Effect of Particle size on Particle movement in a Single Phase Gas Insulated Bus duct

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ABSTRACT

Performance of compressed Gas Insulated Switchgear and Gas Insulated systems are affected by metallic particle contaminants. 20% of failures in Gas Insulated Substations is due to the existence of various metallic contaminations in the form of loose particles. These particles may be free to move in the electric field or may be fixed on the conductors, thus enhancing local surface fields. In this paper basic equations for the movement of metallic particles like aluminum, copper in a bus duct is formulated. The particle motion is simulated using MATLAB. Effect of particle size for various electric fields on particle movement are analyzed. Particles of aluminum, copper , of 10 mm in length at different radii on a 1-phase bus duct enclosure have been considered. The results show that as the size of particle smaller larger the particle movement and leads to break down . It is also observed that peak movement in radial direction for Aluminium particle is higher than that of copper due to its density.

Keywords - Metallic Particles, Gas Insulated Substations, Particle Contamination, MATLAB.

I. INTRODUCTION

Sulphur hexafluoride is the electric power industry's preferred gas for electrical insulation and, especially,for arc quenching current interruption equipment used in the transmission and distribution of electrical energy. Compressed Gas Insulated Substations (GIS) and Transmission Lines (CGIT) consist basically of a conductor supported on insulator inside an enclosure, which is filled with SF 6 gas Basic components of the GIS bay are circuit breakers, disconnectors, earthing switches, bus ducts, current and voltage transformers, etc. The inner live parts of GIS are supported by insulators called spacers, which are made of alumina filled epoxy material. The GIS enclosure forms an electrically integrated, rounded enclosure for the entire substation. Even though SF6 exhibits very high dielectric strength, the withstand voltage of SF6 within the GIS is drastically reduced due to the presence of particles or defects like Free particles on the inner surface of the enclosure, Protrusion on the high voltage (HV) bus, Protrusion on the inner surface of the enclosure and Narrow gaps between the spacer and the electrode due to imperfect casting and_ or imperfect mechanical strength, The presence of contamination can therefore be a problem with gas-insulated substations operating at high fields [1]-[2].

Free conducting particles are most dangerous to GIS. These free conducting particles may have any shape or size, may be spherical or filamentary (wire like) or in the form of fine dust. Particles may be free to move or may be fixed on to the surfaces. wire like particles made of conducting material are more harmful and their effects are more pronounced at higher gas pressures. As given by the authors [2-5], the presence of atmospheric dust containing conducting particles, especially on the cathode, reduces the breakdown voltage

The purpose of this work is to develop techniques, which will formulate the basic equations that will govern the movement of metallic particles like aluminum, copper and silver and to simulate the particle motion using MATLAB for different electric fields.

The specific work reported deals with the charge acquired by the particle due to macroscopic field at the tip of the particle, the force exerted by the field i.e., electric field on the particle, drag due to viscosity of the gas and random behavior during the movement. Wire like particles of aluminum and copper of 10 mm in length and different radii 0.15 mm,0.2 mm,0.25 mm ,0.3mm ,0.35mm as radius on a 1-phase bus duct enclosure have been considered. The movement pattern for higher voltages class has been also obtained.

II.MODELING OF GAS INSULATED BUS DUCT

A typical horizontal single-phase bus duct shown in Figure 1has been considered for the analysis. It consists of an inner conductor and an outer enclosure, filled with SF6 gas. A particle is assumed to be at rest at the enclosure surface, 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 the field after overcoming the forces due to its own weight and drag. For particles on bare electrodes, several authors have suggested expressions for duct the estimation of charge on both vertical/horizontal wires and spherical particles. The equations are primarily based on the work of Felici[5].

Understanding the dynamics of a metallic particle is of vital importance for determining the effect of metallic contamination in a Gas Insulated System (GIS). If the motion pattern of a metallic particle is known, the probability of particle crossing a coaxial gap and causing a

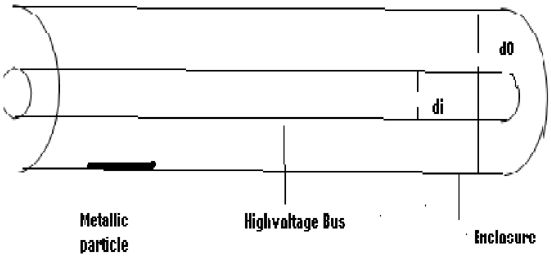

Fig. 1. Typical single phase gas insulated bus

flashover can be estimated. The lift-off field for a particle on the surface of an electrode can be estimated by solving the motion equation. A conducting particle in motion in an external electric field will be subjected to a collective influence of several forces. The forces are : -
-Electrostatic force (Fe)
- Gravitational force (mg)
- Drag force (Fd)
The motion equation is given by

$$m\frac{d^2y}{dt^2} = F_e - mg - F_d \quad (1)$$

where m = mass of the particle
y = displacement in vertical direction
Fe = Electrostatic force
g = gravitational constant

The charge acquired by a vertical wire particle in contact with a naked enclosure can be expressed as:

$$Q = \frac{\pi\epsilon_0 l^2 E(t_0)}{\ln\left(\frac{2l}{r}\right) - 1} \quad (2)$$

where Q is the charge on the particle until the next impact with the enclosure, l is the particle length, r isthe particle radius, E(t0) is the ambient electrical field at t = t0. The charge carried by the particle between two impacts has been considered constant in the simulations.

The electric field in a coaxial electrode system at position of the particle can be written as:

$$E(t) = \frac{V_m \sin wt}{[r_0 = y(t)]\ln\left(\frac{r_0}{r_i}\right)} \quad (3)$$

where Vm Sinwt is the supply voltage on the inner electrode, r0 is the enclosure radius, ri is the inner conductor radius y(t) is the position of the particle which is the vertical distance form the surface of the enclosure towards the inner electrode.

The electrostatic force is

$$Fe = K\,Q\,E(t) \quad (4)$$

Where K is a corrector and is a factor less than unity.
However, for length-to-radius ratios greater than 20 the correction factor, K, is close to unity

The drag force is given by:

$$F_d = y\pi r(6\mu Kd(y) + 2.656[\mu\rho gly]^{0.5}) \quad (5)$$

where y is the velocity of the particle, µ is the viscosity of the fluid (SF6 : 15.5_10−6kg/m_s at 200C), r is the particle radius, ρg is the gas density, l is the particle length, Kd(y) is a drag coefficient.
The influence of gas pressure on the drag force is given by empirical formula.

$$\rho_g = 7.118 + 6.332p + 0.2032p \quad (6)$$

where ρ_g= density p = Pressure of the gas and 0.1 < p < 1mboxMPa.
The restitution coefficient for copper and aluminum particles seem to be in the range of 0.7 to 0.95:R = 0.8 implies that 80% of the incoming impulse of the particle is preserved when it leaves the enclosure.

The motion equation (1) using all forces can therefore be expressed as

$$m\frac{d^2y}{dt^2} = \frac{\pi\epsilon_0 l^2 E(t_0)}{\ln\left(\frac{2l}{r}\right) - 1} \cdot \frac{V_m \sin wt}{[r_0 = y(t)]\ln\left(\frac{r_0}{r_i}\right)} - mg$$

$$-y\pi r(6\mu Kd(y) + 2.656[\mu\rho gly]^{0.5}) \quad (7)$$

The above equation is a second order non-linear differential equation and in this paper, the equation is solved using MATLAB by Runge- Kutta 4th Order Method.

III.SIMULATION OF PARTICLE MOTION

In order to determine the random behavior of moving particles, the calculation of movement in axial and radial directions was carried at every time step using rectangular random numbers. Simulation is carried out using MATLAB software. The above simulation yields the particle movement in the radial direction only. However, the configuration at the tip of the particle is generally not sufficiently smooth enough to enable the movement unidirectional. This decides the movement of particle in axial direction. The randomness of movement can be adequately simulated by Monte-Carlo method. In order to determine the randomness, it is assumed that the particle emanates from its original site at any angle less than φ, where φ/2 is half of the solid angle subtended with the vertical axis. At every step of movement, a new rectangular random number is generated between 0 and 1 and modified to φ. The angle thus assigned, fixes the position of particle at the end of every time step, and in turn determines the axial and radial positions. The position in the next step is computed on the basis of equation of motion with new random angles as described above.

IV RESULTS AND DISCUSSIONS

Table 1 shows the radial and axial movement of the particle in a 3- Phase Gas Insulated Bus duct. The results have been presented by using Monte-Carlo Technique also shown in Table 1. Figure 2 to Figure 9 shows the movement patterns of copper and aluminum particles in Electric Field and with Monte Carlo Technique for applied voltages of 100 kV and 132 kV respectively. The radius of the particles in the case is considered as 0.15 mm,0.2 mm,0.25 mm ,0.3mm ,0.35mm and length of the particle as 10 mm. It is observed that the highest displacement in radial direction during its upward journey is simulated to be 33.09 mm for 132 kV GIS at a

Table:1 Radial movement of aluminum and copper particles with and without Monte-Carlo technique for 100 KV.

Voltage KV	Type of material	Radius of particle (mm)	Max. Radial Movement (mm)
100	Al	0.15	28.2478
		0.2	17.4875
		0.25	8.9165
		0.3	4.5377
	Cu	0.15	4.9433
		0.2	1.0697
		0.25	0.4143
		0.3	0.2178

Table:2 Radial movement of aluminum and copper particles with and without Monte-Carlo technique for 132 KV

Voltage KV	Type of material	Radius of particle (mm)	Max. Radial Movement (mm)
132	Al	0.15	33.0187
		0.2	19.5523
		0.25	13.7561
		0.3	7.2914
	Cu	0.15	10.4421
		0.2	3.5681
		0.25	1.0183
		0.3	0.5318

Particle radius of 0.15 mm (Table 2)..As the radius increases the maximum radial movement decreases . However, it is noticed that at a voltage of 100 kV the particle lowest max displacement is 0.2178806 mm only for Copper particle .It is noticed that the movement of copper particle is far less than aluminum particle of identical size. This is expected due to higher density of copper particle. The radial movement of aluminum and copper particles are calculated using Monte-Carlo technique for the voltages 100 kV,132 kV for different radii with a solid angle of 1degree.

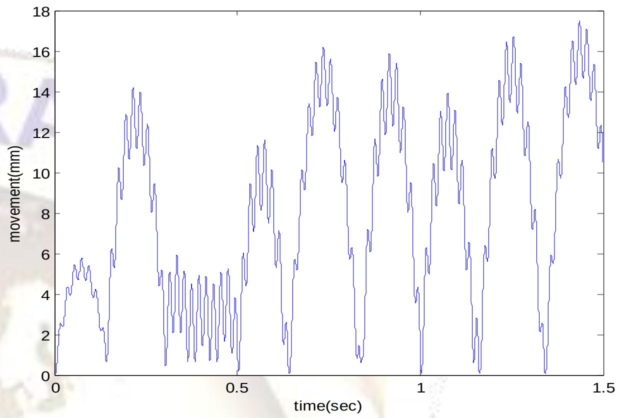

Figure:2 Particle Movement for
Al / 100 KV / 10 mm / 0.15 mm radius / 76mm - 25mm Enclosure

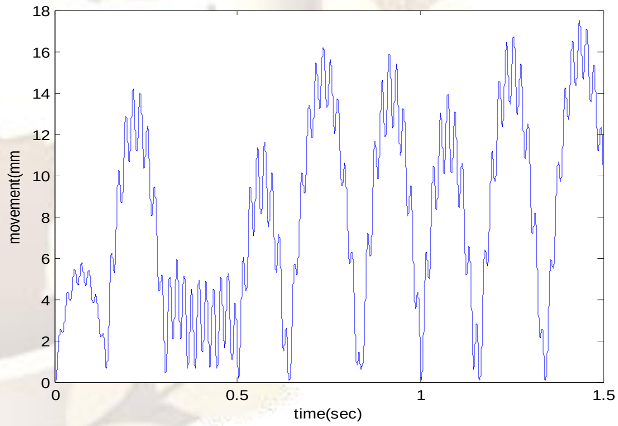

Figure:3 Particle Movement for
Al/ 100KV / 10 mm / 0.20 mm radius / 76mm - 25mm Enclosure

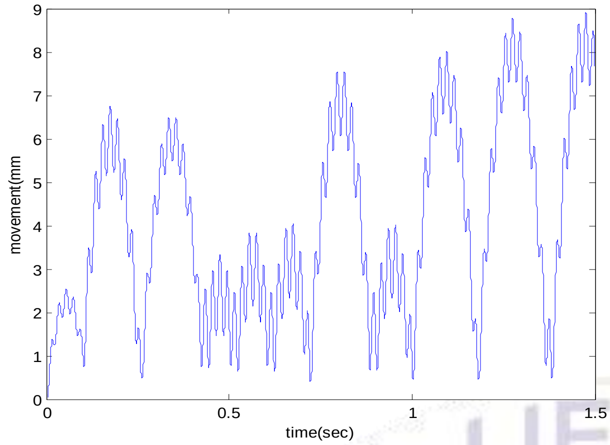

Figure:4 Particle Movement for
Al / 100 KV / 10 mm / 0.25 mm radius / 76mm - 25mm Enclosure

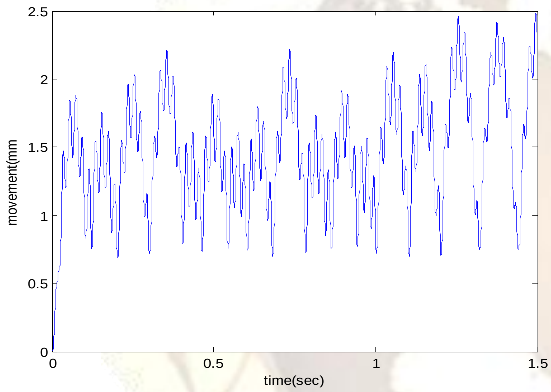

Figure:5 Particle Movement for
Al / 100 KV / 10 mm / 0.30 mm radius / 76mm - 25mm Enclosure

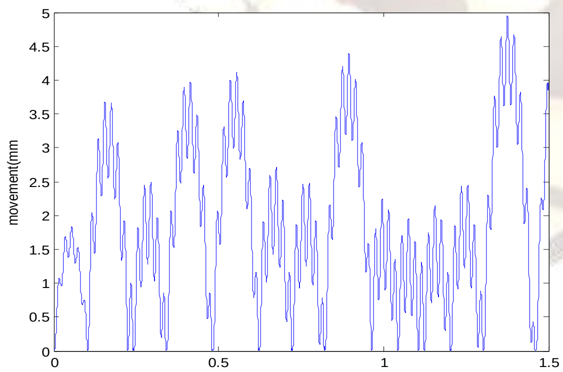

Figure:6 Particle Movement for
Cu/ 100 KV / 10 mm / 0.15 mm radius / 76mm - 25mm Enclosure

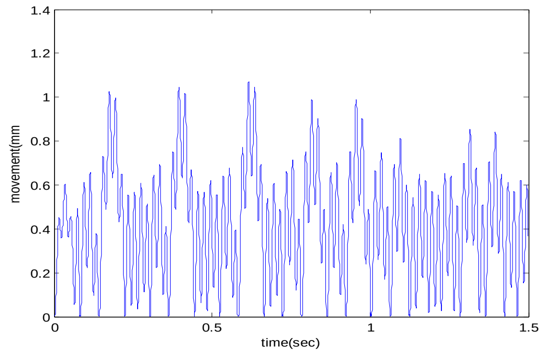

Figure:7 Particle Movement for
Cu / 100 KV / 10 mm / 0.20 mm radius / 76mm - 25mm Enclosure

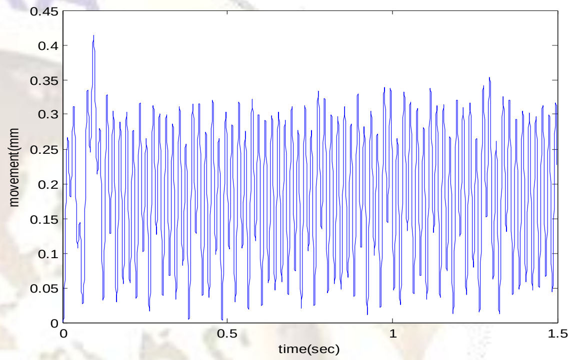

Figure:8 Particle Movement for
Cu/ 100 KV / 10 mm / 0.25 mm radius / 76mm - 25mm Enclosure

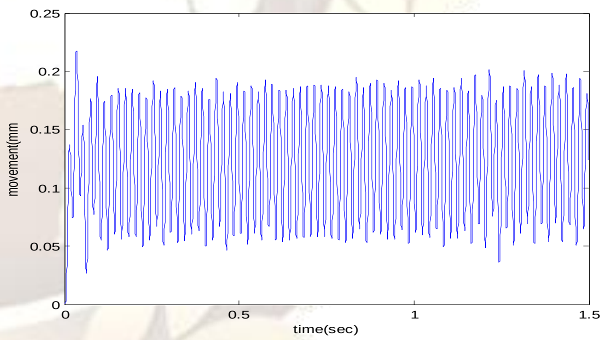

Figure:9 Particle Movement for
Cu / 100 KV / 10 mm / 0.25 mm radius / 76mm - 25mm Enclosure

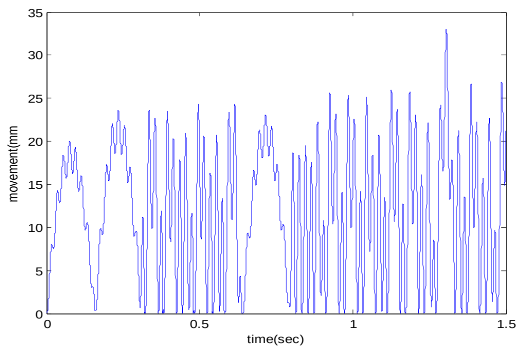

Figure:10 Particle Movement for

Al / 132 KV / 10 mm / 0.15 mm radius / 76mm - 25mm Enclosure

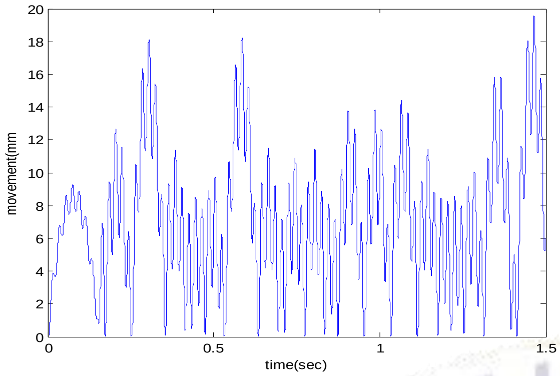

figure:11 Particle Movement for
Al/ 132KV / 10 mm / 0.20 mm radius / 76mm - 25mm Enclosure

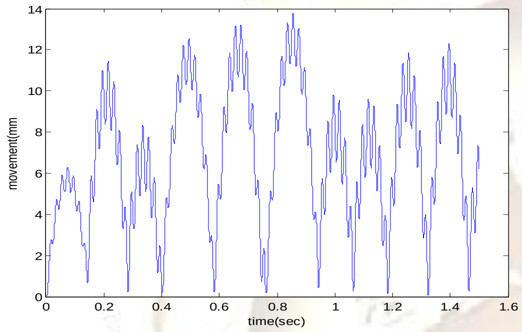

Figure:12Particle Movement for
Al / 132 KV / 10 mm / 0.25 mm radius / 76mm - 25mm Enclosure

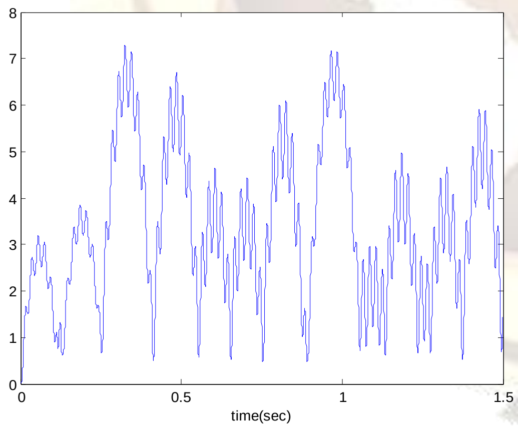

Figure:13 Particle Movement for
Al / 132 KV / 10 mm / 0.30 mm radius / 76mm - 25mm Enclosure

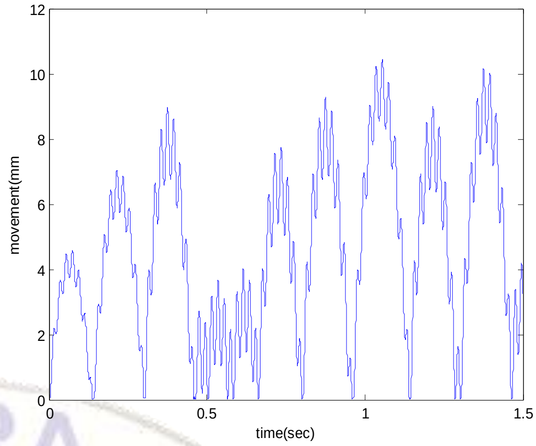

Figure:14 Particle Movement for
Cu/ 132 KV / 10 mm / 0.15 mm radius / 76mm - 25mm Enclosure

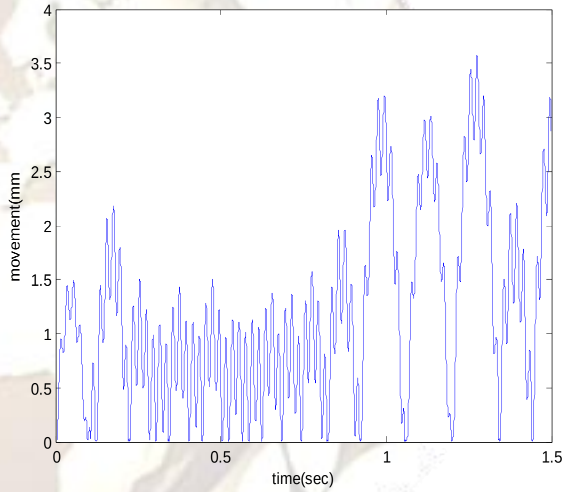

Figure:15 Particle Movement for
Cu / 132 KV / 10 mm / 0.20 mm radius / 76mm - 25mm Enclosure

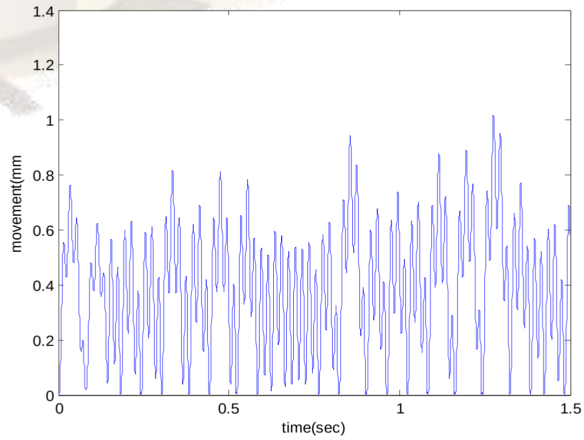

Figure:16 Particle Movement for
Cu/ 132 KV / 10 mm / 0.25 mm radius / 76mm - 25mm Enclosure

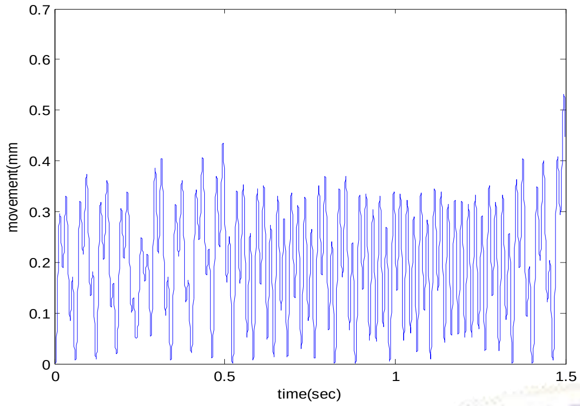

Figure:17 Particle Movement for
Cu / 132 KV / 10 mm / 0.25 mm radius / 76mm - 25mm Enclosure

V CONCLUSION

It is shown that the probability of a flashover occurs at smaller size of the particle The influence of increased voltage level on the motion of the particles is also investigated. If the calculations, as described above, are performed at a higher voltage level, the particle will lift higher from the surface and the time between bounces will increase. The results obtained from the calculations show that additional information about the particle could be obtained when voltage dependence is introduced in the calculations. For instance, it can be noted that aluminum particles are more influenced by the voltage than copper particles due to its lighter mass. This results in the aluminum particle acquiring greater charge-to-mass ratio. The coefficient of restitution, which denotes the ratio of outgoing to incoming velocities, is of vital importance for determining the maximum movement of particle. The results obtained are presented and analyzed. Monte- Carlo simulation is also adopted to determine axial as well as radial movements of particle in the busduct. Distance traveled in the radial direction is found to be same with or without Monte-Carlo simulation. All the above investigations have been carried out for various sizes of the particle and voltages under power frequency.

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