Space Charges Produced in a Rod-to-Plane Gap under Impulse Voltages

By

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Abstract

The space charges produced in a hemispherical rod-to-plane gap in air are measured under the impulse voltage application by the use of a probe, which is constructed by a sphere near the gap space. The space charges accompanied with the streamer occurrence are about 20～200 nC and 5～60 nC for the positive and negative voltage application, respectively. The maximum space charges over the whole process to the flashover are 20～260 nC and 20～60 nC for the positive and negative voltage application, respectively. After the flashover occurrence, the space charges remain in the gap space, the values being below 200 and 30 nC for the positive and negative voltage application, respectively.

1. Introduction

The space charges produced in a hemispherical rod-to-plane gap in air are measured under the standard lightning impulse voltage application. The measurement of the space charge has been carried out by many researchers so far.[1-5] However, it is very difficult to separate the transfer component from the induced component, because the probe usually constructs a part of the electrode surface and the streamer may reach the probe. The probe used here is constructed by a sphere near the gap space,[6),7] so that it can detect only the induction component by a long distance from the electrode.

2. Measuring Method

Fig. 1 shows the probe circuit used in this experiment. The probe sphere is made of brass and its diameter is about 16 mm (5/8″). It is connected to an integrating capacitor (0.03 μF) and an oscilloscope (Tektronics type 556, dual beam) through the 75Ω coaxial cable (3C2V, the length 3 m).

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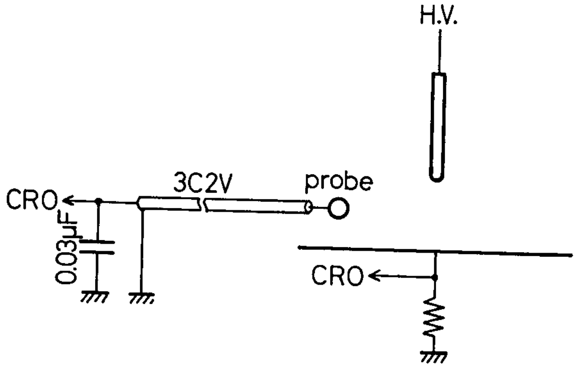

Fig. 1. Probe circuit.

As the reference of the charge quantity, the total charge included in the rod electrode of the 10 cm region from the tip is used, where, the equivalent charge is calculated from the "charge simulation method". Table 1 shows the charge

Table 1. q_0 values corresponding to rod electrode of 1 kV potential.

δ (cm)	5	10	15
q_0 (nC)	1.71	1.60	1.53

quantity q_0 (nC), which is equivalent to the application of 1kV to the electrode, under the experimental conditions.

Fig. 2 shows an example of the probe signal together with the applied voltage, where the voltage is so low that the discharge phenomena does not occur. As shown in Fig. 2, v_{probe} (probe signal) varies almost the same as v (applied voltage).

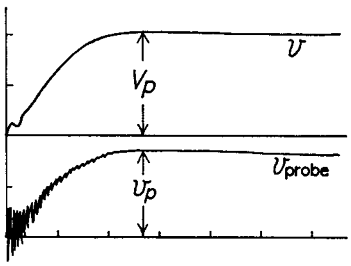

Fig. 2. Example of v and v_{prove} for $\delta=10$ cm, rod positive. sweep: 0.5μs/div., gain: 30 kV/div. for v, 1 V/div. for v_{prove}.

Let V_p and v_p be the peak values of the applied voltage and the probe signal, respectively. Then the magnitude of the probe signal v_p corresponds to the equivalent charge of $q_0 \cdot V_p$ (nC). Thus, by the use of the "probe constant" $k=$

$q_0 \cdot V_p/v_p$ (nC/V), there can be obtained approximately the space charge produced in the gap space.

Experiments are carried out under the conditions whereby the rod diameter $\phi=8$ mm and the gap length $\delta=5$, 10, 15 cm for the positive voltage application and the conditions of $\phi=8$ mm and $\delta=5$, 10 cm for the negative voltage application, respectively.

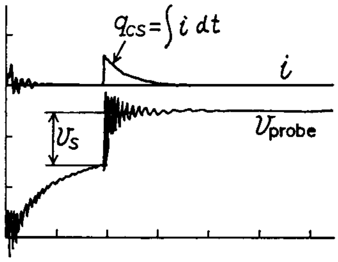

Fig. 3. Example of i and v_{prove} for streamer occurrence, rod positive. sweep: 0.5 μs/div., gain: 0.4 A/div. for i, 2 V/div. for v_{probe}.

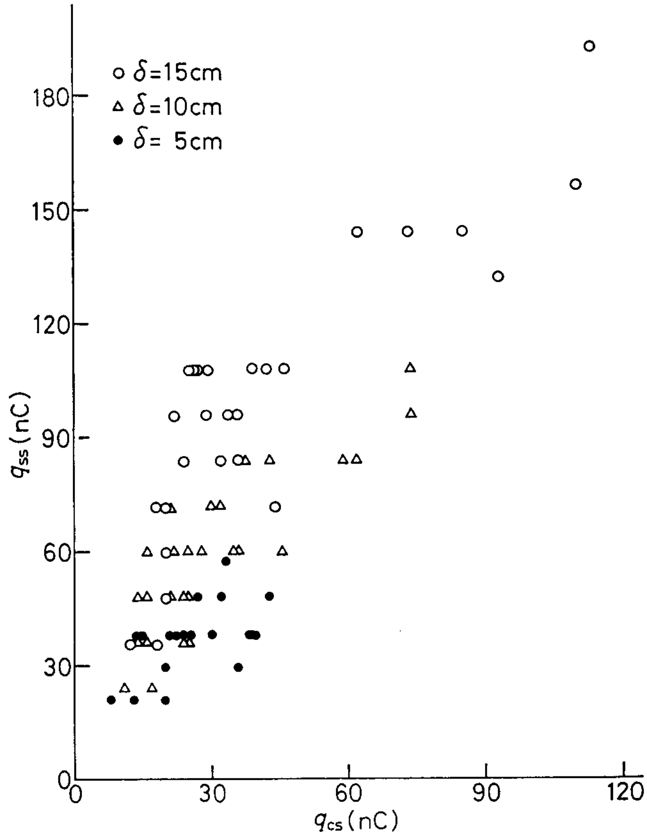

Fig. 4. q_{cs} (integration of streamer current) vs. q_{ss} (streamer space charge) characteristic for positive polarity.

3. Space Charge Accompanied with the Streamer Occurrence

Fig. 3 shows an example of the simultaneous measurement of the current (i) and the probe signal (v_{probe}) when the streamer occurs. Corresponding to the current pulse for the streamer occurrence, v_{probe} increases in step-wise. If the increment of the v_{probe} is v_s, the space charge $q_{ss}=kv_s$ (nC) should be released by the streamer. Figs. 4 and 5 show the relation between q_{cs} and q_{ss} for the positive and negative voltage application respectively, where q_{cs} means the current-integral by the time ($\int idt$) for the streamer. From these figures, it is deduced that q_{ss} is approximately proportional to q_{cs} except for the case of $\delta=10$ cm for the negative voltage application. For the positive case, q_{ss} becomes large when δ is large, and is about 20～50nC, 30～100nC, and 40～200nC for $\delta=5$, 10, and 15 cm, respectively. For the negative case, q_{ss} is small compared with the positive case, and is about 5～60nC and 10～40nC for $\delta=5$ and 10 cm, respectively.

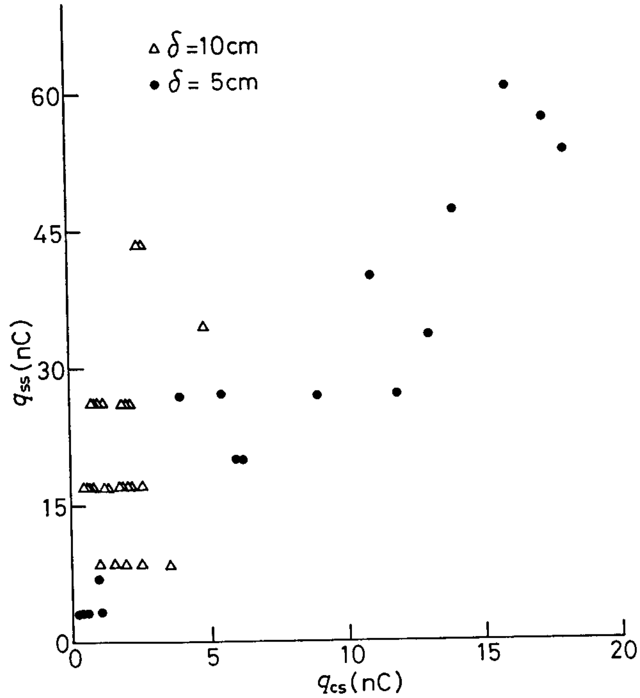

Fig. 5. q_{cs} vs. q_{ss} characteristic for negative polarity.

4. Space Charge in the Flashover Process

Fig. 6 shows an example of the simultaneous measurement of the current

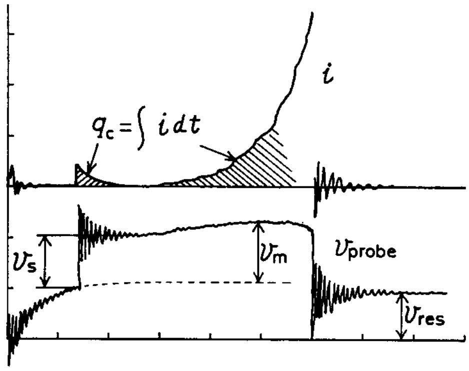

Fig. 6. Example of i and v_{probe} for flashover. $\delta=15$ cm, rod positive. sweep: 0.5 μs/div., gain: 0.4 A/div. for i, 2 V/div. for v_{prove}.

wave and the probe signal when the flashover occurs. Let v_s, v_m, and v_{res} be the increment of the v_{probe} by the streamer occurrence, the maximum value of the v_{probe} (excluding the applied voltage component), and the value of the v_{probe} after the flashover, respectively. From this figure, it is noticed that the space charge q_s scarecely increases in spite of the large increase of the charge quantity q_c which is obtained from the integral of the current through the gap space.

Fig. 7 shows some examples of the trajectories from the streamer occurrence to the flashover in the q_c-q_s plane. The time measured from the streamer occurrence is also indicated in Fig. 7. From this figure, it is deduced that the space charge in the stage of the leader development does not increase so much, and has a tendency to saturate against the increase of the current integral $\int idt$. A similar tendency will be observed for the negative voltage application, but it is very difficult to distinguish such a tendency because the rise-up of the current wave is so sharp that one cannot obtain the value of q_c.

Figs. 8 and 9 show histograms of the maximum space charge q_m. For the positive voltage application (Fig. 8), q_m has a rather wide dispersion under the same gap conditions. (The rate of the maximum value of q_m to the minimum value ranges between 2 and 5.) The mean value of the positive q_m is almost proportional to δ and are 44, 84, and 187nC for $\delta=5$, 10, and 15 cm, respectively. For the negative voltage application (Fig. 9), however, q_m has the opposite tendency compared to the positive case, that is, $q_m=37$ and 32nC for $\delta=5$ and 10 cm respectively. However, it cannot be said that it is the general property because the number of data points are too small to determine the characteristics. The q_m value for the positive voltage is larger than that for the negative voltage.

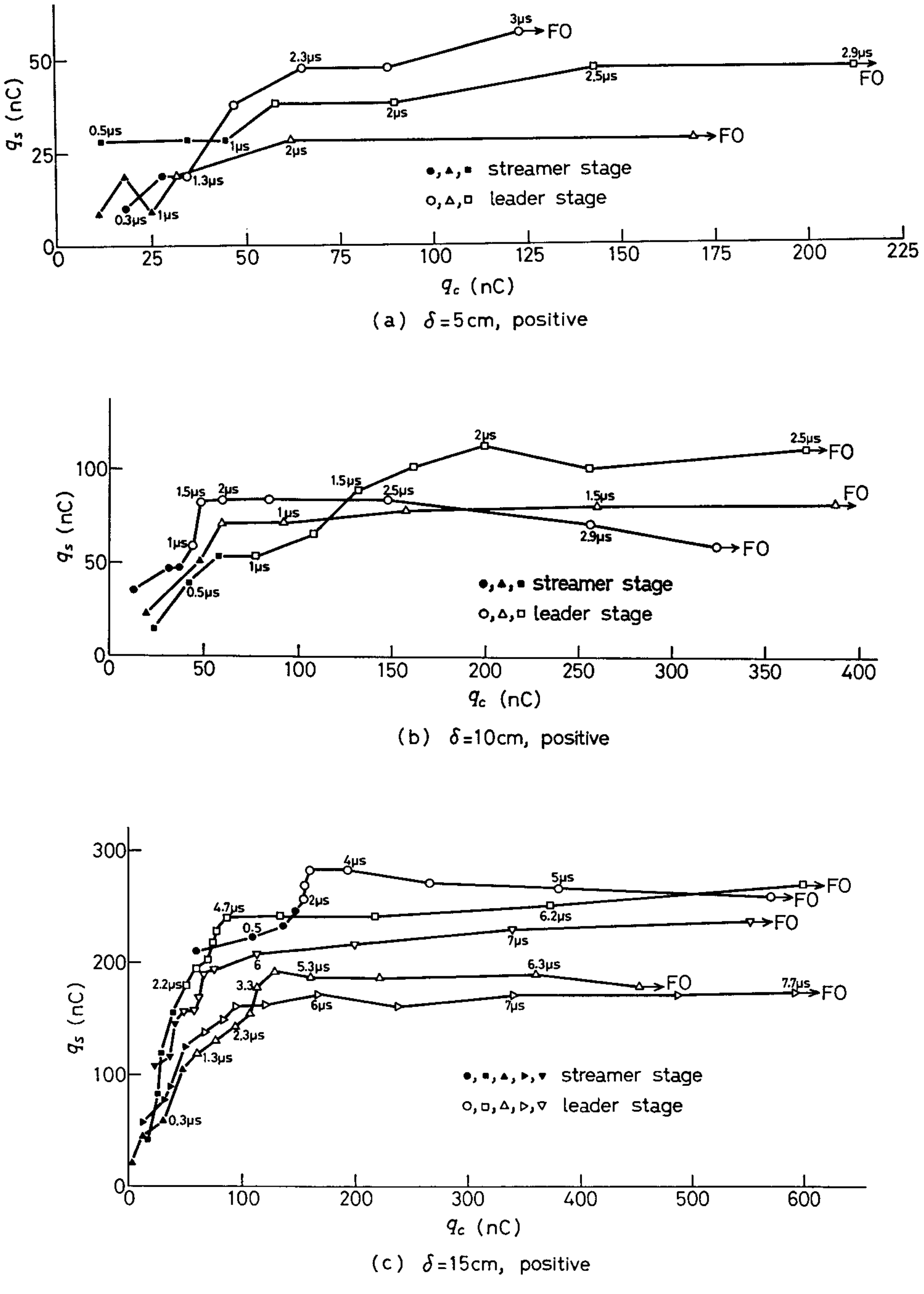

Fig. 7. Examples of q_c-q_s trajectories with time, rod positive.

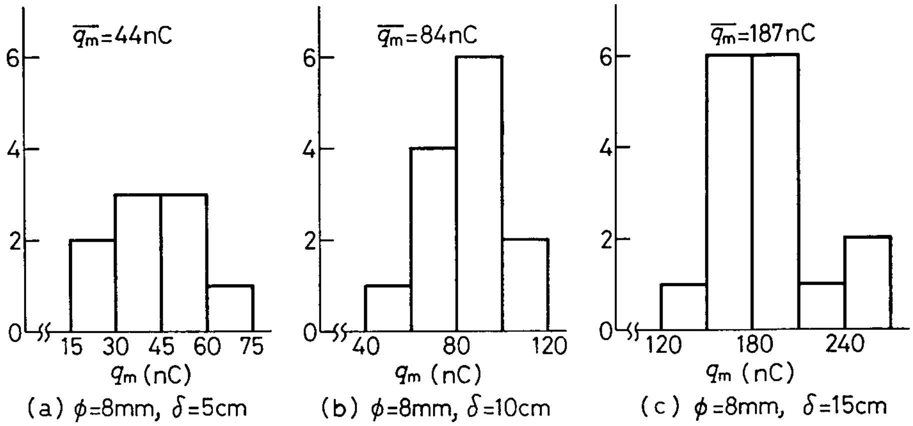

Fig. 8. Histograms of q_m (maximum value of space charge) for positive polarity.

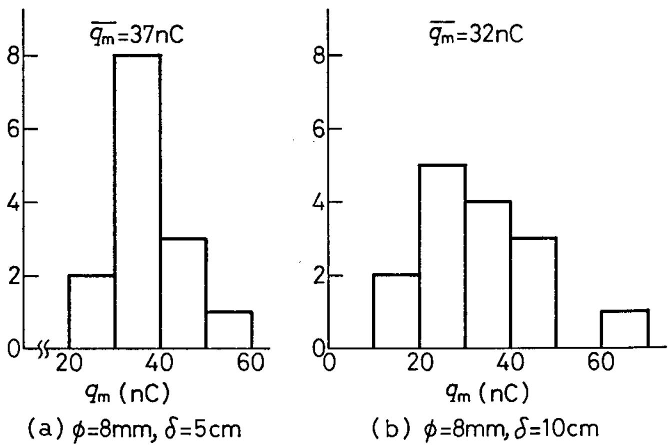

Fig. 9. Histograms of q_m for negative polarity.

Figs. 10 and 11 show the relation between q_{ss} produced by only the streamer and q_m when the flashover occurs. For the positive voltage application (Fig. 10), it is noticed that there exist a large correlation between q_{ss} and $q_m (q_m \doteqdot 2q_{ss})$ thereby satisfying the condition $q_m > q_{ss}$ for every data points. On the contrary, for the negative voltage application (Fig. 11), there is no correlation between them and for $\delta = 5$ cm, q_m lies between 25 to 45nC regardless of q_{ss}. Furthermore, for the negative case, the condition $q_m > q_{ss}$ is not satisfied for three points.

5. Residual Charge after the Flashover

After the flashover occurrence, the v_{probe} does not decay to zero and keeps the value of v_{res} in spite of the reduction of the applied voltage to the sustaining

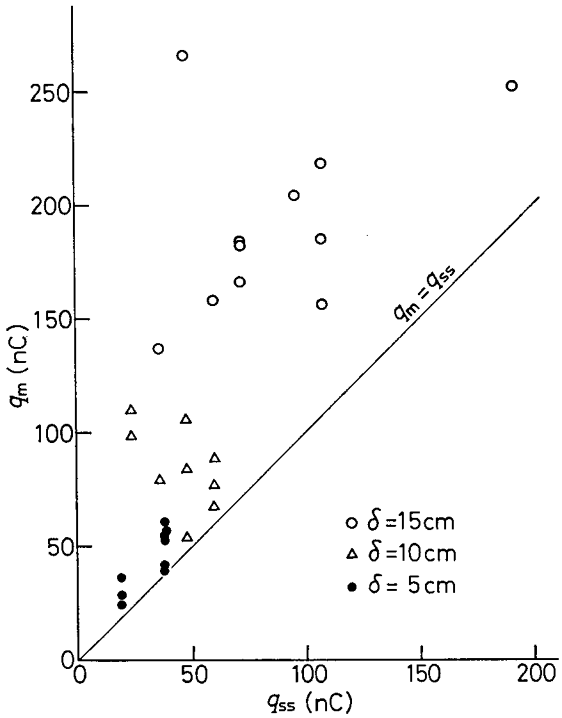

Fig. 10. q_{ss} (space charge due to streamer occurrence) vs. q_m (maximum value of space charge) characteristic for positive polarity.

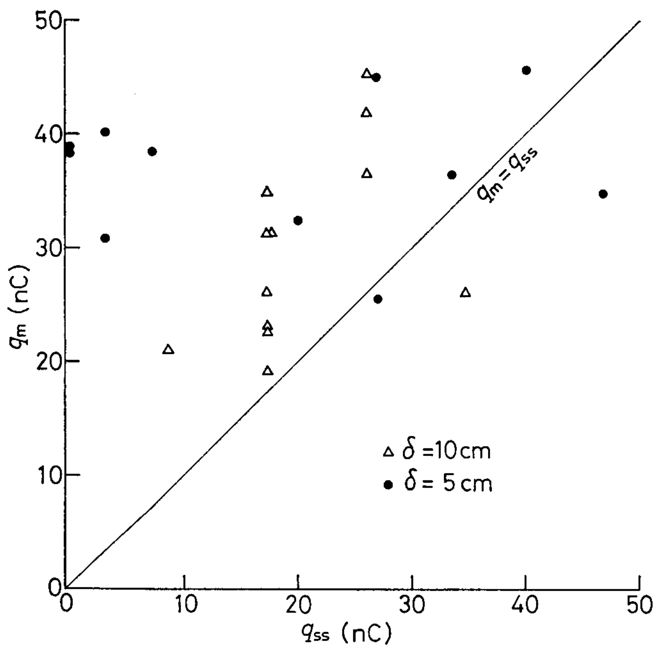

Fig. 11. q_{ss} vs. q_m characteristic for negative polarity.

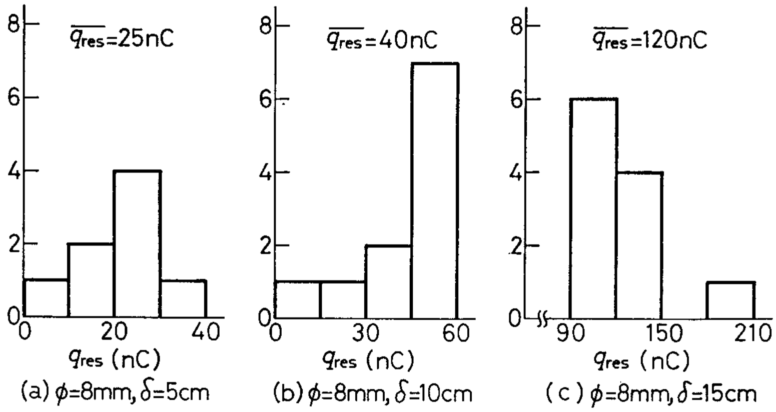

Fig. 12. Histograms of q_{res} (residual space charge) for positive polarity.

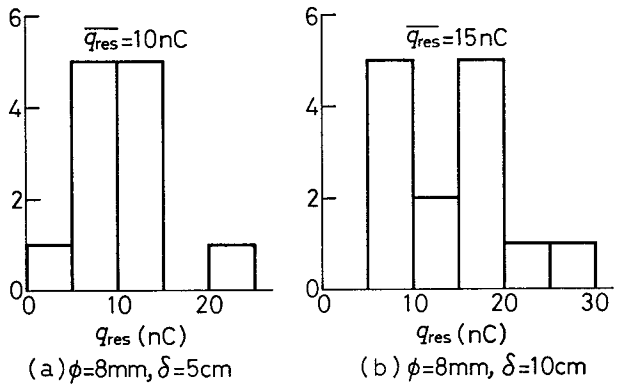

Fig. 13. Histograms of q_{res} for negative polarity.

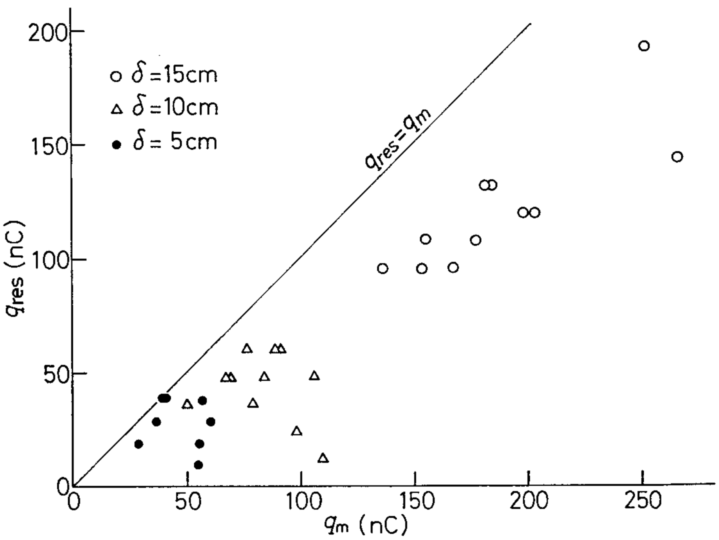

Fig. 14. q_m vs. q_{res} characteristic for positive polarity.

arc voltage (≒100V). This phenomenon indicates that the space charge in the gap remains at a certain value after the flashover. Figs. 12 and 13 show the histograms of q_{res} (residual charge). The dispersion of q_{res} is almost the same as that of q_m. (The difference between the maximum and minimum value of q_m is larger than that of q_{res}, but the ratio of the maximum to the minimum value of q_m is smaller than that of q_{res}.) For the positive voltage, the mean values of q_{res} are 25, 40, and 120nC for $\delta=5$, 10, and 15 cm, respectively. For the negative voltage, they are 10 and 15nC for $\delta=5$ and 10 cm, respectively. Thus, q_{res} for the positive voltage is larger by about 2.5 times than that for the negative voltage.

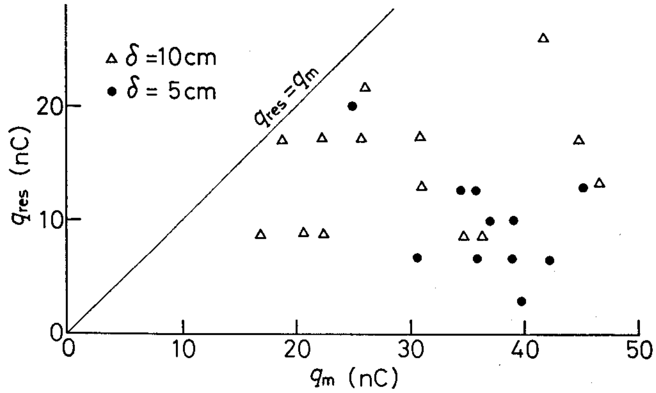

Fig. 15. q_m vs. q_{res} characteristic for negative polarity.

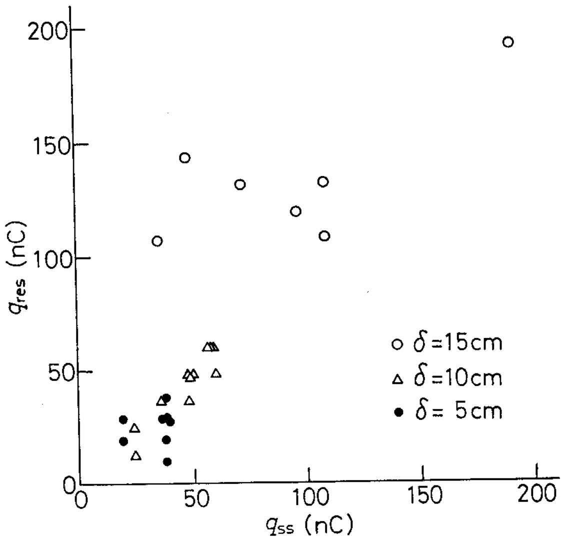

Fig. 16. q_{ss} vs. q_{res} characteristic for positive polarity.

Figs. 14 and 15 show the relation between q_m and q_{res}. For the positive case (Fig. 14), there is a large correlation between them ($q_{res} \doteqdot 2/3\ q_m$), and q_{res} is smaller than q_m for all data points. For the negative case (Fig. 15), q_{res} is smaller than q_m for all data points, but the correlation between q_{res} and q_m is not so clear.

Fugs. 16 and 17 show the relation between q_{res} and q_{ss}. From these figures, there can be observed the weak correlation between q_{res} and q_{ss} for both the positive and negative voltage application. The relation $q_{res} < q_{ss}$ cannot be satisfied in these cases.

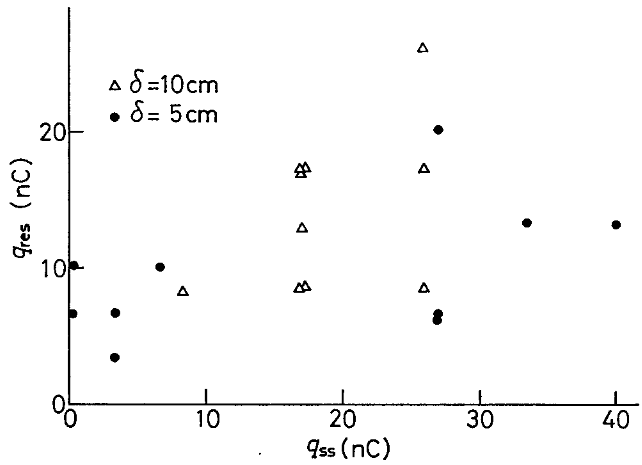

Fig. 17. q_{ss} vs. q_{res} characteristic for negative polarity.

6. Conclusion

In this experiment, the change of the space charge from the streamer occurrence to the flashover was measured in the rod-to-plane gap under the impulse voltage application. The results obtained are summarized as follows:

(1) The space charges accompanied with the streamer occurrence are about 20∼200 nC for δ=5∼15 cm for positive voltage, and about 5∼60nC for δ= 5∼10 cm for negative voltage, respectively.

(2) The maximum space charges over the whole process to the flashover are 20∼260nC and 20∼60nC for positive and negative voltage respectively. They are approximately the same as the charges produced by only the streamer in spite of several hundred nC of the current integral through the gap.

(3) After the flashover occurrence, the space charge remains in the gap space. The values of these residual charges are below 200 and 30nC for the positive and negative voltage.

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