Analysis of the pneumatic actuator of traction machines sand feeding system when the sand-air mixture flows out

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Abstract. In the course of the study, a computational experiment is carried out using ANSYS Fluent software package for three-dimensional models of the outflow of air-sand mixture from the outlet pipe of the locomotive sand feeding system to determine the effect of the shape of the outlet cross-section on the transportation of quartz sand particles at various outlet flow velocities.

1. Introduction

The pneumatic actuator in railway transport has been widely used on rolling stock of various types and purposes; compressed air with a maximum operating pressure of up to 0.9 MPa is used as a drive energy-carrying. Pneumatic systems are used to drive electric devices, mechanical (pneumatic and electro-pneumatic) brakes. On a traction rolling stock, a pneumatic compressor, as a source of compressed air and its consumers, together with control devices, pipelines, shutoff valves, form three pneumatic drive systems: brake, auxiliary and sand (sand feeding system).

The locomotive sand feeding system is used to increase the adhesion of driving wheels to the rails and prevent excessive slippage under difficult and adverse operating conditions in traction mode, as well as in emergency and service braking, thereby reducing the braking distance by increasing the additional resistance to train movement by feeding quartz particles in a stream of compressed air into the zone of contact of the wheels with the rails.

Transportation of quartz sand in a stream of compressed air to the area of contact of the locomotive wheels with the rails to increase adhesion is one of the most effective methods to prevent slipping. Even though this method of increasing and stabilizing the adhesion coefficient has been used for more than one hundred and fifty years, the pneumatic sand feeding system still has several significant drawbacks that reduce its reliability or disable it. Such negative factors are both structural and operational: partial blockage of pipe fittings or its complete blockage; a decrease in the quality of quartz sand when excessive moisture gets into it due to poor preparation and storage, as well as leakage of locomotive sandboxes; low velocity of the outlet flow of the sand-air mixture from the outlet pipe leads to the short flight of large particles and to the blowing away of small sand grains during of its transportation under the locomotive wheels, especially when exposed to cross-wind, it is the reason that is not enough quantity of sand in the cohesion zone; deregulation of sand distributor, which leads to an excessive consumption of sand, and consequently an increase in the resistance to train movement, without a significant increase in the adhesion of wheels to rails, often even to its reduction.

From the technical and scientific literature [1, 2], as well as the authors’ own research, it is known [3] that a significant amount of sand is blown away when it is transported from the outlet pipe to the rail...
surface. The reason for this is low velocity of the sand-air mixture outflow, which is unstable to the effects of cross wind.

So when operating the existing standard sand feeding systems for serial electric locomotives of the main railways with a maximum sand discharge of 1,500 g/min, the outflow rate of the sand-air mixture due to the design features of the actuators and complicated configuration of the air ducts is about 10-15 m/s, and with the known ways of supplying additional air to the transportation line - the velocity does not exceed 20 m/s with twice the flow rate of compressed air. In this regard, much attention is paid to the adjustment and installation of fill sleeves relative to the rail surface and the central axis of the wheels. During maintenance and repair of various levels of rolling stock, an important task is maintenance of the sand system with correctly set up outlet pipe in accordance with the requirements of technical documentation. Accuracy of the outlet pipe's location directly affects efficiency of the sand feed and the necessary amount of particles in the contact zone of the wheels with the rails.

Based on the analysis carried out in [4], a generalized calculation scheme for modeling the outflow of a sand-air mixture was developed (Figure 1).

![Figure 1. Calculation scheme for modeling the outflow of sand-air mixture.](image)

Thus, the task is to assess the influence of the shape of the outlet cross-section of the sand-air outlet pipe on the characteristics of the sand-air mixture transportation.

2. Methods

The gas flow is assumed to be turbulent, the mutual influence of the sand grains movement and outlet flow on each other is possible. The content of sand particles of different quality by size for sandboxes of locomotives is regulated by technical requirements and is modeled by distribution.

To simulate the motion of a continuous medium, a realizable $k$–$\varepsilon$ turbulence model [5] with wall functions in the form of Enhanced Wall Treatment [6] of the Fluent software package is used.

Let us use the Rosin-Rammler Diameter Distribution expression to describe sand grain sizes

$$Y_d = e^{-\left(\frac{d}{\bar{d}}\right)^n},$$

where $n$ – the distribution parameter; $\bar{d}$ – the constant, which in meaning represents the average particle diameter.
The coefficients in (1) were experimentally obtained in [7]. The following parameters are used in the model (Fluent) for modeling the sand-air mixture. Total flow rate (kg/s) 0.025, min. diameter (m) 0.0001, max. diameter (m) 0.002, mean diameter (m) 0.0003842, spread parameter 4.768.

The motion of sand particles is described using the equations presented in [8]. The aerodynamic drag coefficient is according to [9]. The aerodynamic drag coefficient for particle rotation is according to [10]. The lifting force of Magnus [11].

Let us present the computational domain together with the characteristic solutions of the flow velocity and particle concentration in Figure 2. We will describe the boundary conditions. The boundary condition on the boundary: A – ‘wall’ is the surface of the fill sleeve, B – ‘velocity inlet’ is the velocity of air flow from the fill sleeve; C – ‘symmetry’; D – ‘wall’.

![Figure 2. Computational domain.](image)

3. Results
The simulation results for the initial outflow velocities $u_{0} = 5, 10, 30$ m/s and the cutoff angles of the outlet cross-section of the outlet pipe $0^\circ$ on the left and $45^\circ$ on the right are shown in Figures 3 - 8. The particle velocities are constructed — the ordinate axis and particle path length along the trajectory - abscissa axis. The obtained data analysis was carried out using boxplot. On each box, the central mark indicates the median, and the bottom and top edges of the box indicate the 25th and 75th percentiles, respectively. The whiskers extend to the most extreme data points not considered outliers, and the outliers are plotted individually using the ‘+’ symbol.
Figure 3. Particle velocities for an initial outflow velocity of 5 m/s

Figure 4. Particle velocities for an initial outflow velocity of 10 m/s

Figure 5. Particle velocities for an initial outflow velocity of 30 m/s
Figure 6. Statistic characteristics of particles for an initial outflow velocity of 5 m/s

Figure 7. Statistic characteristics of particles for an initial outflow velocity of 10 m/s

Figure 8. Statistic characteristics of particles for an initial outflow velocity of 30 m/s

4. Discussion
The above results in Figure 3 show that the particle velocities visually differ at outlet flow velocities of 5 m/s. At a distance of 0.5 m, the speed of the slow part of the flow is slightly higher on the right graph. This is confirmed on boxplot, if you look at outliers. In other cases, the mean value for the right graph
is higher. In all other cases, a change in the shape of the outlet cross-section with an increase in the outflow velocity does not significantly affect the particle movement.

It should be noted that at a speed of 30 m/s all particles leave the computational domain and do not fall to the lower boundary. At speeds of 5 and 10 m/s, the particles do not leave the computational domain and remain at the lower boundary. The range of a particle at a speed of 10 m/s is, at best, about 1 m further in comparison with 5 m/s.

5. Conclusion

Based on the foregoing, the following conclusions can be made. The shape of the outlet cross-section of the outlet pipe affects the sand-air mixture transportation only at low flow rates. Given the need to increase the outflow velocity of the mixture to compensate for the negative effects of crosswind and other factors to at least 30 m/s, under these conditions the outlet cross-sectional shape will not affect the process.

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