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AN INFLUENCE OF CHARACTERISTICS OF TWO-COMPONENT FLOW ON THE SUPPLY EFFECTIVENESS OF ABRASIVE MATERIAL INTO THE CONTACT AREA OF A LOCOMOTIVE WHEEL AND RAIL

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Summary. The process of interaction of suspension air flow and abrasive material particle in the output device of sand supplying system of the locomotive is considered. Mathematical model of the particle motion is set up, calculated trajectories of the particles motion for different diameters are presented, the recommendations for grading composition choice of the used abrasive material are given.

Key words: coefficient value of the wheel and rail engagement, sandfeed system, air flow, composition of abrasive material.

INTRODUCTION

In the realization process of fraction force and rolling stock braking it is necessary to maintain the coefficient value of the wheel and rail engagement. Quarts sand feed into the contact area of the wheels and a rail is a widely used way of this problem's solution at the railway transport nowadays. Pneumatic systems are widely used for sand supply into the contact area. Quarts sand which is used in railway transport is a polydispersed material. The sand particles of different size acquire different velocity while interacting with transportation air flow. That is why the amount of sand particles which ingress into the contact area is considerably smaller than the amount of sand supplied by a sandfeed system. According to some data the amount of sand which does not ingress into the contact area makes from 20 to 80 % (in dependence on the locomotive motion) from the total amount of sand which is supplied to the rolling stock wheels [4].

In connection with this there appeared some problems concerning nonproductive sand consumption:

- sand contamination of ballast prism of rail track;
- increased wear of wheels and rails operating surfaces;
- decrease of engagement coefficient of wheels and rails;
- economical losses of nonproductive sand consumption.

The solution of these problems is possible on condition that the work effectiveness of sand feeder is increased. The effectiveness is determined by the ratio of sand quantity ingressing into the contact area to the total quantity of supplied sand.

OBJECTS AND PROBLEMS

To increase work effectiveness of sand feeder it is necessary to find out the interaction mechanism of air flow and the sand particles.

The main factors influencing the value and velocity direction of sand particles are their sizes and parameters of air flow in the output devices of the sand feeder.

This paper considers the systems of sand supply with small volume concentration of sand particles in the sand air mixture. If there are small values of concentration volume of solid particles in the air flow it is possible to neglect their influence on the formation of velocity flow field [5]. In this case the study of the sand motion mechanism in the air flow can be carried out on the basis of solitary sand particle motion mechanism analysis in the known velocity field of carrying air flow.

While analyzing sand particle motion the following assumptions were made:

- the particles are monodispersed and have a spherical shape;
- the particles do not interact between each other and with channel walls.

While setting up the equations of the particle motion, weight force and the force of hydrodynamic nature were taken into account which depend only on averaged values of air flow parameters. With the particle sizes (δ > 0,2 mm), the influence of turbulent pulsations on their motion can be neglected [6]. The analysis of big quarts sand particles (size δ > 0,4 mm) motion in the cylindrical channel of sand-providing device situated under the angle α to the horizontal plane was made. The motion is considered in the vertical plane passing through the channel axis (the axis x is directed along the channel axis).

$$\begin{aligned} m_P \cdot \frac{du_{PX}}{dt} &= f_{AX} + m_P g \sin\alpha \\ m_P \cdot \frac{du_{PY}}{dt} &= -f_{AY} - m_P g \cos\alpha - f_{GR} \end{aligned}, \qquad (1)$$

where: $m_P = \dfrac{\pi \cdot \delta^3 \cdot \rho_P}{6}$ – particle mass;

ρ_P – actual density of the material particle;

u_{PX} – projection velocity on the axis x;

f_{AX} – force projection of aerodynamic resistance on the axis x;

u_{PY} – particle velocity projection on the axis y;

f_{AY} – force projection of aerodynamic resistance on the axis y;

f_{GR} – the force stipulated by transverse velocity gradient in the air flow;

g – free fall acceleration.

The force of aerodynamic resistance with the particle motion is determined by the expression [9]:

$$\vec{f}_A = \zeta \frac{\rho}{2} s \cdot \left|\vec{u} - \vec{u}_P\right| \cdot \left(\vec{u} - \vec{u}_P\right), \qquad (2)$$

where: ζ – the coefficient of aerodynamic resistance of the particle;

ρ – suspension flow density;

$s = \pi \dfrac{\delta^2}{4}$ – the area of particle midsection;

$\vec{u}$ – flow velocity;

$\vec{u}_P$ – particle velocity.

In a common case the coefficient of the aerodynamic resistance of the particle is a unique function of Reynolds number *Re*:

$$\mathrm{Re} = \left|\vec{u} - \vec{u}_P\right| \cdot \frac{\delta}{\upsilon}, \tag{3}$$

where: υ – kinematic air viscosity.

For the investigated regime of the values of relative particle velocity and its dimensions Reynolds value will be more than 800 (*Re>800)*. In this case the coefficient value of aerodynamic resistance does not depend on the Reynolds number and takes the value $\zeta = 0,44$ [8].

Force projection of aerodynamic resistance on the coordinate axis is determined by the equations:

$$f_{AX} = \zeta \frac{\rho}{2} s \sqrt{u^2{}_{PY} + \left(u - u_{PX}\right)^2} \left(u - u_{PX}\right), \tag{4}$$

$$f_{AY} = \zeta \frac{\rho}{2} s \sqrt{u^2{}_{PY} + \left(u - u_{PX}\right)^2} u_{PY}. \tag{5}$$

The transverse force has an effect on the particle moving in the flow. This force can be set up by the particle rotation round the axis, perpendicular to the direction of longitudinal velocity (Magnus force), availability of transverse gradient of longitudinal velocity of the flow or joint action of these factors (Safman force) [2].

Suspension air flow in the output device of the sandfeeding system has a considerable transverse velocity gradient. The conditions of the particle input into the flow show that rotation particle effect at the initial moment of time is absent. At the time of the particle motion in the flow with its transverse migration, the difference of velocities of its flow in diametrically opposite places is varied in value and symbol. There are no reasons for appearance of rotary particle motion. In this case the value of transverse force can be determined by Zhukovsky formula [3]:

$$f_{GR} = \int_{-\frac{\delta}{2}}^{\frac{\delta}{2}} \rho \left(u - u_{PX}\right) \Gamma\left(z\right) dz, \tag{6}$$

where: Γ(z) – velocity vector circulation along closed contour.

In each plane sphere section perpendicular to the axis z (the axis z is situated perpendicular to the plane of axis x, y) the radius value *r*:

$$r = \sqrt{\left(\frac{\delta}{2}\right)^2 - z^2}. \tag{7}$$

The circulation of velocity vector along the surface of each elementary part of the sphere with thickness *dz*:

$$\Gamma = 4\pi \cdot r^2\left(z\right) \cdot \frac{du}{dy}. \tag{8}$$

After integration of the expression (6) due to the expressions (7) and (8), we get the equation for transverse force value acting on the particle, stipulated by velocity gradient in the suspension flow:

$$f_{GR} = \frac{2}{3}\pi \cdot \rho \cdot \delta^3 \cdot \frac{du}{dy} \cdot \left(u - u_{PX}\right). \tag{9}$$

After substitution of the equations (4), (5), (9) into the system of equations (1) and division of each equation into m_P, the system of the equation is obtained:

$$\begin{aligned} \frac{du_{PX}}{dt} &= \frac{3}{4}\zeta\,\frac{\rho}{\rho_P \cdot \delta}\sqrt{u^2{}_{PY} + \left(u - u_{PX}\right)^2} \cdot \left(u - u_{PX}\right) + g\sin\alpha \\ \frac{du_{PY}}{dt} &= -\frac{3}{4}\zeta\,\frac{\rho}{\rho_P \cdot \delta}\sqrt{u^2{}_{PY} + \left(u - u_{PX}\right)^2} \cdot u_{PY} - g\cos\alpha - 4\frac{\rho}{\rho_P}\cdot\frac{du}{dy}\cdot\left(u - u_{PX}\right). \end{aligned} \tag{10}$$

The diagram of suspension flow in the channel of output device of sand feeder is presented in Fig. 1. Air jet coming from the nozzle is spread in the channel in accordance with the mechanism for flooded turbulent jets [1], [7]:

$$b = \frac{d_0}{2} + x \cdot tg\frac{\varphi}{2}, \tag{11}$$

$$u_{OC} = u_0\left(0{,}3 + 0{,}14\frac{x}{d_0}\right)^{-1}, \tag{12}$$

$$u = u_{OC}\left(1 - \left(\frac{y}{b}\right)^{\frac{3}{2}}\right)^2. \tag{13}$$

Here b – halfwidth of the jet, u_0 – velocity of the output air flow, u_{OC} – air velocity on the axis of the main area of the jet.

The equations (11) and (13) are just for the jet halfwidth.

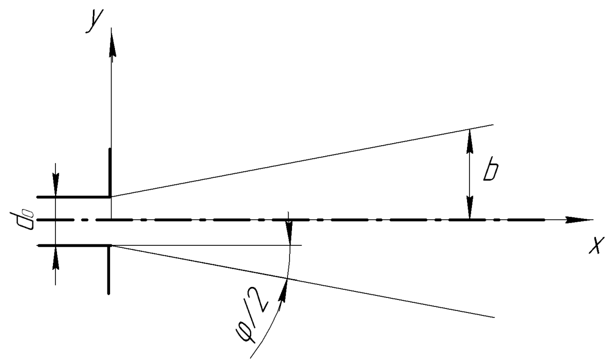

Fig. 1. Suspension air flow in the channel of output device of sand feeder

From the equations (11), (12), (13) we obtain the dependence of velocity of suspension flow on the coordinates x and y for the main part of the jet:

$$u = \frac{u_0}{0{,}3 + 0{,}14\dfrac{x}{d_0}}\left(1 - \left(\frac{|y|}{\dfrac{d_0}{2} + x \cdot tg\dfrac{\varphi}{2}}\right)^{\frac{3}{2}}\right)^2. \tag{14}$$

To calculate the value of transverse force f_{GR} it is necessary to determine the velocity derivative u of the suspension flow by coordinate y:

$$\frac{du}{dy}=\frac{3u_0}{0,3+0,14\dfrac{x}{d_0}}\cdot\left(\frac{y^2}{\left(\dfrac{d_0}{2}+x\cdot tg\dfrac{\varphi}{2}\right)^3}-\frac{\left(|y|\right)^{\frac{1}{2}}}{\left(\dfrac{d_0}{2}+x\cdot tg\dfrac{\varphi}{2}\right)^{\frac{3}{2}}}\right)\frac{|y|}{y}. \tag{15}$$

The equations (14) and (15) are spread for the whole jet area.

The mathematical model allows to carry out optimization of operating characteristics of sandfeeding system in the direction of grading composition selection of the used sand and selection of the parameters of suspension air flow with the purpose of effectiveness increase of sand particles supply into the contact area of a locomotive wheel and rail.

Figure 2 presents the trajectories of sand particles of different sizes which were calculated with the help of the given model. Integration of the equations was carried out under identical initial and boundary conditions for the particles with the diameter δ=1,3; 1,4; 1,5; 1,6 mm.

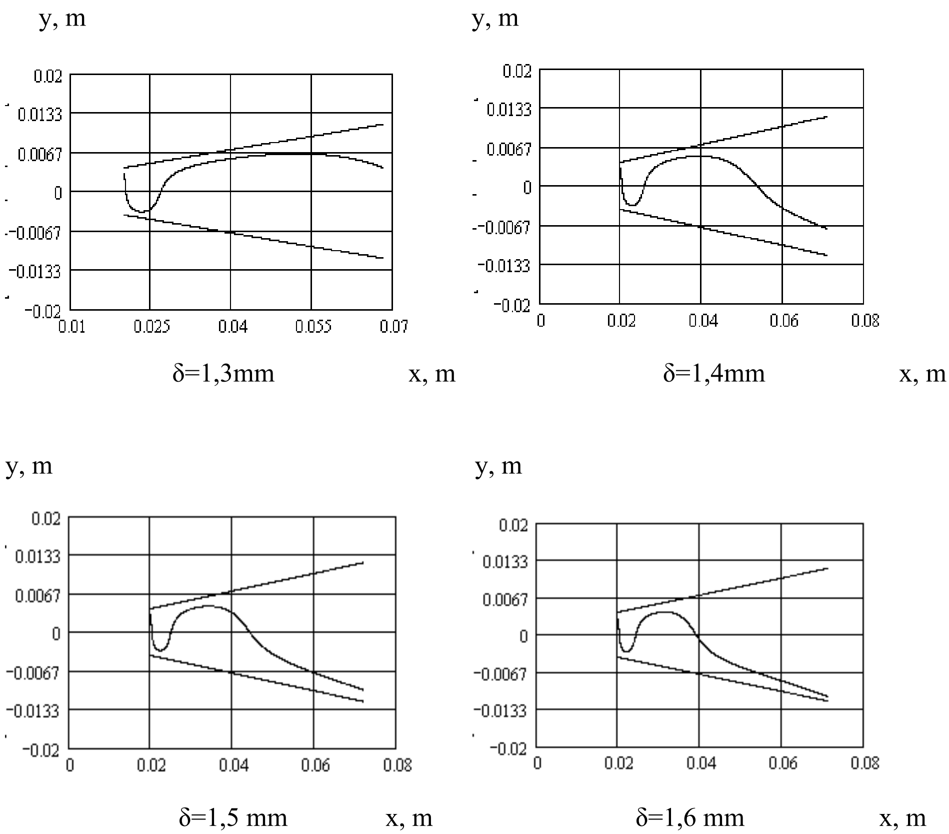

Fig. 2. The trajectories of sand particles of different sizes

CONCLUSION

The obtained results show that the trajectories of the particles of different sizes are rather different. After the collision among the particles their trajectories will have indeterminate nature and it will increase their scattering while moving into the contact area of a wheel and a rail. In this connection it is possible to recommend using monodispersed abrasive materials in accordance with granulometrical composition. For successful ingressing of sand particles into contact area of a wheel and rail the trajectory of their motion must be rather stable. Therefore, it is necessary to use grain size inertional particles.

In this case the particles with the diameter δ=1,5 mm and δ=1,6 mm had closer trajectories. For the particles of these sizes a stabilized part of the trajectory appears earlier.

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WPŁYW WŁAŚCIWOŚCI DWU-SKŁADNIKOWEGO PRZEPŁYWU NA WYDAJNOŚĆ MATERIAŁU ŚCIERNEGO W KONTAKCIE KOŁA LOKOMOTYWY Z TOREM

Streszczenie. Omówiono proces interakcji przepływu powietrza w zawieszeniu i cząstek materiału ściernego w systemie wyrzutu piasku lokomotywy. Zaproponowano matematyczny model ruchu cząstek, obliczono trajektornie ich ruchu dla różnych średnic, przedstawiono możliwości oceny składu używanych materiałów ściernych.

Słowa kluczowe: wartość współczynnika pracy kół i toru, system zasilania piaskiem, przepływ powietrza, skład materiałów ściernych.