Numerical Analysis and Experiment of Floating Conductor Motion due to Contact Charging in High Voltage System

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In this paper, the motion of conductive particles is modeled and analyzed using a coupled equation. A neutral conductive particle obtains charge when it contacts an electrode. The forces acting on a particle consist of electric, drag and gravitational force. When the electric force is dominant over the other forces, a particle lifts up toward upper electrode. The electric force on a particle is calculated using surface charge distribution, which is analyzed using the finite element method. The dominant forces on the particles are used for driving force in Newton's motional equation to analyze a particle motion. The analysis results show that the total charge, which enables the particle to lift off, is calculated using the coupled equation with respect to the applied voltage. The experiment using a spherical conductive particle is conducted, and the experiment result is compared with the numerical one to validate the numerical method.

***Index Terms*— Conductive particle charging, particle motion, surface charge density, electromagnetic force, numerical analysis.**

I. INTRODUCTION

MICRO PARTICLES yield severe problems in not only environment but also engineering field. Those particle consist of conductive and dielectric material, and the conductive ones cause malfunction due to a partial discharge in high voltage system such as a gas insulated switchgear (GIS). The particle generated in GIS is initially neutral floating conductor.

The conductive particle, which is initially neutral, is charged when it contacts a conductor surface of high voltage. So, the charged particle experiences electric force. When the electric force overcomes the gravitational force and the drag force, it lifts off and goes around inside of the GIS. Finally, it can result in a serious damage to the high voltage system.

To understand and prevent such problem, accurate analysis for the moving conditions and the motional characteristic of the particle are required. Among various effects on the particle motion, the electric force is known to plays a key role.

In past researches, the approximate equation, which is a simple function of particle shape, size and applied field, has been used for the charging and the electric force. Due to its inaccuracy, the motion analysis is also incorrect. Furthermore, since it provides only a total force but force density, the rotational motion cannot be analyzed with it [1], [2].

In this paper, we propose a numerical analysis method for levitation and reciprocating motion of a conductive particle. In the analysis model, the conductive particle is placed between circular electrodes where AC voltage is applied. When a floating conductive particle contacts an electrode, the finite element method is used to calculate the surface charge distribution on the particle. The electric force acting on the particle is obtained using the numerical analysis. The total force including the drag and gravity force is used for driving force in the Newton's motional equation.

The total charge on the particle is constant when the particle lifts off due to the electric force. However, its charge varies when it contacts the electrode under AC voltage applied. The particle motion is analyzed considering the total charge variation and elastic collision with the electrode. To validate the proposed method, the numerical results is compared with the experiment results, which is carried out using 60Hz high AC voltage.

II. MODELING OF CONDUCTIVE PARTICLE MOTION

When a conductive particle, which is neutral initially, is suspended in air, the net electric force acting on the particle is zero in homogeneous field. In contrast, a conductive particle with surface charge, σ_s, experiences electric force, which is calculated using the electric field on each side of the surface [3];

$$\mathbf{F_E} = \frac{1}{2}\int_s \sigma_s \left(\mathbf{E}_1 + \mathbf{E}_2\right) dS \qquad (1)$$

where, $\mathbf{E}_1$ and $\mathbf{E}_2$ are the inside and the outside electric field, respectively.

The moving particle suspended in a fluid experiences the drag force;

$$\mathbf{F_D} = 6\pi\eta(\mathbf{u} - \mathbf{v})R \qquad (2)$$

where η, $\mathbf{u}$, $\mathbf{v}$ and R are the viscosity, the fluid velocity, the particle velocity and the particle radius, respectively. The drag force is calculated from relative velocity between the fluid and the particle velocity.

The gravity force ($\mathbf{F_G}=m\mathbf{g}$) is easily obtained from a particle mass density and size. To analyze motion of the particles, these three forces acting on the particles are used for driving force in the Newton's motional equation as follows [4-6];

$$\mathbf{F_E} + \mathbf{F_D} + \mathbf{F_G} = m\frac{d\mathbf{v}}{dt} \qquad (3)$$

where, m is the mass density of the particle, and it is numerically solved using the Runge-kutta method.

III. Analysis of Conductive Particle Motion

A. Description of Analysis Model

The analysis model for the particle motion is shown in Fig. 1; left side depicts the full model, and right side is the axial symmetry model for the particle motion analysis. The electrode radius and the distance between the electrodes are r_e and h, respectively.

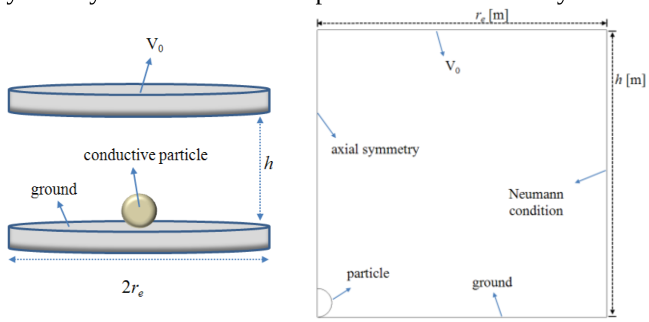

Fig. 1. Analysis model for the particle motion

B. Total Charge Calculation for Electric Force

When the neutral conductive particle contacts with the lower electrode, it gains more charges as the applied voltage increases. The particle moves toward the upper electrode when the electric force acting on the particle is more dominant than both the drag force and gravity. So, it is important to calculate exactly the total charge on the particle.

In the same applied voltage, the shape and size of particle affect the electric force. Fig. 2 shows the analysis result related to the particle shape with the applied voltage, 30kV. The total charge on the particle increases in the same particle mass as the vertical axis, r_b, is longer than the horizon axis, r_a. Under the same particle mass, the rate of total charge variation is a similar tendency.

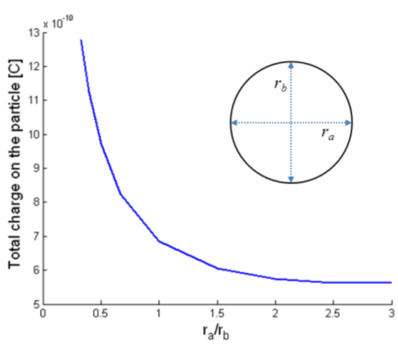

Fig. 3. Total charge as particle shape changes

IV. Particle Motion Experiment Using Spherical Conductive Particle

A. Experimental System

For the particle motion experiment, we use a high speed camera, which is LC320S (Phantom) model; 1,3800 frame per sec, full resolution (1920x1200), minimum exposure (1μs) because it takes about 0.078s during the particle levitation in the electrode gap, 0.01m. The chamber manufactured is the same size of the GIS part containing the electrodes, which are used in the analysis. The AC power supply used in the experiment has the range of 30kV with frequency, 60Hz, and the spherical Fe particle is used. The experimental setup is shown in Fig. 3.

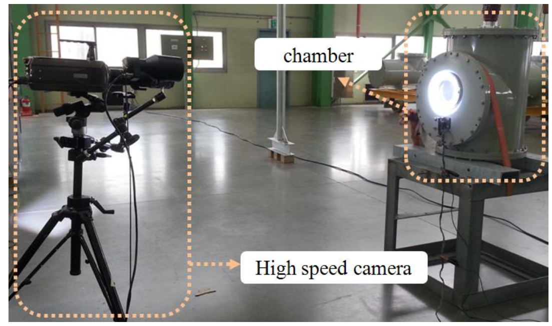

Fig. 3. Experiment setup using high speed camera

B. Experimental Results

The Fe particle is initially place on the center of lower electrode, and the applied voltage increases from 0kV. When the applied voltage is 15.6kV, the particle starts levitation motion. The experiment results with respect to time will be shown in full paper. The particle motion time can be calculated checking the fame of the high speed camera. The experimental results of the particle motion agreed with the numerical one.

V. Conclusion

The analysis results show that the particle motion, which is strongly position-dependent, is affected by its shape and a kind of applied voltage. The experiment using the spherical Fe particle is conducted, and the particle levitation motion is filmed using the high speed camera because the particle moves at high speed in the electrode gap. To validate proposed numerical method, the numerical results are compared with the experimental one. The proposed method can be used for analyzing the particle motion within GIS.

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