerodynamic airflow velocity field in the tube ball mill will be formed by the flowing air through the boot cylindrical bore of the auger with diameter d and the entrainment of aspiration flow loading drum of the tube ball mill into the rotational motion speed mill [omega].

Accordingly a drum in the tube ball mill will form a spiral suction flow moves along the axis of the drum. Due to the axial symmetry of the device in question we'll find the velocity vector field of air flow and introduce a cylindrical coordinate system r, [phi], z which began at the end we'll choose the feed opening and the z-axis directed along the axis of the drum mill. Unit vectors $\vec{e}_r, \vec{e}_\varphi, \vec{e}_z$ directed along the axes r, [phi], z (see Figure-1).

We'll use the equation for isothermal air flow to calculate the velocity field of the air flow in the first chamber in tube ball mill:

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$$\operatorname{div} \cdot \vec{\vartheta} = 0. \tag{1}$$

The equation (1) is convenient to look at the form of the velocity potential $\Phi(r, \varphi, z)$, which air velocity vector [theta] is related to the following expression:

$$\vec{\vartheta} = -\operatorname{grad} \varphi. \tag{2}$$

Substituting the expression (2) into (1) leads the following differential equation:

$$\Delta\Phi = \frac{1}{r} \cdot \frac{d}{dr}\left(r \cdot \frac{d\Phi}{dr}\right) + \frac{1}{r^2} \cdot \frac{d^2\Phi}{d\varphi^2} + \frac{d^2\Phi}{dz^2} = 0. \tag{3}$$

From the above solution of the equation (3) will be sought in the form of a spiral helix of the following form:

$$\Phi(r, \varphi, z) = Y(r) \cdot \cos(k \cdot z - \varphi), \tag{4}$$

which describes the velocity potential in twisting spiral steps $2\pi/k$. Substituting (4) to (3) will enable ordinary differential equation for the unknown function Y(r):

$$\frac{d^2Y}{dr^2} + \frac{1}{r} \cdot \frac{dY}{dr} - \frac{1}{r^2} Y - k^2 Y = 0. \tag{5}$$

Solution of equation (5) are modified Bessel functions $I_1(k \cdot r)$ and $K_1(k \cdot r)$ of the first and second kind. Thus:

$$Y(r) = C_1 \cdot I_1(k \cdot r) + C_2 \cdot K_1(k \cdot r). \tag{6}$$

In view of (6), (4) expression (2) leads to the following form:

$$\vec{\vartheta}(r, \varphi, z) = -\left(C_1 \frac{dI_1(k \cdot r)}{dr} + C_2 \frac{dK_1(k \cdot r)}{dr}\right) \cdot k \times$$
$$\cos(k \cdot z - \varphi) \cdot \vec{e}_r - \frac{1}{r}\left(C_1 I_1(k \cdot r) + C_2 K_1(k \cdot r)\right) \times$$
$$\sin(k \cdot z - \varphi) \cdot \vec{e}_\varphi + \left(C_1 I_1(k \cdot r) + C_2 K_1(k \cdot r)\right) \cdot k \cdot \sin(k \cdot z - \varphi) \cdot \vec{e}_z \tag{7}$$

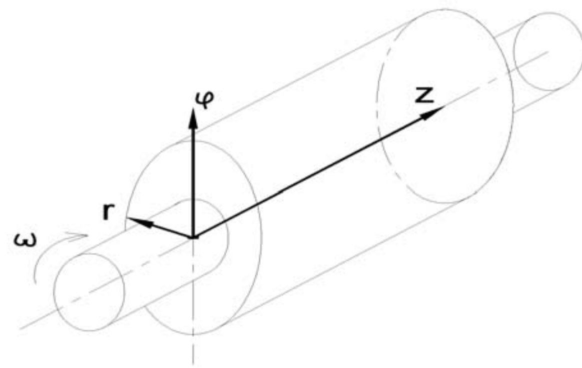

Figure-1. Coordinate system which determines the airflow speed.

On the basis of this relation (7) projection of the velocity vector of the air flow on the coordinate axes r, [phi], z respectively:

$$\vartheta_r = -\left(C_1 \frac{dI_1(k \cdot r)}{dr} + C_2 \frac{dK_1(k \cdot r)}{dr}\right) \cdot k \cdot \cos(k \cdot z - \varphi), \tag{8}$$

$$\vartheta_\varphi = -\frac{1}{r}\left(C_1 I_1(k \cdot r) + C_2 K_1(k \cdot r)\right) \cdot \sin(k \cdot z - \varphi), \tag{9}$$

$$\vartheta_z = \left(C_1 I_1(k \cdot r) + C_2 K_1(k \cdot r)\right) \cdot \sin(k \cdot z - \varphi). \tag{10}$$

On the basis of the relations (9) and (10) we'll establish the following relation:

$$\frac{k \cdot r \cdot \vartheta_\varphi}{\vartheta_z} = -1 = \text{const.} \tag{11}$$

Constants of integration C_1, C_2, and the coefficient k, present in the expressions (7) ÷ (10) can be found from the initial conditions imposed on the values of the components of airflow in the first chamber of the drum in tube mill. On the basis of (11) we conclude that:

$$\frac{k \cdot (R_0 - h) \cdot \vartheta_\varphi^{(0)}}{\vartheta_z^{(0)}} = -1, \tag{12}$$

where R_0 – the radius of the mill's drum.

$$h = h_1 - r_1, \tag{13}$$

where h_1 - thickness per load in rotation mode determined on the basis of the loading factor of the grinding media;
r_1 - average ball radius on the surface layer.

$$\vartheta_\varphi^{(0)} = -\omega(R_0 - h), \tag{14}$$

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where [omega] - speed air flow entrained by the moving loading distance $(R_0 - h_1)$ from the center of rotation. On the basis of the air flow equation we find that:

$$\vartheta_z^{(0)} = \frac{4Q}{\pi d^2}, \tag{15}$$

where Q - volumetric flow of the air mass that passes per unit time through a feed opening of a cylindrical shape with a diameter d.

Account relations (14) and (15) allows us to reduce the expression (12) to the following form:

$$\frac{\pi \cdot k \cdot R_0^2 (1-\xi)^2 \cdot \omega \cdot d^2}{4Q} = 1. \tag{16}$$

From (16) we find that the coefficient K:

$$K = \frac{4Q}{\pi d^2 \cdot R_0^2 \cdot \omega \cdot (1-\xi)^2}. \tag{17}$$

Thus according to the relation (16) the value of the helical pitch of the aspiration flow in moving tube mill drum is directly proportional to the square of the radius of the drum mill, the square of the diameter of the feed opening, the air flow speed in the drum and inversely proportional to the air flow.

If we consider that the projection of air flow velocity ϑ_φ and ϑ_z should have a finite value at r=0, that on the basis of the properties of the modified Bessel functions of the first and second kind in expressions (8)÷(10) a constant C_2 need to be set equal to zero, and the constant C_1 is found from the initial conditions imposed on radial projection of the velocity of air flow in the first chamber of the tube drum mill which will have the following form:

$$\vartheta_r = \frac{\omega \cdot R_0}{R_0} \sqrt{h(R_0 - h)} = \omega \cdot R_0 \sqrt{\xi(1-\xi)}. \tag{18}$$

Therefore, according to (8) and the values $z = 0, \varphi = 0, r = R_0 - h,$ we obtain the following equation for the unknown quantities C_1:

$$C_1 = \frac{d^2 I_1(k \cdot R_0(1-\xi))}{dr} \cdot k = \omega \cdot R_0 \sqrt{\xi(1-\xi)}, \tag{19}$$

solution which subject (17) leads to the following relationship:

$$C_1 = \frac{\pi\sqrt{\xi}(1-\xi)^{\frac{3}{2}} \cdot d^2 \cdot R_0^3}{4Q \dfrac{d}{dr}} = \frac{\omega R_0 \sqrt{\xi(1-\xi)}}{k \dfrac{d}{dr}(I_1(k \cdot R_0(1-\xi))}. \tag{20}$$

here $\xi = \dfrac{h}{R_0}.$

Substituting relations (17) and (20) in the expression (8)÷(10) leads to the following final expression:

$$\vartheta_r = -\frac{\omega \cdot R_0 \sqrt{\xi(1-\xi)}}{\dfrac{dI_1(k \cdot R_0(1-\xi))}{dr}} \cdot \frac{dI_1(k \cdot r)}{dr} \cdot \cos(k \cdot z - \varphi), \tag{21}$$

$$\vartheta_\varphi = -\frac{\pi\sqrt{\xi}(1-\xi)^{\frac{3}{2}} \cdot d^2 \cdot R_0^3}{4Q \dfrac{d}{dr}(I_1(k \cdot R_0(1-\xi)))} \cdot \frac{I_1(k \cdot r)}{r} \cdot \sin(k \cdot z - \varphi), \tag{22}$$

$$\vartheta_z = \frac{\omega \cdot R_0 \sqrt{\xi(1-\xi)}}{\dfrac{dI_1}{dr}(k \cdot R_0(1-\xi))} \cdot I_1(k \cdot r) \cdot \sin(k \cdot z - \varphi). \tag{23}$$

Thus the expression (21) ÷ (23) defines the projection of the air flow rate in the first chamber of the drum in tube mill.

Figure-2 shows a graph of the radial component of air flow velocity depending on the length of the grinding chamber and the distance from the rotational center of the spiral to the load factors at different grinding.

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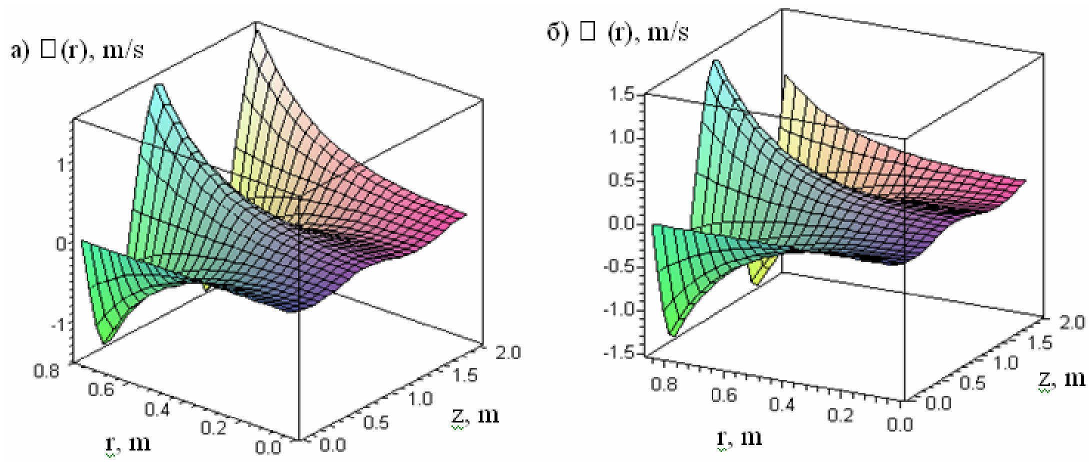

Figure-2. Dependence of the radial component of the velocity of air flow from r and z: φ=0.3; b) φ=0.25.

Figure-3 shows the dependence of modulus of the resultant air flow velocity in the chamber of the mill and the length of the chamber of air mass layer.

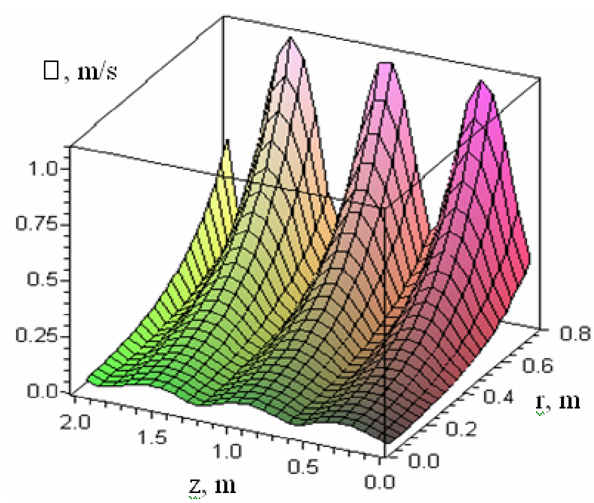

Figure-3. Dependency module airflow from parameters r and z.

According to the graphical dependencies (see Figure-2) the traffic flow in the suction chamber tube mill depends significantly on the length of the chamber.

In the central part of the drum there is a slight change of direction of air flow rate. The amplitude of oscillation speed when approaching flow to the body increases dramatically due to the reflective walls of the body that cause the oscillatory movements of air masses.

Air flow (Figure-3) slides over the surface of the grinding load moving with angular velocity [omega]. The aspiration flow movement through the mills chamber in contiguity to the drum walls and the loading surfaces occurs in the spiral with a step $2\pi/k$. The typical sinusoidal law changes in the flow rates with a small amplitude in the center of the mill.

CONCLUSIONS

The aspiration tube in the ball mill (tube mill) provides the removal of the fine particulate material which in turn significantly reduces the aggregation process of the ground particles; they stick to the grinding balls and the lining. The rationally chosen aspiration mode allows the air flow rate which removes the particulate material of a certain size and also can significantly improve the efficiency of the grinding mill material [14, 15].

Findings

The analytical form of the expressions determined the resultant velocity of components and aspiration flow in the first chamber of tube mill rotated with the drum mill.

It was established that the helical pitch of the aspiration of air in the chamber is inversely proportional to the volumetric flow rate of the air mass and directly proportional to the speed of the drum. The increase of the load factor camera of the grinding bodies decreases the oscillation amplitude of aspiration of the masses.

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