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Tribo-Powder and Electrostatic Phenomenon

The process is controlled by the electrostatic and aerodynamic factors and takes into account the powder load and mass, the external flow, as well as the air speed around the spraying cone. The value of the electric field is rather important, because it provides information on the thickness of the covering layer, on the values of the electric forces, as well as on the covering quality. The speed distribution is also important, because it influences the value of the electric field.

Keywords: *electrostatic, electric field, tribo-powder*

1. Introduction

Taking over the results described and analysed in the defence issued so far in the speciality literature, the autors of this article analyse the process of covering objects with tribo-powder, taking into consideration the most important factors od dependence: the volume density of the load, the electrostatic field, the path of the particles at any point being between the emiting source and the target. We know that the electric charge of the loaded particles is distributed within their volume, and thet this is the only source of the electric field generating electric forces responsabile for the movement of these particles toward the objects to be covered. During the movement, the load distribution is unknown, and that the numeric calculation methods are used: the method of the finite element for calculating the electric field, and the method of the finite differences, including the condition of continuity for the following current, in the differential equations governing this movement.

Covering objects with electrostatic powder is done in order to refine surfaces of the pieces with a complicated geometry, for increasing lifetime and improving the performance of the instalations.

The powder is electrically charged, due the firction amog particles, and between them and the walls of the emiting device. The movement of the electrically charged particles is submited to forces of an electrical (Fe), inertial (Fi), air sweeping (Fs), and gravitational (Fg) natures [1], [2].

2. Mathematical formulation

Starting from different configurations of the tribo-powder covering system [3], [4], the spraying gun is made of a dielectric material of small permittivity, of a concave cylindrical shape and surrounded by a metallic screening grounded system. The powder stream is cone-shaped, with the axis perpendicular on the surface of the object to be covered. The gun ejects powder with known load/mass relationship and external flow. The areal path of the powder particles result from the interaction of all the forces, they are linear and limited [1].

Dealing with the problem will be done in two dimensions, in the plane (r,z), and due to the axial symetry, there is no dependence of the parameters on the angular coordinate.

We are writing the Poisson equation:

$$\frac{1}{r}\cdot\frac{\partial}{\partial r}\left(r\frac{\partial V}{\partial r}\right)+\frac{\partial^2}{\partial z^2}=-\frac{\rho v}{\varepsilon} \qquad (1)$$

where:

V – scalar electric potential (V);

P_v – volume density of the electric charge (C/m^3);

E – air permittivity (F/m); $\varepsilon = \varepsilon_0 \cdot \varepsilon_r$

The electric charge produced by the powder is the only source of electric current, and ρ_v is a complex function of r and z, and of the total current [4], [5].

The total current is constant in any cross section of the powder stream, while the density of the conduction current takes different values, because the gun has an oscillatory movement and on the body to be covered appears uneven concentrations of powder along the vertical axis.

In every point of the calculation range, the electric current density varies also depending on the location of the analysed point either within the powder cone, or outside it ($\bar{J} = 0$)

In order to find out the electric and drainage forces of the air, we should determine the electric field distribution and the air speed distribution within the gap gun-object. The electrostatic interaction among particles is one of a mutual rejection and one of attraction between particles and the body to be covered. The speed difference between the powder particles speed and t the air speed creates a forward current equivalent to an air sweeping force.

The gravitational forces intervene over the powder particles if the system is vertically positioned, and they can lead to acceleration or slowing down of the particles speeds, depending on the position of the gun compared to the one of the object to be covered.

If the size and concentration of the powder particles are small, the air flow is considered rotational and it is described by means of the potential V, using Laplace equation, obtained from the continuity condition:

$$\nabla^2 V = \frac{1}{h_1 h_2 h_3}\left\{\frac{\partial}{\partial x_1}\left(\frac{h_2 h_3}{h_1}\frac{\partial V}{\partial x_1}\right)+\frac{\partial}{\partial x_2}\left(\frac{h_1 h_3}{h_2}\frac{\partial V}{\partial x_2}\right)+\frac{\partial}{\partial x_3}\left(\frac{h_1 h_2}{h_3}\frac{\partial V}{\partial x_3}\right)\right\}$$

(2)

The equation is written in cylindrical coordinates, imposing the conditions: $x_1=z$, $x_2=\rho$, $x_3=\varphi$, $h_1=h_2=1$, $h_3=\rho$, and it will be obtained:

$$\nabla^2 V = \frac{1}{\rho}\left\{\frac{\partial}{\partial x}\left(\rho\frac{\partial V}{\partial x}\right)+\frac{\partial}{\partial \rho}\left(\frac{\partial V}{\partial \rho}\right)+\frac{\partial}{\partial \varphi}\left(\frac{1}{\varphi}\frac{\partial V}{\partial \varphi}\right)\right\} \quad (3)$$

relation which, adapted to the cylindrical coaxial symmetry, becomes:

$$\frac{\partial^2 V}{\partial r^2}+\frac{\partial^2 V}{\partial z^2} \quad (4)$$

This approximation is valid for the laminar flows and large Reynolds numbers. The equation solution should satisfy the limit conditions, that is $v_z=0$ at the surface of the body to be covered, and $v_z=v_0$ at the gun mouth. Both equations lead to Newman conditions, where V is even on the surface of the body to be covered, and uneven at the gun mouth.

For a known distribution of the load density, the electric potential is given by the Poisson equation, $\nabla^2 V_2 - \rho/3$ or for the fields with plane parallel symmetry, the equation becomes in cylindrical coordinates

$$\frac{\partial^2 V}{\partial r^2}+\frac{\partial^2 V}{\partial z^2}=\frac{\rho(r,z)}{\varepsilon} \quad (5)$$

The density of the volume load depends on the particles concentration, which is unknown. That is why the simulation of the electrostatic field is done by analysing together the electric field and the density of the volume load, which is obtained by using the continuity equation of the current density:

$$\nabla J = \nabla(\rho \cdot V) = 0 \quad (6)$$

where:

J – induction current density (A/m^2)

V – powder particles speed (m/s)

The paths of the powder particles were calculated by integrating the movement equation within bi-dimensional cylindrical coordinates:

$$m\frac{\partial \vec{v}}{Jt} = \vec{F}_e + \vec{F}_d + \vec{F}_g = m \cdot \bar{a} \quad (7)$$

By solving equation (7) in bi-dimensional cylindrical coordinates, on the directions r and z, we obtain:

$$m \cdot \frac{dv_z}{dt} = qE_z + Fd_z + mg \quad (8)$$

$$m \cdot \frac{dv_r}{dt} = qE_r + Fd_r \quad (9)$$

where:

q – gravitational constant

v_r – radial component of the speed vector

v_z – axial component of the speed vector

the sweeping force of the air depend on the values of the forces intervening in the fluids flow (viscosity, density, sweeping rate), as well as on the relative speed of the powder particles, compared to the one of the air:

$$\bar{F}_d = \frac{\pi R^2}{2} \cdot \frac{24 \cdot \eta}{2R\rho v_{rel}} \cdot \rho |v_{rel}| \cdot \vec{v}_{rel} \quad (10)$$

and $m = \frac{4}{3}\pi R^3 \rho$

In order to solve the above equation, the following hypothesis was considered [5]:

- all the powder particles are spherical and uni-dimensional;
- the powder particles are considered as punctual, so that they do not influence the air flow;
- the body to be covered acts like a shunt, because it is grounded;
- the gun wall is infinitely thin and unloaded;
- at the end of the gun, the particles are evenly distributed, and their initial speed is equal to the one of the sprayed air.

The expression $\nabla_2 V$, in which appears the function potential V (r, z0), has the following representation after developing in power series, in the case of the net with straight lines:

$$V_1 + V_2 + \left[\left(\frac{r_0 \Delta z^2}{\Delta r} \right)^2 - \frac{1}{2r_0} \frac{(r_0 \Delta z)}{\Delta r} \right] V_3 + \left[\left(\frac{r_0 \Delta z}{\Delta r} \right)^2 \right] V_4 - \left[2 + 2\left(\left(\frac{r_0 \Delta z}{\Delta r} \right)^2 \right) \right] V_0 =$$

$$= -\frac{1}{\varepsilon_0} f(r_0, z_0)(r_0 \Delta z)^2$$

(12)

where $(r_0,z_0)$is the filed point around which developing is done.

The relation simplifies and is written as:

$$C_1V_1+C_2V_2+C_3V_3+C_4V_4+R_0=C_0V_0 \qquad (13)$$

where:

$$C = \frac{1}{r_0^2} \cdot \frac{2}{\Delta z(\Delta z_1 + \Delta z_2)} \qquad C = \frac{1}{r_0^2} \cdot \frac{2}{\Delta z_2(\Delta z_1 + \Delta z_2)}$$

$$C_3 = \frac{2}{\Delta r_3(\Delta r_3 + \Delta r_4)} - \frac{1}{r_0} \frac{\Delta r_4}{\Delta r_3(\Delta r_3 + \Delta r_4)}$$

$$C_3 = \frac{2}{\Delta r_4(\Delta r_3 + \Delta r_4)} - \frac{1}{r_0} \frac{\Delta r_4}{\Delta r_4(\Delta r_3 + \Delta r_4)}$$

$$C_0 = C_1 + C_2 + C_3 + C_4 \qquad Q_0 = -(\nabla^2 V)_0$$

Knowing the elctric field distribution, the particles paths and speeds will be determined.

The electrically charged powder ejected by the gun creates an alectric current

Taking the current continuity condition, it is constant within any cross section of the powder stream and the volume density of the load is calculated by means of the formula.

$$\rho = \frac{I}{\pi R_g^2 \cdot v_0} \qquad (15)$$

where:

R_p – radius of space powder distribution, cone-shaped

v_0 – particles initial speed

I – electric current intensity

Knowing the load density, the finite element method is used in order to calculate the electric potential and, by differentiation, the components of the electric field E_r and E_z - [6], [7].

By knowing the air speed and powder particles electric field distributions, the particles paths can be described.

3. Conclusion

The implementation of the process of covering objects with tribo-powder involves researching the electrostatic field, the particles movement equation, and the effects showing up during the process.

The simulation of electric fields with known distributions of the load density was done by using the method of finite differences, of finite element and of the load. The results of the simulation showed the effects of the parameters characterizing in the process. The following items were analysed: size of the powders particles, distance up to the object to be covered, external flow of the powder, carrying force of the air, positioning force acting over the powder, relationship between the electric charge and the mass of the powder particle, as well as the characteristic of the powder path depending an the electric field distribution. The author analysed different covering systems, with the advantages and disadvantages of each of them.

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