Simulation of the kinematics and gas dynamics of the centrifugal dispersion stand

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Abstract. The article studies the kinematics and gas dynamics of the centrifugal dispersion stand for spheroidizing hard alloy materials. When studying the process of centrifugal spraying on an experimental setup, it was found that the behavior of particles in the volume of the dispersion chamber is determined by the aerodynamics of gas flows formed in the working chamber. It is assumed that under the influence of gas flows, a spontaneous classification of the particles of the medium occurs, determined by the size of the latter. To study the trajectory of movement of particles of powder material in the working chamber and the deposition process, a gas-dynamic model of a centrifugal dispersion unit in the SolidWorks FlowSimulation application is proposed. The developed model of the centrifugal dispersion unit showed the possibility of operational analysis of the behavior of the gas flow, the trajectory of the particles of the powder material and the temperature of the obtained powder material, depending on the design and technological factors. The simulation results allow one to determine the principles of separation of a heterogeneous medium of particles into fractions, directly at the installation for the implementation of the method.

1. Introduction
At present, additive technologies for the manufacture of products in industry and powder metallurgy are becoming more and more widespread [1]. The raw materials for these technologies are various metallic and non-metallic powder materials. The spread of technologies for manufacturing parts from powder materials is limited by the availability, price and quality indicators of the composition of powders.

The qualitative indicators of powder raw materials for additive technologies are the shape and fractional size of particles, the presence or absence of heterogeneity of the structure of the material of the particles, surface texture, surface activation, the level of contaminants and their distribution gradient over the surface and volume of particles [2, 3, 4, 5, 6].

The production of finely dispersed powder materials by centrifugal spraying of melts is a promising and inexpensive method for obtaining raw materials for additive technologies [7].

For the spheroidization of hard alloy materials, a centrifugal spraying method has been developed [8]. Centrifugal spraying is carried out on a stand, which consists of a sealed chamber containing a disk with a vertical axis of rotation, a melt supply system, a cooling system and a trap for collecting the resulting material. The dosed supply of the molten material is carried out by a special device to the end surface of the rotating disk. The normalized gap between the feed device and the disc, as well as the high angular velocities of the disc ensure the atomization of the melt and its subsequent crystallization, provide the possibility of obtaining spherical powders with a particle size suitable for additive
technologies [9]. The design of the stand as a whole and the trap in particular was determined by calculating the kinematics of the spray plume of melt particles [10].

In addition to thermodynamic parameters, which are fundamental for describing the operation of the stand, the kinematic parameters of the spraying process have a significant impact on the result of dispersion. The condition for the spraying of the melt is the high linear velocity of the droplets imparted by the centrifugal forces when they leave the edge of the disk, due to which the layer of the melt is separated into individual particles. The next stage of obtaining a powder material is the crystallization process, which must occur before collision with the structural elements of the installation and the trap, due to which the production of spherical powders is ensured. Further, the powder particles under the action of inertial forces move into the storage ring, where, after collision with the medium of the trap or its walls, they settle and, after cooling, are removed.

2. Methods

To implement the method and study the process of centrifugal spraying, an experimental setup was developed and manufactured, the main part of which is a high-speed rotor with a spraying disk. The dispersion process takes place in an inert argon gas environment, which prevents oxidation of the material. When debugging the technology, a wide range of materials was used as model dispersible media, from copper M1 [GOST 1173-2006] to tungsten carbides WC / W2C and tungsten VA [GOST 19671-91]. As a result, powder materials with a particle size of 45 nM to 120 μm were obtained (according to the results of a study on an Analisette 22 Nanotec laser size analyzer). As studies of the fractional composition have shown, the resulting heterogeneous powder medium has a certain scatter of particle sizes, depending on a large number of technological factors (figure 1). Different fractions of powders obtained in the process of dispersion have different technological purposes - from raw materials for pressing tool blanks to powders used for laser sintering.

![Figure 1. Tungsten carbide particles obtained in a centrifugal dispersion unit.](image)

The behavior of particles in the volume of the dispersion chamber was determined by the aerodynamics of gas flows that form around the rotor and are complicated by the inert gas supply system. Analysis of video materials of the spraying process showed that in the experimental stand for obtaining significant volumes of powder material, this factor significantly affects the operation of the installation and the composition of the resulting medium. It was hypothesized that, as a result, a spontaneous classification of the particles of the medium occurs, determined by the size of the latter, and that mainly the coarse fraction of the powder fell into the trap under the action of inertial forces, and the fine fraction remained in the working zone of the installation, and partially re-enters the melting zone. An experimental study of the motion of powder particles of various sizes was hindered by the presence of high temperatures, small sizes, and high speeds of particle motion.
To study the trajectory of movement of particles of powder material in the working chamber and the deposition process, a gas-dynamic model of a centrifugal dispersion unit in the SolidWorks Flow Simulation application is proposed. For this, a three-dimensional solid computational model of the installation (figure 1) has been developed on the basis of a three-dimensional design model, by removing some of the structural elements that do not affect the flow. The computational model had a closed volume of the dispersion working chamber, so an internal problem was solved for the study, when the movement of the fluid occurs in the cavity of the three-dimensional model. Argon was used as an aerodynamic medium at a temperature of 293 K and atmospheric pressure. For the formation of the calculated gas flow caused by the rotating rotor of the installation, the element "Area of rotation" is used, which creates a local rotating coordinate system. To define local regions of revolution that simulate the melt layer, an auxiliary component has been created - a thin-walled part on the disk surface. The flow parameters in the specified local rotating coordinate system of the area of rotation are calculated by the Averaging method. In this case, the flow parameters calculated in adjacent flow regions are transferred to the boundary of this region as boundary conditions.

3. Results

As a result of the calculation (see figure 2), a computer model of the gas flow formed by the rotating rotor in the chamber of the centrifugal dispersion experimental stand was obtained. The gas flow rate varies from 0 to 30 m/s at the operating speeds of the rotor spraying disc. It is expected that the highest speed is at the peripheral part of the rotor, but the gas velocity in the trap does not exceed 3 m/s. Moreover, at the entrance of the trap, a vortex of flows with velocities from 6 to 30 m/s is formed.

Since the concentration of sprayed particles in a heterogeneous flow medium is relatively low, it is assumed that the SolidWorks Flow Simulation application will adequately investigate the propagation of an impurity (gaseous, liquid or solid particles) in the main flow of the working medium using the "Calculate impurity propagation" option, and that the presence of an impurity will not have a significant effect on the flow, at a really low mass concentration of impurities.

To calculate the propagation of an impurity, the type of impurity was chosen - a solid material and, directly, the most relevant material for the research being carried out - tungsten; as a source, the face of the nozzle of the feeding device was selected as an emitting impurity. Also, the contact conditions on the walls, the mass flow rate of the impurity [8], as well as the diameter of the impurity particles, corresponding to the fractional composition of the particles obtained in experiments and relevant for
further technological use, are specified. On this basis, the calculation model studied the motion of particles of monofractions with a particle size of 1 μm, 10 μm, and 100 μm. The mass flow rate was determined by the feed of the dispersed material and was adopted for tungsten 0.0048 kg/sec. The visualizations of the trajectories of the particles of the fractions with the listed sizes are shown in figure 3.

![Figure 3](image)

**Figure 3.** The trajectory of motion of tungsten particles of various diameters in the centrifugal dispersion stand n = 11000 rpm: (a) 100 μm, (b) 10 μm, (c) 1 μm.

Analysis of the results of calculating the trajectory and speed of movement of particles of different fractions showed that the behavior of particles of different fractions of a heterogeneous powder medium (tenths, hundredths, and thousandths of a millimeter) differs significantly. Although the initial velocity of the particles is equal to the initial velocity in the zone of contact with the rotor disk, particles of 0.1 mm in size move along a trajectory close to the tangent to the edge of the disk from the point of melt feeding and then along a straight trajectory move into the trap (figure 3.a), collide with the wall, and slow down (figure 4), repeatedly ricocheting from the walls. A significant proportion of particles, colliding with the catcher wall at a right angle, are reflected and return to the area adjacent to the rotor of the installation. Thus, it can be concluded that the aerodynamic component of the force effect from gas flows does not have a decisive influence on the behavior of particles of a fraction of 0.1 mm or more. The trajectory of motion of particles of this fraction is determined by the forces of inertia and the geometry of the structural elements of the trap walls.

The aerodynamic component has a more significant effect on the motion of a fraction of particles with a size of 10 μm (figure 3.b), deflecting the rectilinear trajectory at the exit from the tangent closer to the center, which leads to a collision with the edge of the passage window into the trap. After the collision, the particles lose their initial velocity (figure 4) and are displaced by the vortex gas flow to the entrance to the trap.

The trajectories of motion of particles of a fraction of 1 μm in size almost completely coincides with the trajectory of the gas flow, since the inertial forces for particles of small mass are incomparable with the aerodynamic force component of the gas flow (figure 3.c). And the speed at a distance of more than 0.1 m from the spray zone is greater than the speed of larger particles due to being in the gas flow.
To analyze the difference in the behavior of particles of different diameters, it is necessary to determine the force factors that determine the movement of particles and the dependence of these factors on the particle size. The forces of inertia are directly proportional to the mass and, accordingly, the volume of the particles, which has a cubic dependence on the size of the spherical particle. The aerodynamic force acting on a particle is directly proportional to the area of the particle, which in turn is proportional to the square of the particle size. Thus, the difference in the behavior of particles in a gas flow is explained by the fact that as the particle size decreases, the ratio between the inertial force and aerodynamic force decreases in proportion to the particle radius. The only parameter of the installation that can affect the movement of particles is the speed of rotation of the disk. To determine the possibility of controlling the motion of particles using the speed of rotation of the disk, it is necessary to determine the dependence of the inertial forces and the aerodynamic force of the gas action on the speed. The kinetic energy received by the particles from the disk, which allows them to move by inertia, is proportional to the square of the speed as well as the aerodynamic force of the gas flow. To determine the possibility of controlling the behavior of the flow of particles by changing the speed, the calculation of the behavior of particles of the same size at a low rotational speed of the rotor disk, of the order of 3000 ... 5500 rpm, was performed. The results showed that the nature of the movement of a particle with a size of 0.1 mm does not change, and particles with a size of 10 μm and 1 μm practically completely stop moving from the near-rotor zone, being held by gas flows and gradually settling in the immediate vicinity of the sputtering point. Thus, the withdrawal of the finely dispersed fraction from the trap is possible only by increasing the rotor speed and by organizing the geometry of the spraying chamber and trap, suggesting a different dynamics of gas flows.

An equally important component of centrifugal dispersion of a melt is a change in the temperature of particles after sputtering, since crystallization should have a certain character and occur before the collision of a particle [11, 12]. In addition, the temperature of the particles affects the materials of construction used. Figure 5 shows the results of calculating the temperature of particles with a diameter of 100 μm, 10 μm and 1 μm of tungsten in a centrifugal dispersion stand at a disk rotation frequency of 11000 rpm. The calculation showed that particles with a size of 1 μm cool down already at the exit from the spray zone and have an ambient temperature. The temperature of 10 μm particles is equalized with the gas temperature in the working chamber at a distance of 0.2 m from the spray zone. Particles with a size of 100 microns do not have time to cool down in the working chamber and at the entrance to the trap have a temperature of more than 2500 degrees, upon collision with structural elements of the order...
of 1500 degrees. That is, the cooling rate is sufficient for crystallization prior to collision, but requires the use of heat-resistant materials in the structure of the catcher.

![Figure 5. Temperature distribution for different particles by distance from the spray zone.](image)

**4. Conclusion**

The developed model of the installation of the centrifugal dispersion process has shown the possibility of operational analysis of the trajectory and temperature of the resulting powder material, depending on the speed of rotation of the rotor disk, the size of the powder, design and technological factors. Analysis of the results showed that the behavior of powder particles depends significantly on its size. The principle of operation and design of the collection system depend on the size of the resulting powder particles. The original design of the trap was modified by the introduction of flow cutoffs to prevent reflection into the working chamber and allows collecting powder particles with a size of 0.1 mm or more. To obtain powder of finer fractions, it is necessary to study the design of the trap from the standpoint of aerodynamics. For particles of the order of 10 microns, the design of the trap is modernized to form a different aerodynamics. Collecting fractions with a particle size of the order of 1 micron requires the use of a different capture principle: transferring the powder to the separation device by a gas flow and filtering it or settling fine particles. It can be noted that the analysis of the simulation results makes it possible to develop a design for separating the heterogeneous medium of particles into fractions, directly at the installation for the implementation of the method [8]. These principles were fully used in the design of an industrial plant and radically changed the design of the dispersion device.

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