Modeling the electromagnetic processes in a technological device for producing ultradispersed particles in pulsed arc discharges

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Abstract. The article contains a brief description of the operation principles of the device for creating ultrafine metal powders under the action of electrically charged flows with a high power density. The results of creating a mathematical model of electromagnetic processes in the installation are presented. The results of solving the problem of current flow in the installation during its operation are presented. The dependence of the magnetic field strength in the section of the plasma bunch during the operation of the apparatus is illustrated.

1. Introduction
Nowadays the ultradispersed particles (nanoparticles) and materials and their unique properties are used in many scientific and technological fields. The most perspective of which for today are medicine, chemical industry and automobile manufacturing [1–3].

There’re many principally different ways of producing different types of ultradispersed particles [4–6]. And in the Laboratory of “Electric Impulse Technologies” the new method of producing the ultradispersed particles in pulsed arc discharge [7–9], moving along the extended electrodes is being developed [10]. The principles of the developed device are schematically presented in figure 1.

2. Model description
The main arc discharge 2 is being ignited by the additional spark in gap between the main 1 and secondary 11 electrodes. The main discharge is supported by the energy accumulated in the capacitive batteries 10. The main discharge exists in the gap between the main electrodes, which constructively are two extended parallel metal bars. The main electrodes are connected to the capacitors with a coaxial cable 13. In between the main electrodes the dielectric inset is placed 3.

The interaction of the magnetic fields in the main discharge and the main electrodes (rails) causes the motion of the discharge along the surface of the electrodes. The impact of the main discharge 6 on the electrodes cause the forming 7 and dispersing 8 the particles. Ultradispersed particles condence 9 on the surface of the product 4, where they are supposed to be used.

In order to evaluate the parameters of the device in the paper [11] the mathematical model was suggested, which was based on presenting the electromagnetic processes as the number of substitution circuits, connected in a certain way. The parameters (R, L, C) needed for the circuit were determined experimentally, using the immitance measuring device MNIPI E7-20 in a wide dynamic range.
Such an approach gives a detailed and correct image of the processes. Though, in order to define them numerically, a lot of effects must be taken into consideration, which couldn’t be determined using simple measurements. Moreover, the presented model could only describe completed experiments. Particularly, it can’t predict changes in the electromagnetic processes while changing the geometry of the arc gap. So, the solution required much more detailed description of the electromagnetic processes in the device.

Creation of such a mathematical model, capable for describing transient electromagnetic processes is only possible using Maxwell equations. Due to model being principally three-dimensional, (apart from the ones, presented in [12, 13]) only numerical solution is possible, which considered the properties of geometry of the device. So, the very paper is dedicated to a mathematical model development.

In case when the radiation energy losses are not needed to consider, the description of the processes requires only two first of Maxwell equations without a derivative vector flux member. The numerical solution was processed in ASNYS program environment. It is comfortable to solve three-dimensional transient models in it. The Cartesian system was used for modeling. The borders of the volume where the model was built (figure 2) were chosen in the way not to affect the processes while defining zero electrical and magnetic fields boundaries.
Boundaries at the end face of the electrodes were assigned after solving the system of equations for the rest of the substitution circuit (the capacitor and co-axial cable). Such boundaries allow to simulate the capacitor discharge process considering its own parameters and the parameters of the matching circuit between it and the main electrodes.

To check the adequacy of the developed mathematical model, the results received during the solution were compared to experimental ones, measured in the device. During the experiments, the capacity changed from 100 up to 1000 uF, the initial capacitor voltage changed from 1500 up to 3500 V, the height of semi-conductive insert from 0.4 to 3 mm.

3. Solution analysis

We only measured and compared the integral parameters (the voltage at the end faces of the electrodes) as the transient parameter of the electromagnetic field is extremely complicated to measure. The voltage dynamics at the end faces of the rails was measured using the oscilloscope Tektronix TDS 3012C. The variation between experimental and calculated results never exceed by 10 %. Particularly, in figure 3 the typical results of the comparison are presented.

![Figure 3](image)

**Figure 3.** Experimental and numerically calculated voltage dynamics at the end faces of the main electrodes (voltage in the capacitors = 2000 V, the capacitance = 500 uF, the height of the semi-conductive insert = 2 mm).

Current density distribution across the conductor at different time moments is presented in figure 4. It’s easy to see that the most of the current is positioned only in a narrow “skin” area of the conductor. It depends on time. And the most of the current is at the side of the electrodes where a semi-conductive insert belongs. Such a current distribution explained by the surface effect and the short-range effect. According to their effects the resistance of the conductors changes in time, which previously was considered to be constant [10]. Such transient changes are very difficult to measure experimentally.

![Figure 4](image)

**Figure 4.** Current density distribution in the main electrodes after 20 us after the ignition
Received results would improve the precision of the calculations dramatically. Particularly, in the presented case, the rails resistance, calculated considering the experimental frequency characteristics, appeared to be three times less that in numerically calculated one.

Current flow and density dynamics allow to figure the magnetic field distribution. The gradient of the square of the absolute value of it shows the direction and the value of the force affecting the plasma model. Such a distribution is presented in figure 5. The gradient direction of the magnetic field distribution is angled to the rails surface. Such force direction is characteristic for the initial discharge moments conditions. In steady-state conditions this direction is supposed to be parallel to the main electrodes.

![Magnetic field distribution](image)

**Figure 5.** Magnetic field distribution in the cross-section at the middle of the main discharge. The conditions are; Voltage in the capacitors = 2000 V, the capacitance = 500 μF, the height of the semi-conductive insert = 2 mm.

### 4. Conclusions
1. Developed mathematical model simulated the electromagnetic processes in the device.
2. Achieved results allow to learn the electromagnetic processes in the device and particularly: transient current density parameters and power in rails and discharge plasma; figure the direction and the value of the forces acting on the electrodes and discharge plasma; improve the substitutional circuit parameters.
3. To predict the parameters of the device when changing the discharge gap.

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