Jaroslav DŽMURA

Technical University of Košice, Faculty of Electrical Engineering and Informatics, Department of Electric Power Engineering

Macroscopic particles in direct and alternating electric field

Streszczenie. (Cząsteczki makroskopowe w stałym i przemiennym polu elektrycznym). *Uwzględniając efekty sił pola elektrycznego, wpływające na transport elektrycznie naładowanych cząstek makroskopowych, przedstawiono analizę matematyczno-fizykalną ruchu (dynamiki) cząstek w polu elektrycznym, wytwarzanym przez źródło wysokiego napięcia stałego lub przemiennego. W artykule opisano rozwiązanie podstawowego równania ruchu dla toru i prędkości cząstek oraz ich porównanie dla obu tych rodzajów pola elektrycznego.*

Abstract*. Considering the force effects of the electric field, affecting the transport of electrically charged macroscopic particles, mathematic-physical analysis of motion or dynamics of particles in electric fields created by direct or alternating high voltage source is described. In this paper the basic equation of motion for particles trajectory and velocity and their comparing in both types of electric field are derived.*

Słowa kluczowe: siły pola elektrycznego, cząstki makroskopowe, ruch cząstek.
Keywords: electric field forces, macroscopic particles, particles motion.

Introduction

Physical problems related to transport of macroscopic particles in a quasi-homogenous or non-homogenous electric field are solved in the area of the utilisation of electric discharge in the technological process. The separation or deposition of particles to conductive substrates in dc or ac electric field is one of them. The mechanism of charging or the form of getting of the charge from particles in the environment of a charging electrode is different [1], [2].

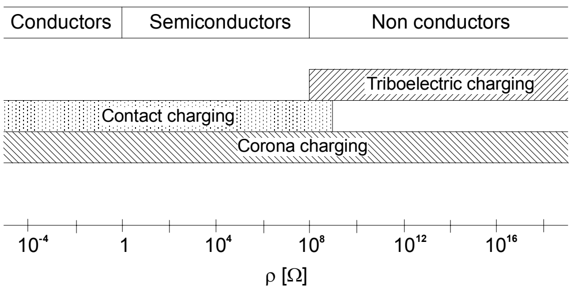

Fig. 1 Different methods of charging in relation to this specific electric resistance

Basically, three ways of charging particles can be used [1]. Coronary charging is theoretically not dependent on the conductivity of the particles, direct charging needs at least minimal conductivity of the particles and the charging by friction (tribo-charging) is only possible by extremely low conductivity of at least one of the friction partners (Fig. 1).

For particles, which have surface conductivity only two of these methods of charging are practically in use. Firstly, direct charging by contact with high voltage electrode and secondly corona charging by intensive bombardment with free charges to the surface of particles in area of the corona discharge from the electrode.

From qualitative and quantitative points of view, solving the transport of charged macroscopic particles is necessary.

The solution introduced in this paper does not have to refer only to the transport of electrically charged particles during precipitation of exhaust in high voltage precipitators or applying powder painting, but even to movement of impurities created during manipulation in gas-insulated systems as well.

Motion of electrically charged particles in DC quasi-homogenous electric field

The suggestion for the solving of motion equations (trajectory, velocity and acceleration) issued from the deposition or separation technology of particles of spherical form [4]. We decided to submit a solution of the basic equation of motion provided that the particles have spherical shape with diameter within the range of 10^{-6} to 10^{-3} m, weight within the range of 10^{-9} to 10^{-3} kg and they occur in an electric field. We suppose that particles obtain an electric charge within the range of 1 pC to 1 µC.

The electrons in the electric field which have no mass (carrying negative charges) have a higher velocity than the molecules of ionised air and these again have a far larger velocity than macroscopic particles [1].

Mobility at 20°C and standard pressure:

positive ions	b_{+i} = 1.36·10^{-4} m^2/Vs
negative ions	b_{-i} = 1.87·10^{-4} m^2/Vs
electrons	b_e = 500·10^{-4} m^2/Vs
macroscopic particles	b_{mp} = 10^{-8}…10^{-5} m^2/Vs

To derive the equations of trajectory and velocity we will go out of the real conditions which are typical in deposition technology [6]. Drawing of simplified arrangement is in the Figure 2. Particles are dosed into a coronary electrode area with a small bend radius by the dose equipment. These electrodes have parallel adjustment towards the plain target electrode.

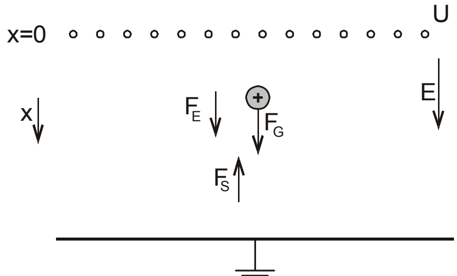

Fig. 2 Experimental set-up for particles deposition

In order to characterise the state of particle motion the balance over all forces acting upon the particle is needed [4]. We can express the force effect equation by expression (1):

$$F = F_E + F_G - F_S + F_{grad} \quad (1)$$

where F_E is the force of the electric field which is affecting the charged particle, F_G is the gravity force and F_S is the Stokes force.

The gradient force F_{grad} which affects the particle only in strong electric field (in surroundings of coronary electrode) will be omitted. After mathematical adjustment equation (1) acquires form (2).

$$\frac{d^2x}{dt^2}+\frac{6\pi\eta r}{m}\cdot\frac{dx}{dt}=\frac{QE}{m}+g \qquad (2)$$

Equation (2) is second order linear differential equation with constant coefficients. We will specify the integration constants by initial conditions, it means if time t=0, then will be x=0 and speed v=v_0, because the macroscopic particles come from the dose equipment into the high voltage electrode environment with starting speed v_0. After several mathematical adjustments the equation acquires form (3).

$$x(t)=\frac{m}{6\pi\eta r}\left[v_0\left(1-e^{-\frac{6\pi\eta r}{m}t}\right)+\frac{QE+mg}{6\pi\eta r}\left(e^{-\frac{6\pi\eta r}{m}t}+\frac{6\pi\eta r}{m}t-1\right)\right] \qquad (3)$$

The velocity equation of particle is obtained by differentiating equation (3):

$$v(t)=v_0e^{-\frac{6\pi\eta r}{m}t}+\frac{QE+mg}{6\pi\eta r}\left(1-e^{-\frac{6\pi\eta r}{m}t}\right) \qquad (4)$$

The time dependence of trajectory and velocity for a real particle and is moving in air is shown in the Figure 3 and Figure 4.

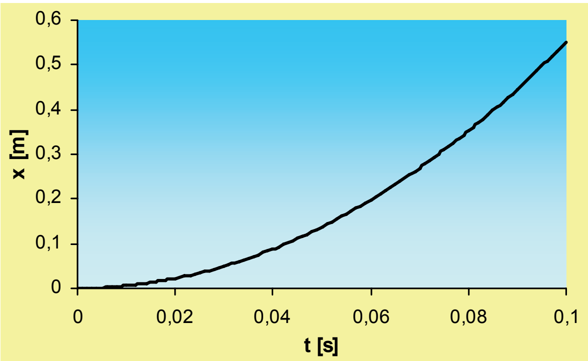

Fig. 3 Time dependence of particles trajectory in direct electric field

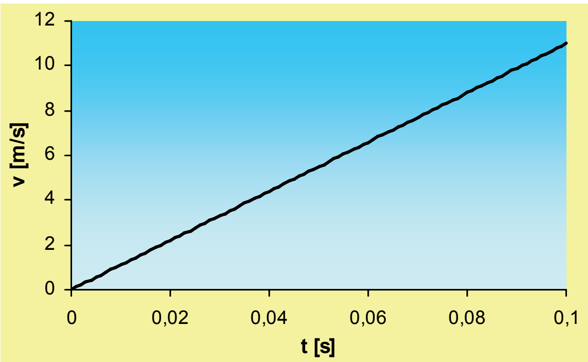

Fig. 4 Time dependence of particles velocity in direct electric field

Movement of particles in AC high voltage electric field

The equilibrium of the force effect in electric quasi-homogenous field is considered and the force activity from the alternating electric field is expressed by equation (5).

$$\frac{d^2x}{dt^2}+\frac{6\pi\eta r}{m}\cdot\frac{dx}{dt}=\frac{QE}{m}\sin(\omega t+\varphi)+g \qquad (5)$$

Taking the same initial conditions which are used in the direct electric field the solution of equation (5) can be found in the form

$$\begin{aligned} x(t)=&\frac{g}{A^2}\left(e^{-At}+At-1\right)+\frac{v_0}{A}\left(1-e^{-At}\right)+\\ &+\frac{K}{A\omega}\Big[\cos\psi-\frac{1}{A^2+\omega^2}\cdot\\ &\cdot\left(\omega^2e^{-At}\cos\psi-A\omega e^{-At}\sin\psi+\right.\\ &\left.+A\omega\sin(\omega t+\psi)+A^2\cos(\omega t+\psi)\right)\Big] \end{aligned} \qquad (6)$$

The theoretical migration path is plotted in Fig. 5. The equation of velocity is obtained differentiating equation (6).

$$\begin{aligned} v(t)=&\frac{g}{A}\left(1-e^{-At}\right)+v_0e^{-At}+\frac{K\omega}{A^2+\omega^2}\cdot\\ &\cdot\left[\frac{e^{-At}}{\omega}(\omega\cos\psi-A\sin\psi)-\right.\\ &\left.-\frac{1}{\omega}\left(\omega\cos(\omega t+\psi)-A\sin(\omega t+\psi)\right)\right] \end{aligned} \qquad (7)$$

In the Figure 6 there is shown the time dependence of the velocity of particles in an alternating electric filed. It is shown that the trajectory and velocity of particles are modulated by the alternating field with frequency f=$\omega/2\pi$.

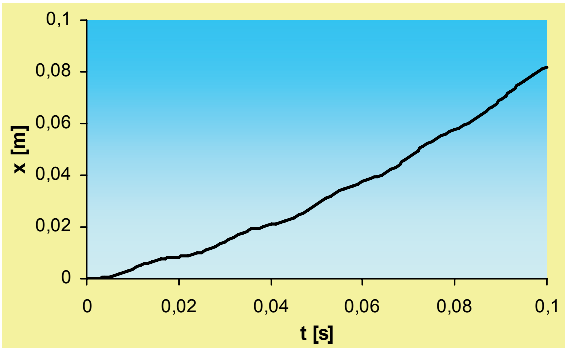

Fig. 5 Time dependence of the path of particles in an alternating electric field

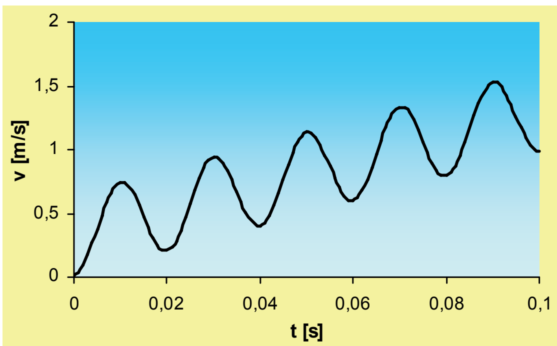

Fig. 6 Time dependence of the velocity of particles in an alternating electric field

Precipitator with linear coronary electrodes supplied by alternating high voltage

Macroscopic particles diffused in surroundings of coronary electrode, which is connected to alternating high voltage, are not charged by hypothesis. For this reason it is necessary to create electro-physical condition for creation of monopolar electrical charges in area of feeder embouchure. One possibility is to utilise the physical phenomena in metal-dielectric-gas boundary.

For experiments the cascade coaxial precipitator consisted from four sections was created (Fig. 7). The PVC tube as collecting electrode is the basis of precipitator section. Thin aluminium electrode is attached on the outside of the tube and it create ground electrode.

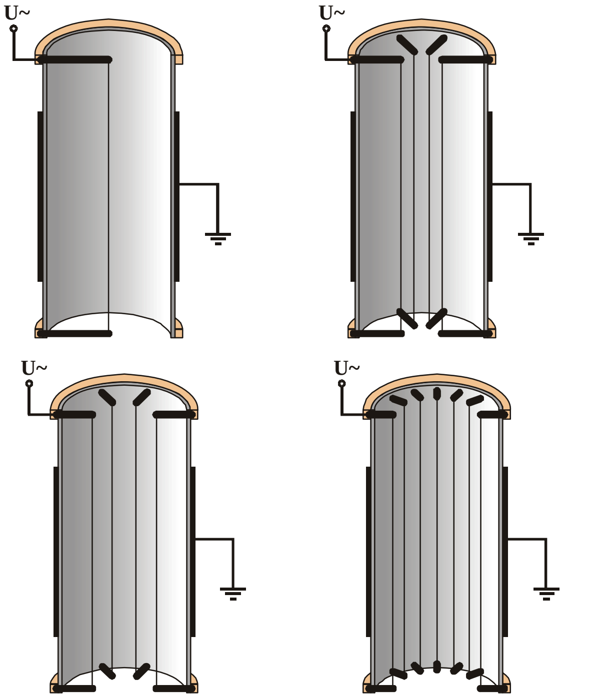

Fig. 7 Sections configuration of cascade tubular precipitator supplied by alternating high voltage

Inside of tube as coronary electrode there is fixed a thin cooper wire. Any sections of cascade contain different number of coronary electrode and they arte placed in different distance from collecting electrode. The function of coronary electrode is strong inhomogeneous electric field creation. This field can be created with electrodes with small radius of bend. If coronary electrode is positive the new electrons are created as consequence of bomb of point by electrons. If coronary electrode is negative it is analogical, but the difference is that the avalanches emitted from negative point are moved to more homogeneous field, as a consequence of it the mobility and ability to ionise decreases.

In electrical precipitator supplied by alternating voltage with using the metal coronary electrode there is used the insulating barrier as a collecting electrode. For maximal efficiency it is necessary to choose insulating materials with great value of resistance and permittivity. The choice of materials depends on another non electrical quantity as for example temperature of flying gas, enough mechanical solidity and other too. Insulating barrier must not to change their mechanical and dielectric attributes under temperature influence.

For finding the efficiency of precipitator model the three types of dust with different values of resistance were used. The model of precipitator with length 30cm has efficiency in the range of 60 % to 97 % for each of dusts.

Table 1. Average values of efficiency for each of sections of cascade tube-type precipitator supplied by alternating voltage

	Efficiency [%]			
	1. section	2. section	3. section	4. section
Powder with ρ_e= 3 Ω.m	83,16	70,72	73,94	62,02
Powder with ρ_e= 4 kΩ.m	96,82	81,72	83,7	72,12
Powder with ρ_e= 4,8 MΩ.m	93,45	93,56	97,82	95,14

From measured values it is possible to estimate that the precipitation solid admixture form flying air at alternating voltage is comparable with precipitation at direct voltage and at specific conditions reaches better values of efficiency.

Conclusion

The paper refers to possibility of application alternating voltage for precipitating macroscopic particles in unconventional electrode system: coronary electrode – dielectric barrier as collector – grounded electrode. These systems use physical phenomena from high voltage field with barrier theory. On basics of numerous measurements and experiments this coaxial flying dust precipitator supplied by alternating high voltage with linear coronary electrode proves to be one from possible option of precipitation of fly-ash with great conductivity. Advantage of this system opposite the system supplied by direct voltage is the economic aspect of regulation of precipitation process. This fact can be the important step to general utilisation of this technology in practice.

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***Author**: Ing. Jaroslav Džmura, PhD., Technical University of Košice, Faculty of Electrical Engineering and Informatics, Department of Electric Power Engineering, Mäsiarska 74, 041 20 Košice, Slovak Republic, E-mail: jaroslav.dzmura@tuke.sk;*