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EFFECT OF VARIOUS PARAMETERS ON THE MOVEMENT OF METALLIC PARTICLES IN A SINGLE PHASE GAS INSULATED BUS DUCT WITH IMAGE CHARGES AND DIELECTRIC COATED ELECTRODES

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ABSTRACT

The insulation performance of gas insulated systems (GIS) can be substantially affected by the presence and movement of contaminating metallic particles. With and without Image charge effect on metallic particle movement in a single phase GIB (Gas Insulated Bus duct) and also with and without dielectric coating on the enclosure is considered in this paper. In the present work the equations describing the motion of the particle due to image charge has been proposed to obtain the particle trajectories. The simulation has been carried out to obtain the particle trajectories at an applied voltage of 132 KV and also the effect of various parameters like radius and length of the Particle, pressure in the bus duct has been examined and presented. Typically a GIB of inner conductor and outer enclosure diameters of 55/155 have been considered for analysis. Different metallic contaminations viz Aluminum and Copper have been considered for the above study.

Keywords: metallic particles, electrostatic effect, image charge effect, gas insulated substations, gas insulated bus duct.

Nomenclature

m: mass of the particle
y: displacement in vertical direction
g: gravitational constant
f_e :electrostatic force
f_d: drag force
$\dot{y}$: velocity of the particle
μ: viscosity of the fluid
r: particle radius
ρ_g: gas density
l: particle length
e: resultant electric field.
x: position of the particle in the enclosure.
h: distance between centre of the conductor and enclosure.

1. INTRODUCTION

The development and design of compressed gas insulated substations (GIS) and compressed gas insulated transmission line (GITL) equipment has progressed during the last three decades. It is known, however, that electrical insulation performance of GIS/GITL system is adversely affected by metallic particle contaminants [1]. The conducting particles can either be free to move in the GIB or they may stick to an energized electrode or to an enclosure surface [2,3].

It is a fact that free conducting particles in GIB could reduce the insulation strength drastically. In practical systems it is very difficult to remove conducting particle contamination in GIB. Such contamination may be caused by mechanical aberration, incorrect assembling and movement of conductors under load cycling [4-6]. The free conducting particles drastically reduce the break down voltage as a result of their movement in the electric field. 20% of failures in GIS are due to the existence of various metallic contaminations in the form of loose particles. If the effects of these particles could be eliminated, then this would improve the reliability of compressed gas insulated substations [7-9].

At the time of manufacturing of GIS equipment, care should be taken to ensure that all components are free from metallic particles. However, metallic contaminants are inevitable in installed systems. The most common causes are mechanical vibrations during shipment and service, thermal expansion/contraction at expansion joints etc., [10,11]. Several methods of conducting particle control and deactivation have been proposed and some of these in current use are [12]:

a. Electrostatic trapping.
b. Use of adhesive coating to immobilize particles.
c. Discharging of conducting particles through radiation.
d. Coating conducting particles with insulating films.
e. Dielectric coating on the inner surface of the outer enclosure.

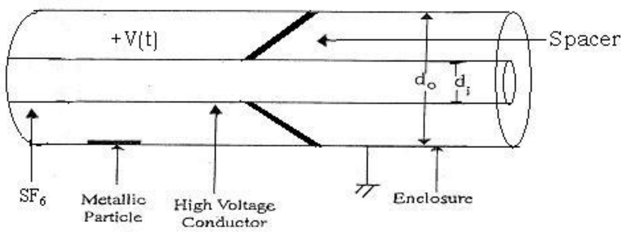

Figure-1. Gas insulated bus duct.

2. UNCOATED ENCLOSURE

The system studied corresponds to very closely to the dimensions of a 132KV GIB system. The aluminum and copper wire particles selected for simulation study has

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a radius and length of o.25mm and 10mm, respectively. The inner and outer diameters of the co-axial system are 55mm and 152mm, respectively.

A wire particle may lift-off horizontally under sudden applied voltages. The lift-off field E_{LO} and charge q for horizontal wire particle are

$$E_{LO} = 0.84\sqrt{\frac{\rho g r}{\varepsilon_0}} \qquad (1)$$

and $q_{hw} = 2\pi\varepsilon_0 rlE$

By approximating the wire to a semi-ellipsoidal of base radius r and vertical length l, the lift-off field E_{LO} and charge q are

$$E_{LO} = \left[\ln\frac{2l}{r} - 1\right]\left[\frac{r^2 \rho g}{\varepsilon_0 l(\ln(l/r) - 0.5)}\right]^{1/2} \qquad (2)$$

and $q_{vw} = \pi\varepsilon_0 l^2 E_l \Big/ \left[\ln\frac{2l}{r} - 1\right]$

Once the wire is elevated from the horizontal to the vertical position, it acquires more charge and requires a lower electric field to remain erect. Therefore, a particle can remain active in the inter electrode gap at voltages lower than the initial lifting voltage.

3. DIELECTRIC COATED ENCLOSURE

In the case of GIS, by using a coating with a light shade on the inside of the enclosure, it is easier to detect impurities such as metallic particles or pieces of dielectric material in the system. Charging of metallic particles in contact with a coated electrode is mainly based on two different charge mechanisms.

i) Conduction through a dielectric coating.
ii) Micro discharges between the particle and the coating (for high electrical fields and lower gas pressures)

The circuit model of particle charging through the dielectric coating. As shown in Figure-2 C_g represents capacitance between the conductor and the particle whereas Cc represents capacitance between the particle and the enclosure. The conductance G represents the part of the dielectric coating where the Charging current is flowing.

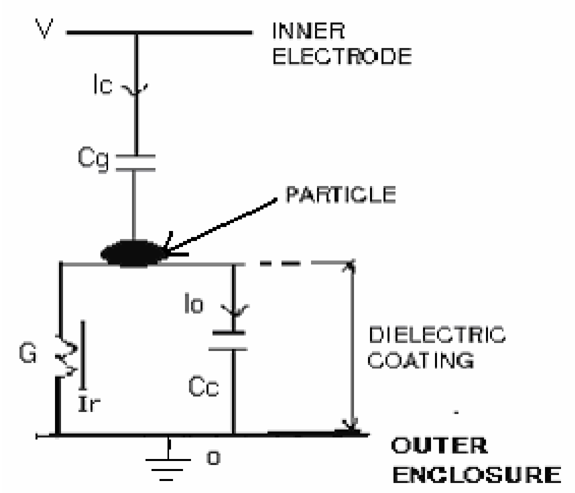

Figure-2. Circuit model of particle charging through the dielectric coating.

$$m\ddot{y}(t) = \left[\frac{\Pi\varepsilon_0 l^2 E(t_0)}{\ln\left(\frac{2l}{r}\right) - 1} \times V \times 292.48 \times 10^3\right]\left(\frac{1}{76 - x}\right)\sin\omega t$$

The equation for the electric lift-off field E_{LO} is given as

$$E_{L0} = \left[\frac{mg}{\frac{K}{\omega}B(\phi)r_0 \ln\frac{r_0}{r_i}}\right]^{0.5}\left[R\left[1 + \frac{C_C}{C_g}\right]^2 + \left[\frac{1}{R^2\omega^2 C_g^2}\right]^{0.5}\right]^{0.5}$$

$$= K\left[\left[1 + \frac{C_C}{C_g}\right]^2 + \frac{1}{R^2\omega^2 C_g^2}\right]^{0.25}\left(\frac{\rho_c T}{S}\right)^{0.5} \qquad (3)$$

Where K is a constant. It can be noted that E_{LO} is approximately proportional to square root of the thickness and resistivity of the dielectric.

4. MODELING TECHNIQUE

As per the earlier work, while arriving a mathematical model of the movement of particles inside a bus duct, various properties of gas and particle as well as electrical properties of the system have been taken into account. The dynamic equation comprises the gravitational force on the particle, charge acquired by the particle, field intensity at the particle location, drag force, gas pressure, restitution co-efficient and the Reynolds's no.

When the electric field surrounding a particle is increased, an uncharged metallic particle resting on a bare electrode will gradually acquire a net charge. The charge accumulated on the particle is a function of the local electrical field, orientation, shape and size of the particle. When the electrostatic force exceeds the gravitational force, the particle will lift. The equation of motion for a particle can be expressed as

$$m\frac{d^2y}{dt^2} = F_e - mg - F_d \quad (4)$$

The direction of drag force is always opposed to the direction of motion.
The motion equation using all forces can therefore be expressed as:

$$m\ddot{y}(t) = \left[\frac{\Pi\varepsilon_0 l^2 E(t_0)}{\ln\left(\frac{2l}{r}\right)-1}\times V\times 292.48\times 10^3\right]\left(\frac{1}{76-x}\right)\sin\omega t$$

$$-mg - \dot{y}(t)\Pi r\left[6\mu K_d\left(\dot{y}\right)+2.656\left[\mu\rho_g l\dot{y}\right]^{0.5}\right] \quad (5)$$

The above equation (5) is a second order non-linear differential equation for motion of a metallic particle.

4.1 Image charge effect on the particle

Figure-3 shows a horizontal single phase bus duct has been considered for the analysis of image charge effect. In Figure-3 'A' represents the conductor and A[1] be the image of the conductor A and 'a' denotes the particle which is assigned to be at rest in the enclosure surface, just beneath the conductor A, until a voltage sufficient enough to lift the particle and move in the field is applied .After acquiring an appropriate charge in the field, the particle lifts and begins to move in the direction of field having overcome the force due to its own weight and drag.

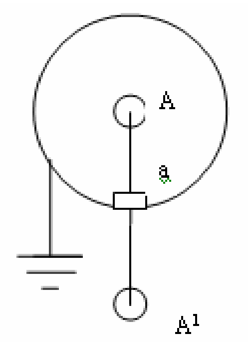

Figure-3. A single phase Gas insulated busduct with Image charge.

4.2 Expression for electric field

Let the particle move to a distance 'x' form the inner surface of the enclosure at the point 'a' in Figure-3.
General expression for electric field intensity due to conductor A includes the image charge effect is given as:

$$E = \frac{1}{2\ln\left(\frac{2h}{r}\right)}\left(\frac{1}{h-x}+\frac{1}{h+x}\right)V_m\sin\omega t \quad (6)$$

The motion equation is given by

$$m\ddot{y}(t) = \left[\frac{\Pi\varepsilon_0 l^2 E(t_0)}{\ln\left(\frac{2l}{r}\right)-1}\times V\times 292.48\times 10^3\right]\left(\frac{1}{76-x}+\frac{1}{76+x}\right)\sin\omega t$$

$$-mg - \dot{y}(t)\Pi r\left[6\mu K_d\left(\dot{y}\right)+2.656\left[\mu\rho_g l\dot{y}\right]^{0.5}\right] \quad (7)$$

The above equation (7) is a second order non-linear differential equation for motion of a metallic particle while considering Image charge effect.

5. SIMULATION OF PARTICLE MOTION

The study of the motion of moving metallic particles in GIS requires a good knowledge of the charge of the particle. Several authors have suggested solutions for the motion of a metallic particle in an isolated particle bus duct system. simulation of the motion of metallic particles have been carried out on single-phase GIB of 55mm diameter of inner conductor and 152 mm diameter of the outer enclosure with 132 KV applied to inner conductor. Aluminum, copper and silver wires like particles are considered to be present on the enclosure surface. To solve the motion equation Runge-Kutta 4th order method is adopted.

6. RESULTS AND DISCUSSIONS

The particle dimensions are considered as 12 mm in length with 0.2 mm radius. Initially the particle is supposed to be resting at the bottom of the enclosure and positioned horizontally. The simulated results of maximum movement of particles are shown in Table-1. The maximum radial movements of the particle in a single phase isolated Gas Insulated Bus duct of Aluminum, Copper and Silver particles by considering with and without Image charge effect on the particles under dielectric coating on the enclosure is shown in Figure-4 to Figure-14 for applied voltage of 132KV.

It is observed in the Figure-4, that the maximum movement of the Aluminum particle is 49.75, while considering without Image charge effect at a given voltage of 132KV. It has also been observed in the Figure-5 and Figure-6, that the maximum movement of Aluminum particle is greatly reduced under dielectric coating on the enclosure is considered which has been shown in the Table-1 below.

Figure-7 and Figure-9 show that the maximum movement of the Copper particle is 42.36 which is higher in case of considering Image charge effect than without Image charge effect on the particle, which is 16.07 at a given voltage of 132KV. It has also been noticed from Figure-8 and Figure-10, that the maximum movement of copper particle which is greatly reduced under dielectric coating on the enclosure is considered which has been shown in the Table-1 below.

Figure-11 and Figure-13 show that the maximum movement of the silver particle is 39.66 which is higher in case of considering Image charge effect than without

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Image charge effect on the particle, which is 19.31 at a given voltage of 132KV. It has also been noticed from Figure-12 and Figure-14, that the maximum movement of silver particle is greatly reduced under dielectric coating on the enclosure is considered which has been shown in the Table-1 below.

Table-1. Radial movement of aluminum and copper particles with and without image charge effect (200 μ m dielectric coating).

Voltage	Type	**Maximum radial movement** (mm)			
		Without image charge effect		**With image charge effect**	
		Uncoated	**Coated**	**Uncoated**	**Coated**
132KV	Al Cu Ag	49.75 16.07 19.31	1.34 0.30 0.22	CG 42.36 39.66	4.61 1.59 1.38

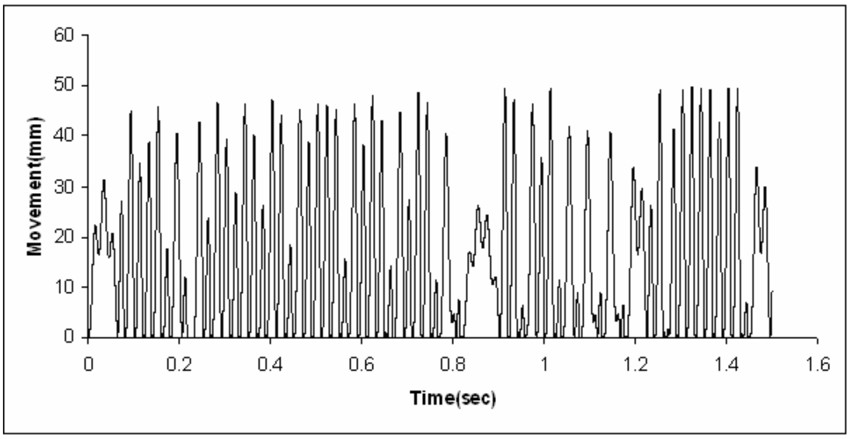

Figure-4. Particle movement without image charge effect in a 1-phase GIB for 132KV /Al/12mm / 0.2mm radius.

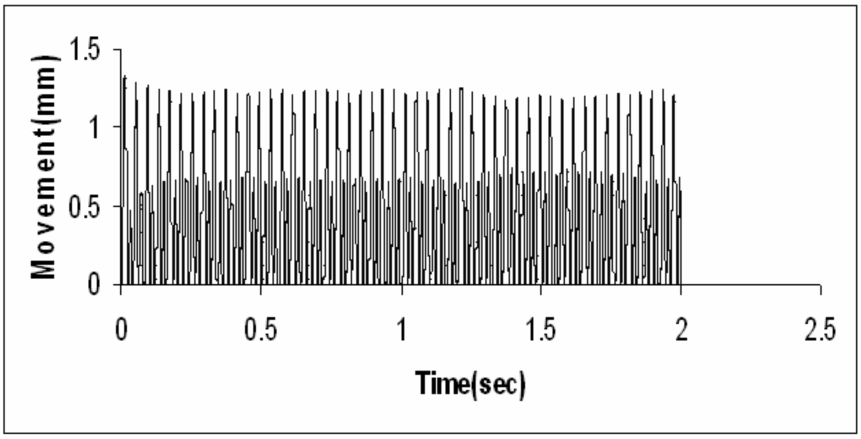

Figure-5. Particle movement without image charge effect in a 1-phase GIB for 132KV /Al/12mm / 0.2mm radius for a 200μm dielectric coated enclosure.

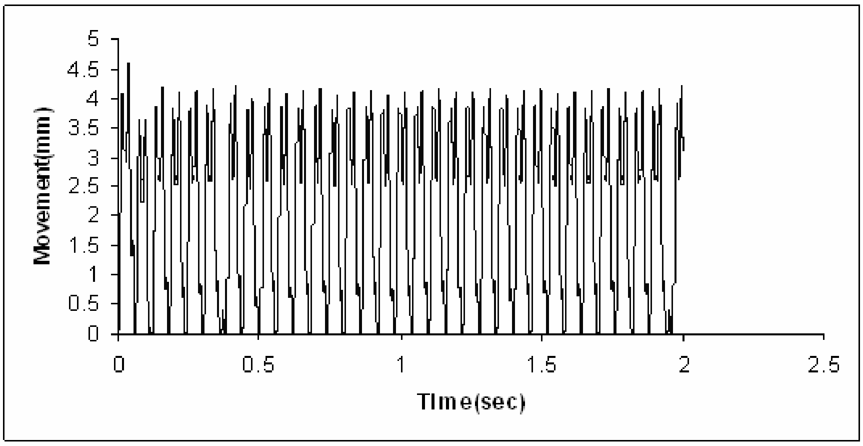

Figure-6. Particle movement with image charge effect in a 1-phase GIB for 132KV/Al / 12mm / 0.2mm radius for a 200µm dielectric coated enclosure.

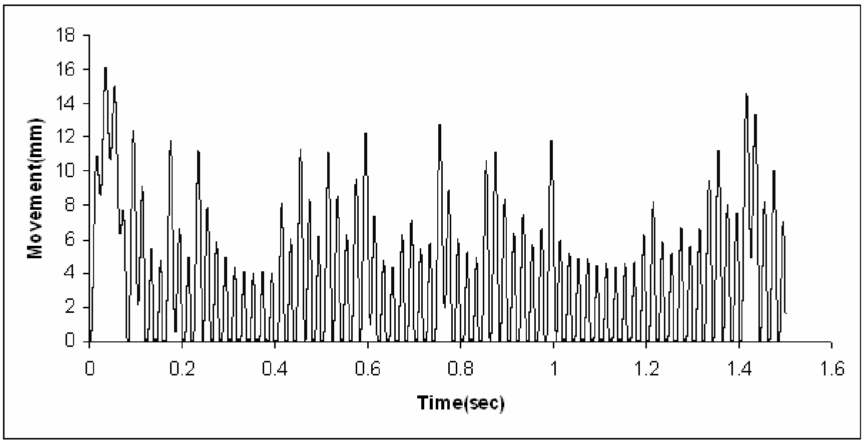

Figure-7. Particle movement without image charge effect in a 1- phase GIB for 132KV/ Cu /12mm / 0.2mm radius.

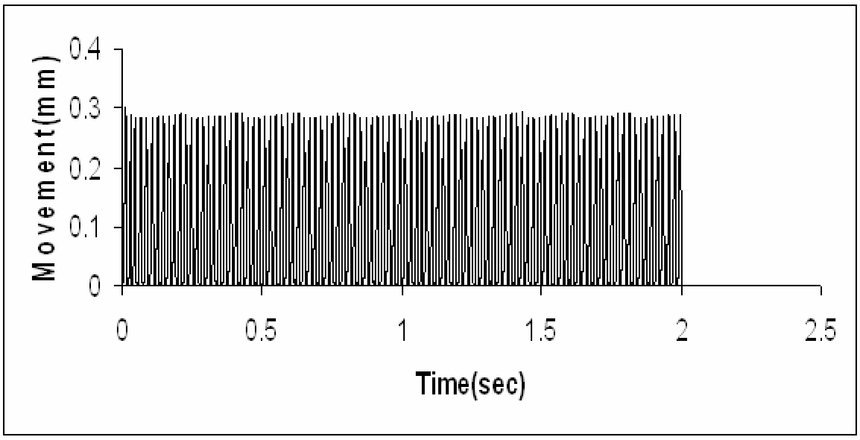

Figure-8. Particle movement without image charge effect in a 1- phase GIB for 132KV/ Cu /12mm / 0.2mm radius for a .200µm dielectric coated enclosure.

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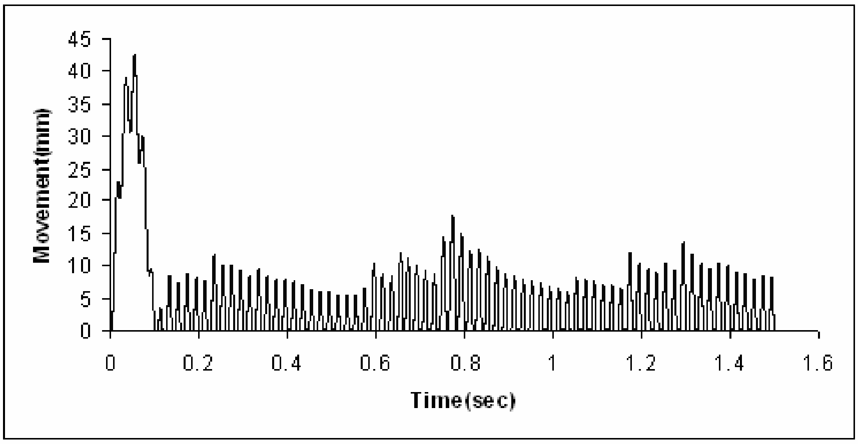

Figure-9. Particle movement with image charge effect in a 1-phase GIB for 132KV /Cu/ 12mm / 0.2mm radius.

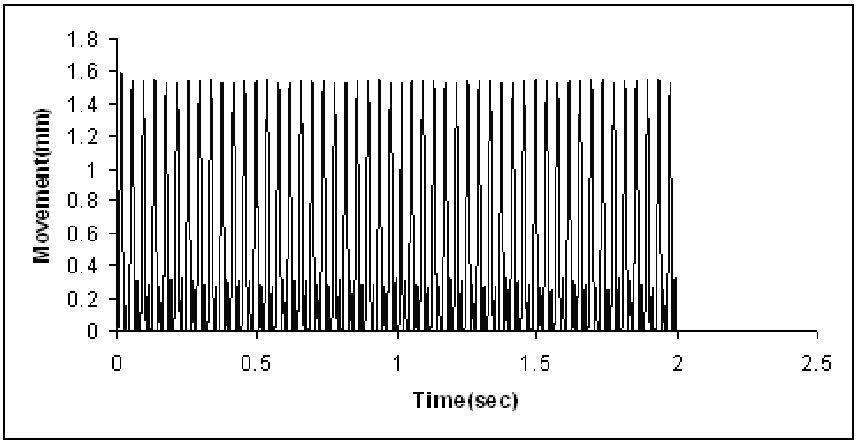

Figure-10. Particle movement with image charge effect in a 1-phase GIB for 132KV / Cu / 12mm / 0.2mm radius for a 200µm dielectric coated enclosure.

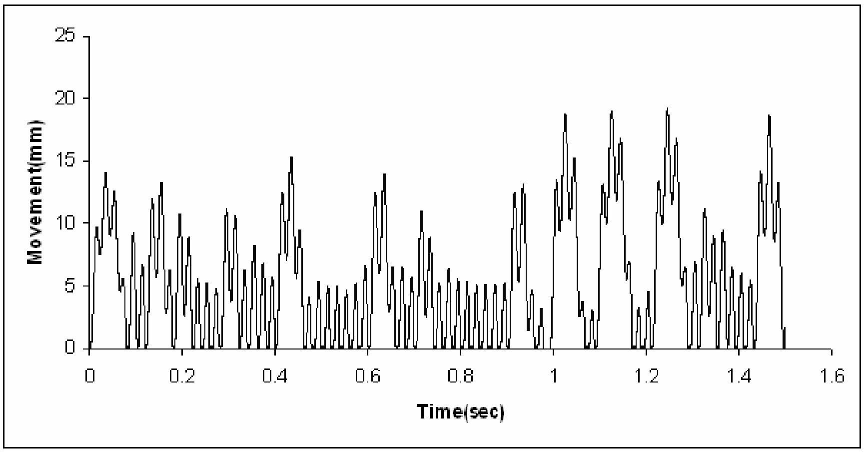

Figure-11. Particle movement without image charge effect in a 1-phase GIB for 132KV /Ag/12mm / 0.2mm radius.

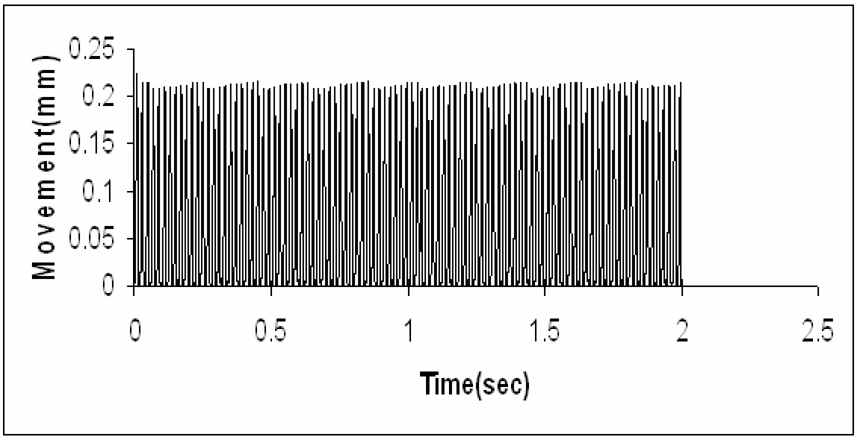

Figure-12. Particle movement without image charge effect in a 1-phase GIB for 132KV /Ag/12mm / 0.2mm radius for a 200μm dielectric coated enclosure.

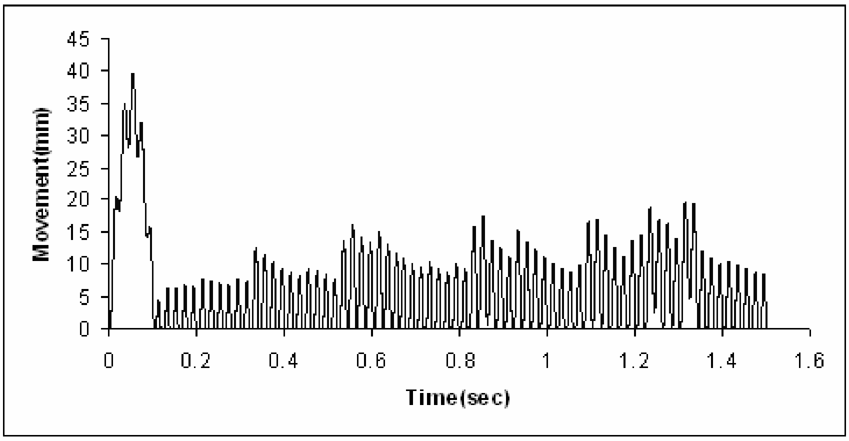

Figure-13. Particle movement with image charge effect in a 1-phase GIB for 132KV/Ag/12mm / 0.2mm radius.

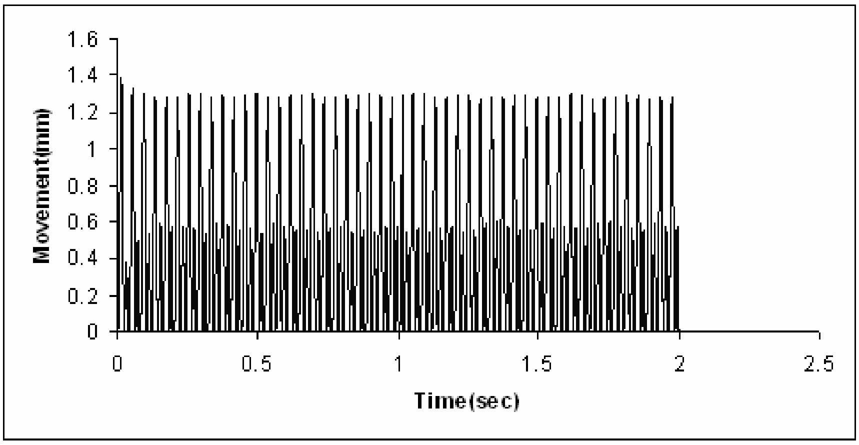

Figure-14. Particle movement with image charge effect in a 1-phase GIB for 132KV/Ag / 12mm / 0.2mm radius for a 200μm dielectric coated enclosure.

The maximum movement for aluminum, copper and silver with variation of length of the particle is shown in Figure-15. For a given voltage level and duration, maximum bounce height increases with particle length for any type of particle. This is mainly because, the charge on the particle increases with particle length.

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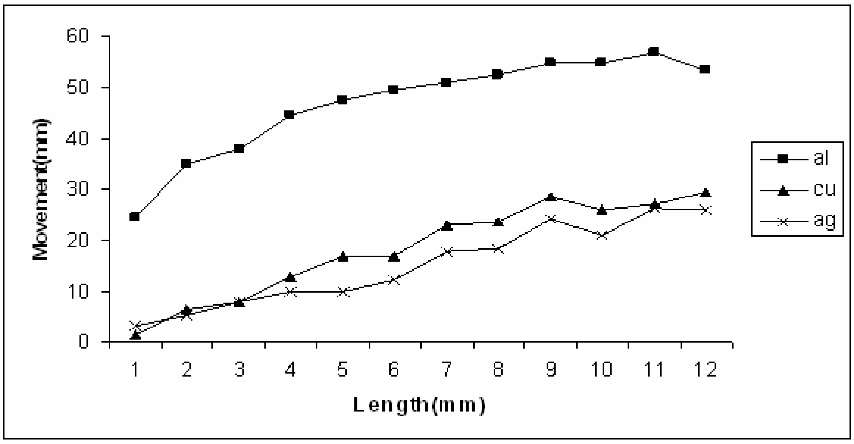

Figure-15. Movement of particle with variation of particle length.

Figure-16 shows the effect of the radius of particles' maximum movement of flight for the same length of aluminum, copper and silver particles. The maximum movement decreases with increasing radius of the particles.

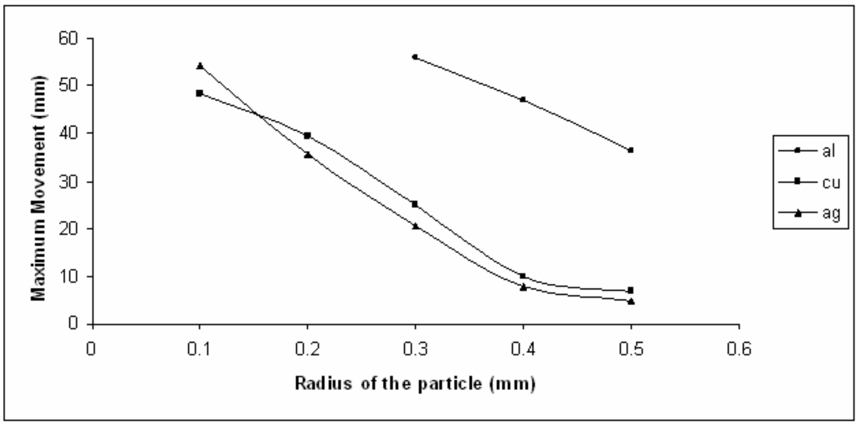

Figure-16. Movement of particle with variation of particle radius.

Figure-17 shows the maximum movement of particles with increase in pressure. As the pressure increases there is a Marginal decrease in maximum movement that is almost constant of Aluminum, Copper and Silver particles.

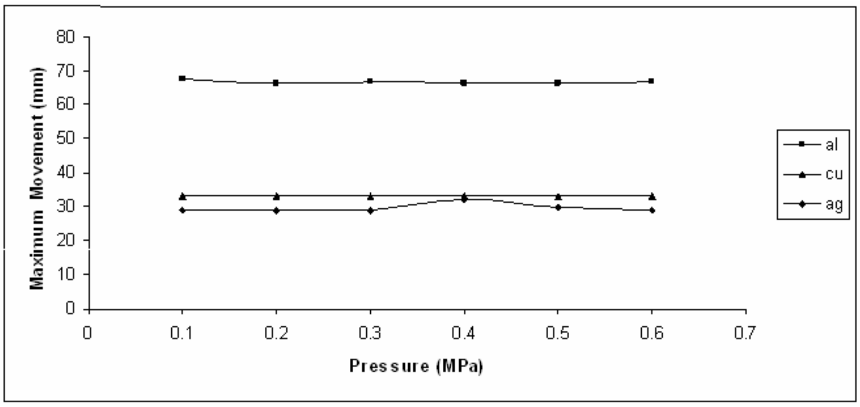

Figure-17. Movement of particle with variation of pressure.

Figure-18 shows the relation between the Restitution Coefficient and the maximum movement of Aluminum, Copper and Silver Particles. It can be observed that the maximum movement of the particles slightly increases with the increase in the Restitution Coefficient.

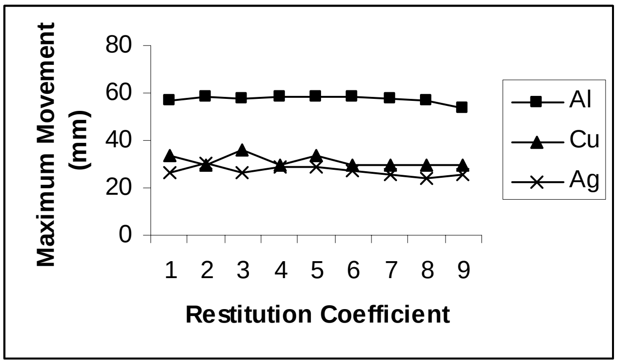

Figure-18. Movement of particle with variation of restitution coefficient.

7. CONCLUSIONS

The movement patterns of Aluminum, Copper and Silver particles under the applied voltage of 132 KV, with and without Image charge effect on the particles have been observed for a single phase isolated conductor GIS on bare electrode as well as coated electrode system. A model has been formulated to simulate the movement of particle in a single phase isolated Gas Insulated Bus Duct. The results have been presented and analyzed. It is observed that the movement of Aluminum, Copper as well as Silver particles in GIB greatly reduces, when dielectric coating on the enclosure is considered. But there is a significant increase in movement of Aluminum, Copper and Silver particles when the image charge effect is considered. It is also observed that if the length, radius and restitution coefficient of Al, Cu and Ag particles increases the maximum movement. Similarly if the pressure is increased the movement remains almost constant for all the particles with and without image charges.

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