Electrical Discharge Occurring between a Negatively Charged Particle Cloud and a Grounded Sphere Electrode

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Abstract. Electrostatic discharge occurring between a space-charge cloud and a grounded object was investigated using a large-scale charged particle cloud formed by using three set of cloud generators consisting of a blower and corona charger. The ejecting velocity of the particles affects the formation of the charged cloud. At the lower velocity, the charged cloud spread due to electrostatic repulsion force, while at the higher velocity cloud forms an elongated conical shape. To cause electrostatic discharge between the cloud and a grounded object, a grounded sphere electrode with 100 mm in diameter was set at the inside or outside of the cloud. The brush-like discharge channels reached the maximum length of 0.55 m. The discharge current has a waveform with single or multi-peak, a current peak of several amperes, the maximum charge quantity of 2 µC, and the duration of several microseconds. The relationship between the charge quantity and the current peak or the duration in each discharge was examined. The discharge between the cloud and the electrode placed at the outside of the cloud has relatively longer channels and multi-peak current with the longer duration, while that at the inside of the cloud has the lower charge quantity with single peak.

1. Introduction

Electrostatic discharges occurring between a space charge cloud and a grounded object might be a source of disaster when the discharge occurs in an oil tank and a silo. The source of the space charge discharge is a cloud of charges distributed in space, which never has a constant potential unlike a metal electrode connected to the voltage source. Thus, discharge from or in a space charge cloud might be quite different that from a metal electrode. To clarify the inception and extending mechanism of the space charge discharge as well as the characteristics of the discharge, it is necessary to generate the space charge cloud with a given charge density and the size with reproducibility.

The trials to form a space charge cloud and to cause the electrostatic discharge have been carried out by using water droplets [1-4] and powder particles [5-7]. Temnikov et al. reported electrostatic discharge up to 2 m length occurred in a charged water aerosol cloud [2]. We have investigated the charged particles cloud formed by charged water droplets [3, 4] and charged powder particles [5, 6]. When powder particles charged by corona charging were used, relatively long streamer discharge extended from the grounded electrode toward the charged cloud [6]. This paper introduces the effect of the ejecting velocity of the charged particles on the electrostatic properties of charged particle cloud such as distribution of charge quantity in the cloud and the electric field strength around the cloud. Furthermore, from the detail analysis of the waveform of the discharge current, the relationship between the charge quantity neutralized in discharges and the peak current or duration were obtained.
2. Experimental

A charged particle cloud was formed outdoors using three sets of a cloud generator consisting of a blower, a powder feeder and corona charger, connected with PVC pipe [6]. To form a large-scale charged-particle cloud, soil-conditioning particles made of pulverized seashell were used. The particles, sieved into the diameter under 250 μm, were supplied into the PVC pipe with a constant rate of 20 g/s by the particle feeder and were carried to the corona charger by a strong airflow. While the particles passed through the corona charger, the particles were charged.

The corona charger consists of a tungsten wire of 0.1 mm diameter and a cylindrical grounded electrode with 60 mm in diameter and 300 mm in length as shown in Figure 1. To prevent the undesired discharge between the leeward edge of the cylindrical electrode and a charged cloud, a round-grounded adapter was attached to the outlet of the corona charger. Negative pulsed voltage generated by a rotary gap switch was applied to the wire electrode of the corona charger. The magnitude and repetition rate of the pulsed voltage were set at 23 kV and 280 pps, respectively. By applying negative voltage to the discharging wire to cause negative corona discharge, the supplied particles are charged negatively.

A charged particle cloud was formed by ejecting charged particles for 5 s upward with a tilt angle of 45 degrees as illustrated in Figure 2. To obtain the charge distribution the cloud, the charge-to-mass ratio of the charged particles was measured with a Faraday cup located at 1 m leeward from the outlet, incase when the cloud was formed with a single cloud generator. The ejecting velocity of the airflow at the outlet was set at 16 and 30 m/s. To grasp the amount of charge quantity acquired by particles, the electric field strength on the ground formed by a charged particle cloud was detected by three field mills placed at the ground at an interval of 1 m in the ejecting direction.

To observe electrical discharge occurring between the charged particle cloud and a grounded electrode, the sphere electrode with a diameter of 100 mm was placed at the distance of 1 m forward of three sets of the corona charger. The position of the electrode was varied in the radial direction from the center axis of the charged particle cloud. The luminous aspect of discharge was taken by a digital video camera (Panasonic, NV-MX5000) equipped with an image intensifier (Hamamatsu, C5100-10). The waveform of discharge current was measured by a digital oscilloscope (Tektronix, TDS5104B), which was capable to record all waveforms larger than the preset trigger level.

3. Results and discussion

3.1. Formation of a charged particle cloud

The shape of a charged particle cloud formed by a single cloud generator was taken by the digital video camera of 30 frames per second. The time variation in shape of the charged particle cloud for an ejecting velocity with 16 or 30 m/s was compared by sketches of the outline of the cloud as shown in...
Figure 3. When the particles were ejected at a velocity of 16 m/s, the charged particle cloud spread in the radial direction. In contrast, when the ejecting velocity was set at 30 m/s, the charged cloud formed an elongated conical shape.

The time variation of a width of the charged particle cloud at the distance of 2 m forward of the outlet is shown in Figure 4. The width of the radial extension of the charged cloud for an ejecting velocity of 30 m/s kept constant at about 1.2 m during the feeding period of 5 s, while that of 16 m/s increased from 0.4 to 2.5 m with the time. In case of small ejecting velocity, the charged cloud became wider around the outlet of a corona charger, because of large electrostatic repulsion force. When the ejecting velocity was large, the cloud hardly widened at the vicinity of the outlet. As a result, a conical elongated cloud was formed.

3.2. Charge distribution

The electrical properties of a charged particle cloud were characterized by the distribution of charge quantity in the cloud and the electric field strength around the cloud. Since pulsed voltages are applied to the corona charger, the exposed frequency of the particles to corona discharge depends on the velocity passing through the corona charger. To examine the influence of ejecting velocity on the charge distribution in a cloud, the value of charge-to-mass ratio of the particles in the cloud was obtained by using the Faraday cage located at 1 m leeward from the outlet of the corona charger.

Figure 5 shows the radial distribution of charge-to-mass ratio of charged particles in the cloud. The charge-to-mass ratio for an ejecting velocity of 16 m/s was larger than that of 30 m/s. From the length of the corona charger of 300 mm and the number of the pulsed discharge of 280 pps, the average exposure time to discharge is evaluated 5.3 and 2.8 for a velocity of 16 and 30 m/s, respectively. Thus, the charge quantity acquired by the particles depends on the time exposed to corona discharge.

The charge-to-mass ratio of charged particles at the outer region of the charged cloud was larger than that of the centre one, the charge-to-mass ratio at the position of 200 mm from the centre axis of the charged cloud reached around 450 µC/kg, regardless of the ejecting velocity. The particles with relatively larger charge quantity would tend to disperse outward of the cloud by electrostatic repulsion force.

To confirm the movement of the charged particles in the charge cloud, the size distribution of the particles captured by the suction type Faraday cup was obtained by photomicrograph. Figure 6 shows the size distribution of the particles at the centre and outer region in the charged particle cloud for an ejecting velocity of 16 m/s. At the outer region of the charged cloud, the larger particles ranging from 150 to 250 µm were relatively few and the particles with the smaller sizes existed more than at the centre one. It means that the smaller charged particles with the larger charge-to-mass ratio moved toward at the outer region of the charged cloud.
To increase the particle and charge density of a charged cloud, the charged cloud was formed with three cloud generators. Figure 7 shows the time variation of the electric field strength at the ground during formation of a charged particle cloud. Contrary to expectation from the difference in charge-to-mass ratio, the electric field strength for an ejecting velocity of 30 m/s was larger than that of 16 m/s and reached the maximum electric field strength of 160 kV/m. Highly-charged small particles tend to move toward the outer region of the cloud by electrostatic repulsion force and to adhere to the grounded adaptor. When the charged particles were ejected at a velocity of 16 m/s, the amount of 20% in mass out of the total ejected particles attached to the adaptor, while that for 30 m/s was 6%. Consequently, although the charge-to-mass ratio of the particles ejected at the air flow with a velocity of 16 m/s was larger than that of 30 m/s, the electric field strength at the ground formed by the cloud for 16 m/s became considerably weaker due to loss of the charged particles.

3.3. Positive discharge
To cause electrostatic discharge, the sphere electrode with a diameter of 100 mm was placed at a distance of 1 m forward of the outlet as shown in Figure 8. At an ejecting velocity of 16 m/s, visible electrical discharge never occurred. At an ejecting velocity of 30 m/s, electrical discharge recognized by naked eyes occurred repeatedly. Figure 9 shows an example of the brush-like discharge channel taken with a digital video camera equipped with an image intensifier. The discharge extended from the grounded electrode at the distance of 0.5 m from the centre of the charged cloud, which was located at the outside of the cloud. The length of discharge channels reached 0.55 m. From the
measurement of discharge current, the number of discharges occurring during 5 seconds was decreased as the distance of the sphere electrode was apart from the center of the charge cloud. The average period between discharges for the electrode position of d=0, 0.7, and 1 m was 96, 132, and 203 ms, respectively.

The waveform of discharge current was classified into two kinds of the waveform with a single peak and multi peaks. Each example of the current waveform was shown in Figure 10. Multi-peak current waveform usually appeared. This means the discharge consists of some several streamer discharge channels. At d=0 m, some parts of the current waveform had a single-peak. The rise time of current waveform ranged from 20 to 140 ns. The mean rise time was around 60 ns.

The charge quantity neutralized in each discharge was obtained by time integral of the current waveform. Figure 11 shows the relationship between the charge quantity and current peak of discharge occurred at the position of the electrode of 0, 0.7, and 1 m. At d=0 m, the current waveform with a single peak tended to have relatively small charge quantity, regardless of the current peak. At the position of d=0.7, discharge with a single peak never occurred and discharge with relatively larger charge quantity above 1.2 μC occurred exclusively. Since the discharge associated with current waveform with multi peaks would consist of several streamer discharge channels or extend farther, the discharge would neutralize the larger region of the cloud. At d=0.7 m, the relation of the charge quantity to current peak has narrow distribution and large-scale electrostatic discharges occurred with reproducibility. In contrast, at d=1 m, both small and large discharges with charge quantity ranging from 0.3 to 2 μC occurred.

Figure 12 shows the relationship between the charge quantity and the discharge duration. The charge quantity was increased with the discharge duration. The discharge duration would be related closely to the time in which the discharge channel has extended. If the discharge channel extended into the cloud, the charge distributed in a wide region would be neutralized. Therefore, the charge quantity strongly depends on the discharge duration. The current waveform with a single peak reasonably relates to the shorter discharge duration.

Figure 8. Arrangement of a grounded sphere electrode to cause electrostatic discharge.

Figure 9. Luminous aspect of the discharge from the grounded sphere electrode placed at d=0.5 m.

Figure 10. Two kinds of waveform of discharge current occurring between a charged particles and a grounded electrode, (a) the waveform with single-peak and (b) the waveform with multi-peak.
4. Conclusion
A large-scale charged particle cloud was formed by charged particles ejected in assist of air flow and was examined the property of the cloud. Highly-charged small particles tend to move toward the outer region of the cloud by the electrostatic repulsion force and to attach to the grounded object. Consequently, the electric field strength at the ground formed by the cloud was relatively smaller, although charge-to-mass ratio of the particles ejected at the lower air flow was larger than that at the higher one owing to longer charging time. Electrostatic discharge occurred from the sphere electrode had several current peaks indicating extension of the discharge channel. The charge quantity depended on the discharge duration.

To produce the larger-scale discharge and to make clear the relationship between the space charge discharge and the current waveform would be future subject.

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