Study of Low Frequency Electric Field Treatment of Granular Materials

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***Abstract*—The aim of the work is precise investigation of low frequency electrical field treatment of natural granular materials (seeds and grains). The components of electric field strength, current density, power losses and mechanical force along the surface of the grain have been obtained and estimated. The theoretical approach is based on AC conduction theory. The local models of each elementary grain region accounted simultaneously for the dielectric system dispersion and conductive system contributions. The field distribution has been studied using the finite element method and QuickField 5.6 software package.**

***Keywords*—granular materials; low frequency electric field treatment; finite element method**

I. Introduction

Granular materials, which contain both conductive and dielectric (insulating) phases, are a classical example of complex system. Such systems are extremely heterogeneous with respect to their electrical properties (local conductivity σ and relative dielectric permittivity ε) and both passive and active interaction mechanisms (thermal and non-thermal in nature).

Thermoelectric phenomena in granular systems with the application of low frequency electric field are important to a vast array of industries. Electric fields and currents have been demonstrated to be effective in processing novel advanced materials such as electronic components, ceramic powders, polymers, biopolymers, colloid systems (emulsions and micro emulsions), biological cells, and liquid crystals [1]. Such fields may be generated in various ways, including the use of DC, pulsed DC and AC fields. While DC transport properties of insulating thin films and coatings have been widely studied, much less attention has been paid to the AC response of these systems, for which many effects are not yet completely understood [2].

The paper deals with numerical modeling of electric field of natural granular materials (seeds and grains) based on AC conduction theory and finite element method. The aim of the study is estimation of electric field strength components, current density, power losses and mechanical force along the surface of the grain.

II. Electric Field Modeling

A. Description of Investigated System

The principal scheme of the investigated system for low frequency electric field treatment of natural granular materials is shown in Fig. 1. Voltage with amplitude 200 V and 50Hz frequency has been applied between the two electrodes.

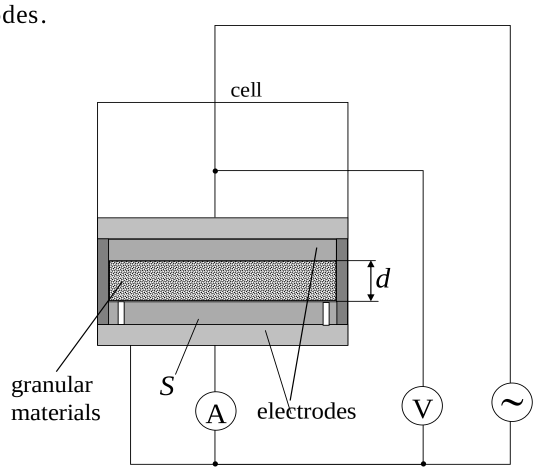

Figure 1. System for low frequency electric field treatment

The region of modeling (Fig. 2) consists of multilayered particles – seeds, composed of core, shell and surrounding medium. The dimensions of the seeds are as follows: core diameter - 0.4mm; shell outer diameter - 0.5mm and distance between the centres of two adjacent seeds - 1.1mm. The particle layers have different properties: core with permittivity ε_1 and conductivity $\sigma_1 = 0$; shell with permittivity ε_2 and conductivity $\sigma_2 \neq 0$; surrounding medium with permittivity ε_3 and conductivity $\sigma_3 = 0$.

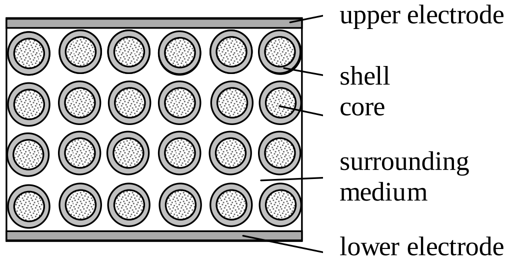

Figure 2. Region of the field modeling.

The study has been done for different kinds of seeds and different surrounding medium.

B. Governing Equations

The problem relates to the AC conduction analysis which is used to analyze the electric field, caused by time-harmonic voltages applied. The dielectric media is assumed to be non-ideal with a small, but non-zero electric

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conductivity. The quantities of interest are voltages, active and reactive currents, electric fields, Joule losses and electric forces.

For modelling of the electric potential V distribution and electric field density $\mathbf{E}$ are used equations:

$$\nabla\left((\varepsilon - \frac{j\sigma}{\omega})\nabla V \right) = 0 \qquad (1)$$

$$\mathbf{E} = -\nabla V$$

The density $\mathbf{J}$ of the currents, flowing in the regions with varying dielectric permittivity and conductivity consists of two components – active (conduction) current $\mathbf{J}_{active}$ and reactive (displacement) current $\mathbf{J}_{reactive}$:

$$\mathbf{J} = \mathbf{J}_{active} + \mathbf{J}_{reactive} = \sigma\mathbf{E} + j\omega\varepsilon\mathbf{E} \qquad (2)$$

III. FEM Analysis and Results

The field problem was considered as two dimensional (plane-parallel), using finite element method (FEM) and QuickField 5.6 software package [5]. Dirichlet boundary conditions were applied on the upper and lower boundary (Fig. 2) of the studied region with the respective potential on each of them. Homogeneus Neumann boundary conditions were applied on the left and right boundary due to the symmetry on vertical boundaries.

The field distribution has been studied for different combinations of permittivity and conductivity parameters. Some results for the field distribution in the whole area (when ε_1 = 1.5ε_0, ε_2 = 3.5ε_0, ε_3 = ε_0 and σ_2 = 200 μS/cm) are shown in Fig. 3 and Fig. 4.

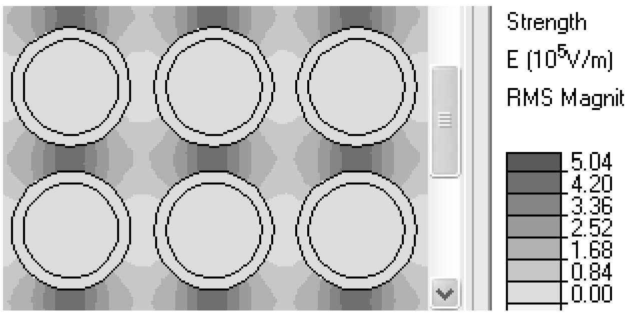

Figure 3. Electric field strength

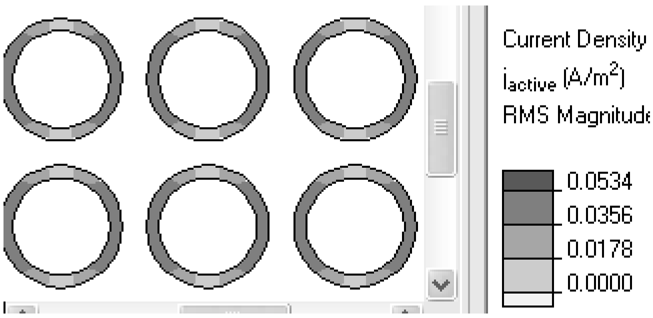

Figure 4. Current density – active component

Fig. 5 presents vectors of the electric field strength and calculation of the mechanical force along the upper surface of elementary grain.

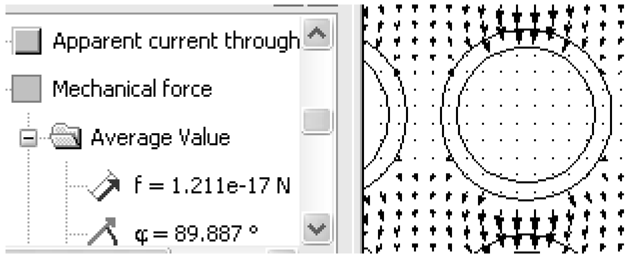

Figure 5. Electric field strength vectors and mechanical force, along the upper surface of elementary grain.

The variation of electric field strength normal *En* and tangential *Et* components along the surface of elementary grain is presented in Fig.6.

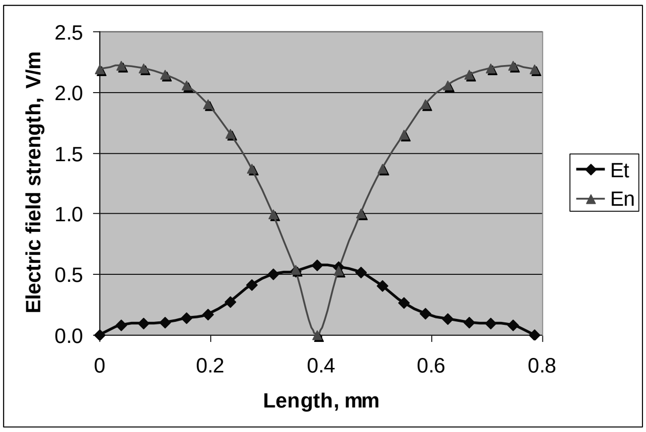

Figure 6. Electric field strength components along the grain surface.

IV. Conclusion

The numerical modeling of the low frequency electric field distribution in complex granular material, with both conductive and insulating phases, has been done on the bases of AC conduction theory and finite element method. The field model takes into account the specific properties of the material particles and surrounding medium and allows precise estimation of electric field strength, displacement, active and reactive current density, power losses and forces.

References

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