Discharge Phenomena in SF_6 and SF_6-Air Mixture Gas under Impulse Voltage

By

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Abstract

The discharge phenomena in pure SF_6 and SF_6-air mixture gas are observed by electrical and optical technics. Current and light pulses accompanied with the corona discharge in pure SF_6 gas have very low peak values and a short duration time compared with those in air. The velocity of the corona development in pure SF_6 gas is about 10^7cm/s, and is almost the same as that of the leader in air. When the SF_6 density in SF_6-air mixture gas is high, the discharge channel becomes fine and short. The space charge production of 1~60 nC is observed for the occurrence of the corona in SF_6-air mixture gas.

1. Introduction

Recently, SF_6 gas has been used in electric power devices because of its high ability of electric insulation. The authors have previonsly reported the discharge phenomena in air under the impulse voltage[1-2]. In this paper, we attempt to clarify the difference between air and SF_6 in discharge phenomena by the same measurement as in air. Namely, current and light pulse characteristics, space charge characteristics, $V-t$ characteristics, and the photographs accompanied with the pre-breakdown phenomena in pure SF_6 and SF_6-air mixture gas under the impulse voltage application are reported here.

2. Experimental Method

Fig. 1 shows a schematic diagram of the experimental apparatus. In this figure, IG indicates an impulse voltage generator which is constructed of 4-stages and has a nominal voltage of 280kV. The output voltage has a wave form of the standard lightning impulse, namely $\pm(1\times40)\mu s$. Tank T, which is made of iron, has a diameter

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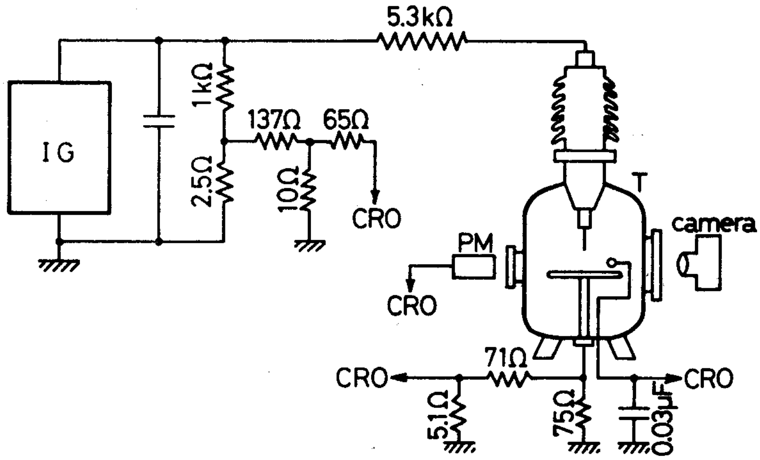


Fig. 1. Schematic diagram of experimental apparatus.

of 60cm and a height of 80cm, and the volume is about 220*l*. T has two windows which are made of acrylite for the observation of the discharge phenomena.

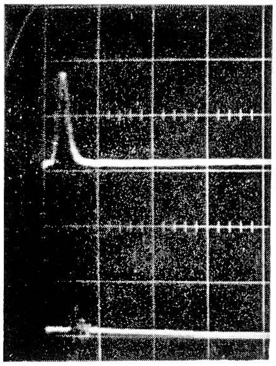
The discharge gap is constructed by a hemispherical rod and a plane electrode which are made of brass. The diameter of the rod electrode ϕ and the gap length δ are 1～15mm and 1～6cm, respectivley. The plane electrode has a diameter of 25cm, and the edge is rounded. The gas pressure p is changed between 1～6 ata. The discharge phenomena occurring in the gap space is observed by the naked eye or photographed by using an image intensifier or a usual camera. The total light pulse intensity is also measured by using a photomultiplier together with the current pulse measurement. A Tektronix type 556 oscilloscope is used for the measurement of the light and current pulse. In addition, the space charge accompanied with the pre-breakdown phenomena is measured in this experiment by using a sphere probe which has a diameter of 16mm.

3. Current, Light Pulse and Still Photograph in Pure SF_6 Gas

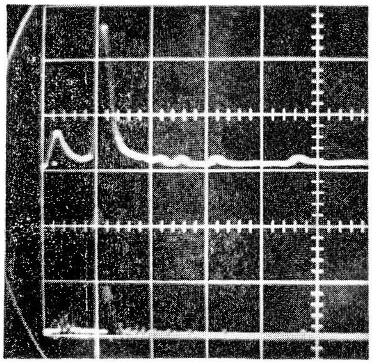
The width and height of the current and light pulse in pure SF_6 gas are extremely narrow and small compared with those in air.

<3.1> Positive Polarity

Fig. 2 shows the experimental results obtained in the case of ϕ (diameter of the rod electrode) = 1mm, δ (gap length) = 3cm, p (gas pressure) = 1 ata. When V_p (peak value of the applied voltage) $\leq$ 93kV, the light wave has only one pulse, or successive smaller pulses as indicated in Fig. 2 (a). The corresponding phenomenon appears as a small bright spot at the rod tip. (The brightness is too weak to take a photograph.)

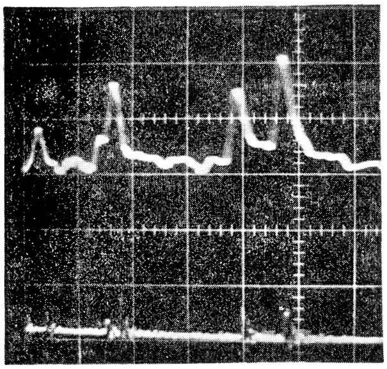


(a)
$V_p=93$ kV

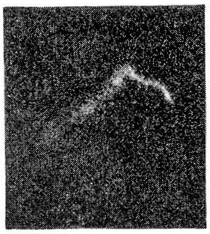


(b)
$V_p=103$ kV

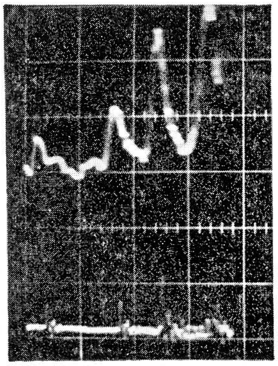
(b′)



(c)
$V_p=108$ kV



(c′)

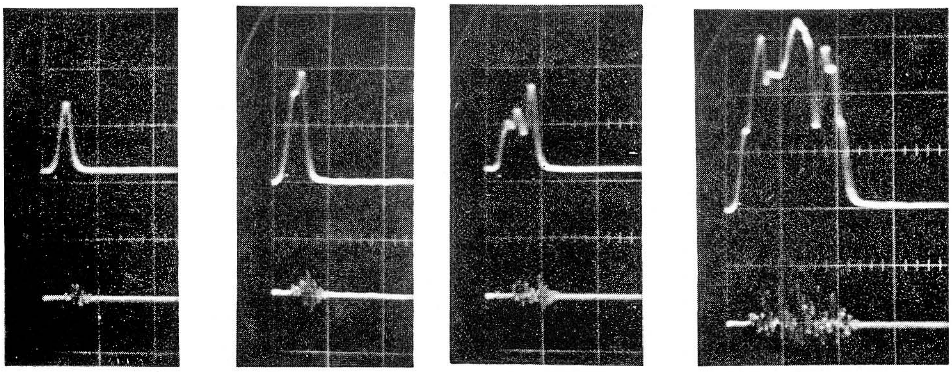


(d)
$V_p=108$ kV

Fig. 2. Some examples of light and current waves, and still photographs. $\phi=1$ mm, $\delta=3$ cm, $p=1$ ata, rod positive. upper trace: light wave, lower trace: current (1.4 A/div.), sweep: 200 ns/div., V_p: peak value of applied voltage.

When $V_p=103$kV, the successive light pulses become greater than the first one, and the corona developed from the electrode can be seen in the photograph, as shown in Fig. 2 (b). By an increase of the applied voltage, the number of successive pulses increases. Correspondingly, the corona shape becomes multiple filament-like or bead-like. Fig. 2 (d) shows the case where the flashover occurs. As shown in this figure, the light pulse in the pre-breakdown stage is not different from that in Fig. 2 (c).

Fig. 3 shows the current and light pulses obtained under the same conditions in Fig. 2, excepting $p=3$ ata. In these conditions, the voltage range where the corona appears is very narrow, so the applied voltage is near the flashover voltage. In this case, a single pulse, shown in Fig. 3 (a), is seldom observed and the multiple pulses become dominant. By an increase of the applied voltage, the pulses do not separate



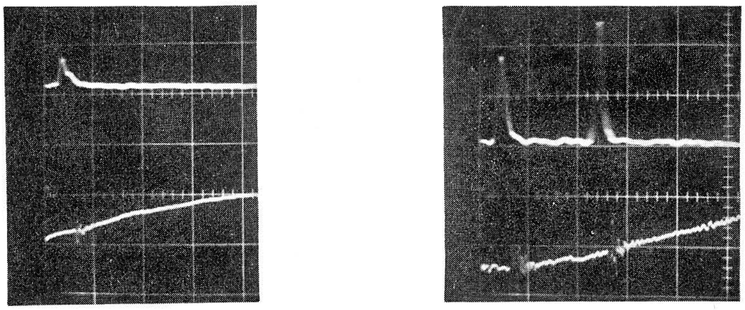
(a) $V_p=86$ kV (b) $V_p=86$ kV (c) $V_p=86$ kV (d) $V_p=90$ kV

Fig. 3. Some examples of light and current waves. $\phi=1$ mm, $\delta=3$ cm, $p=3$ ata, rod positive. upper trace: light wave, lower trace: current (0.7 A/div.), sweep: 200 ns/div..

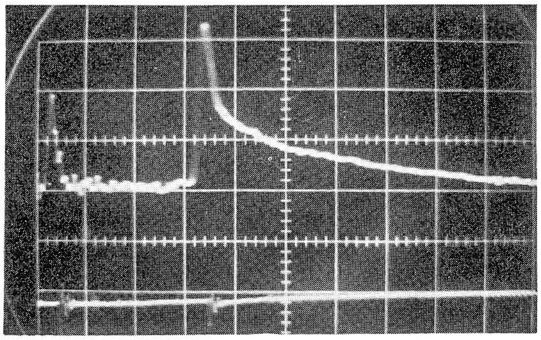
from each other as in the case of $p=1$ ata, but apparently accumulate to form a large pulse. The time interval between each pulse is about 50 ns.

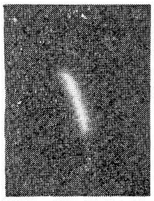
<3.2> Negative Polarity

Fig. 4 shows some examples of the light and current pulses, still photographs obtained under the conditions of $\phi=1$mm, $\delta=3$cm, $p=1$ ata, in a negative voltage application. When V_p is low, a single pulse appears as shown in Fig. 4 (a), but by the increase of V_p, successive pulses take place [Fig. 4 (b)]. When $V_p=110$kV, the tail of the successive pulses become long and a streamer-like discharge can be observed in the photograph [Fig. 4 (c)]. When $V_p=140$kV (which is just below the flashover voltage), the successive pulses become greater [Fig. 4 (d)]. Sometimes, double successive pusels can be observed. In such cases, the discharge channel also appears as dual stramers [Fig. 4 (e)]. In a negative voltage application, for $p=3$ ata, each pulse occurs separately. However, for $p=4$ ata, those pulses accumulate as in the case of $p=3$ ata



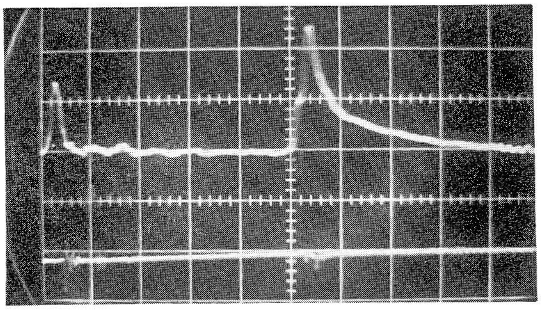
(a) $V_p=51$ kV (b) $V_p=93$ kV

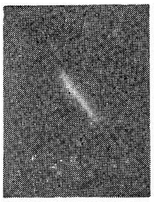




(c')

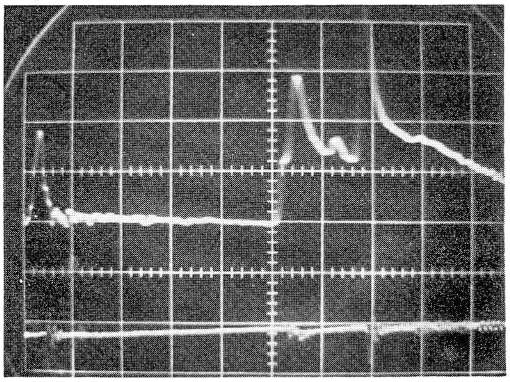
(c)
$V_p = 110$ kV

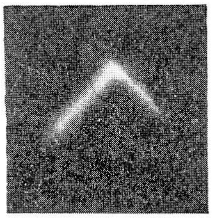




(d')

(d)
$V_p = 140$ kV





(e')

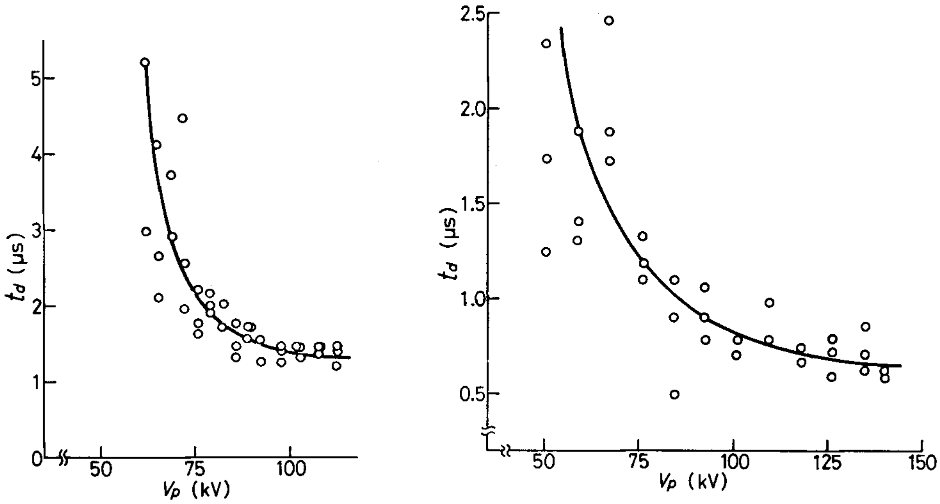
(e)
$V_p = 140$ kV

Fig. 4. Some examples of light and current waves, and still photographs. $\phi = 1$ mm, $\delta = 3$ cm, $p = 1$ ata, rod negative. upper trace: light wave, lower trace: current, sweep: 200 ns/div.. current gain: (a): 0.07 A/div., (b): 0.14 A/div., (c)～(e): 1.4 A/div..

for positive polarty.

<3.3> Time Lag of Corona Occurrence

Fig. 5 shows some examples of time lag distribution of the corona occurrence obtained under the conditions of ϕ=1mm, δ=3cm. From these figures, it is deduced that the time lag (t_d) reduces with an increase of the applied voltage in both positive and negative voltages. The experimental results with t_d are summarized as follows:



ϕ=1 mm, δ=3 cm, p=1 ata, rod positive. ϕ=1 mm, δ=3 cm, p=1 ata, rod negative.

Fig. 5. Time lag distribution for corona occurrence.

(1) Positive Polarity

For p=1 ata, t_d reduces from 5.2μs (V_p=63kV) to 1.3μs (V_p=100kV), and keeps almost constant until reaching the breakdown voltage. For p=3 ata, V_p reduces from 15μs (V_p=85kV) to 6 μs (V_p=93kV) and reaches the breakdown voltage.

(2) Negative Polarity

For p=1 ata, t_d reduces from 2μs (V_p=50kV) to 0.6μs (V_p=140kV). t_d has the same tendencies for p=3 and 6 ata. In general, the value of t_d in a negative case is smaller than that in a positive case.

<3.4> Developing Velocity of Corona

Fig. 6 shows some examples of the spatial development of the first corona pulse along the gap axis measured by using two photomultipliers. From this figure, it is deduced that the first corona develops in the gap space about 10 and 30mm for δ=3 and 6cm, respectively. The developing velocity of the first corona is about 10^7cm/s,

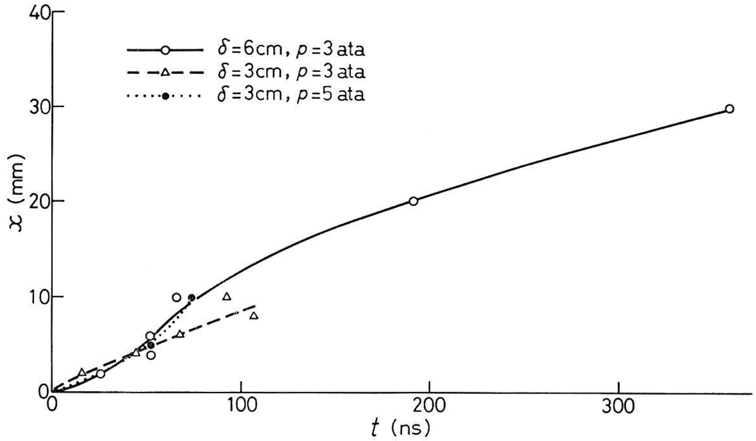


Fig. 6. Development of first light pulse along the gap axis. $\phi=1$ mm, rod positive.
x: distance from the rod tip.

which is smaller by 0.1 than that of the primary streamer in air[1], and is almost the same as that of the leader[2].

4. Discharge Phenomena in SF_6-Air Mixture Gas

As shown in chapter 3, the phenomena in pure SF_6 gas are quite different from those in air. In this chapter, the observation of the discharge phenomena was carried out by changing the contents of the SF_6 gas between 0 and 10%. In this chapter, ϕ and δ are fixed to 4mm and 5cm, respectively.

Fig. 7 shows some examples of the typical discharge phenomena for the positive voltage application taken by using an image intensifier under the conditions of $p=1\sim3$ ata and SF_6 content $k=0\sim10$ volume %. From this figure, the following results are obtained.

(a)
$k=0\%$, $p=1$ ata,
$V_p=51$ kV

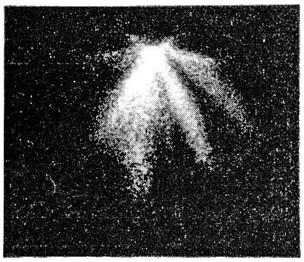
(b)
$k=0\%$, $p=2$ ata,
$V_p=91$ kV

(c)
$k=0\%$, $p=3$ ata,
$V_p=136$ kV

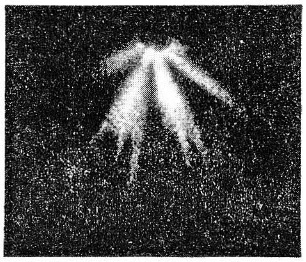
(d)
$k=0.1\%$, $p=1$ ata,
$V_p=68$ kV

(e)
$k=0.1\%$, $p=2$ ata,
$V_p=113$ kV

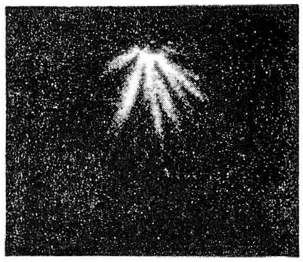
(f)
$k=0.1\%$, $p=3$ ata,
$V_p=128$ kV



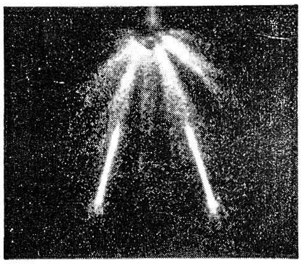
(g)
$k=1\%$, $p=1$ ata,
$V_p=76$ kV



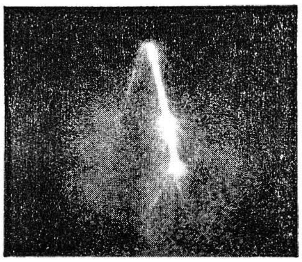
(h)
$k=1\%$, $p=2$ ata,
$V_p=136$ kV



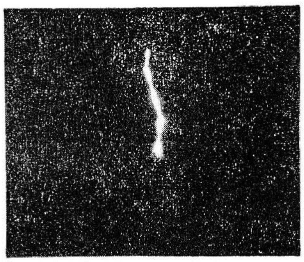
(i)
$k=1\%$, $p=3$ ata,
$V_p=166$ kV



(j)
$k=10\%$, $p=1$ ata,
$V_p=91$ kV



(k)
$k=10\%$, $p=2$ ata,
$V_p=91$ kV

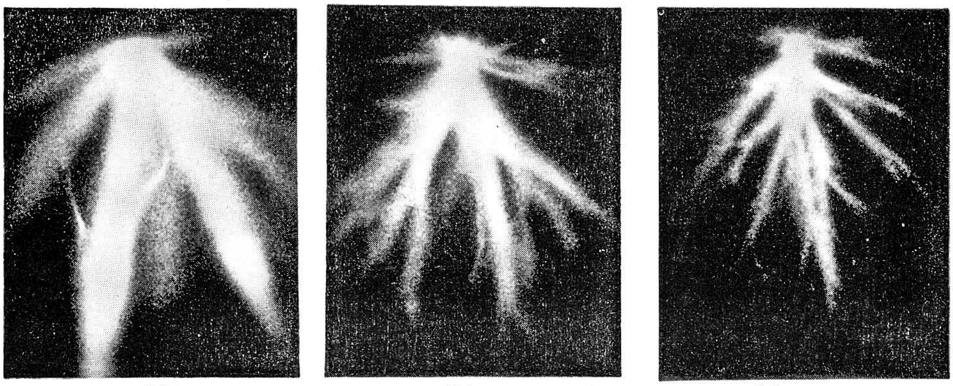


(l)
$k=10\%$, $p=3$ ata,
$V_p=91$ kV

Fig. 7. Examples of corona photographs for positive voltage application.
$\phi=4$ mm, $\delta=5$ cm. k: content of SF_6 gas.

(1) When the content of $SF_6(k)$ is 0. 1%, the corona shape and the current wave form (not shown in Fig. 7) do not change so much compared with the case of $k=0\%$. However, the duration time of the current pulse reduces slightly. The corona has many streamer branches.
(2) When $k=1\%$, the length of the corona development reduces extremely. The height of the current pulse and the duration time reduces by about 1/5 and 1/10 respectively, compared with the case of $k=0\sim0.1\%$. The corona seldom has branching streamers.
(3) When $k=10\%$, a leader-like discharge channel is frequently observed. Correspondingly, the successive pulses appear in the current wave. When the current pulse consists of only one pulse, a weak and small corona is observed around the rod tip.
(4) When the gas pressure is high ($p=2\sim3$ ata), the discharge channel becomes fine and small. For $k=10\%$ and $p=3$ ata, a so called bead-like discharge can be observed.

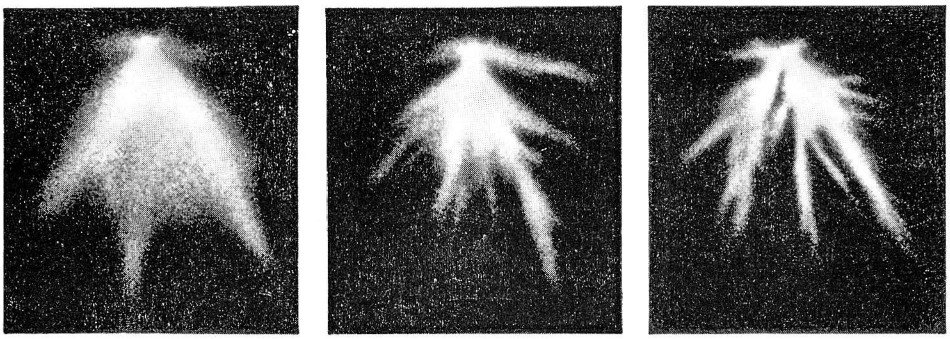
Fig. 8 shows some examples of still photographs under the same conditions in Fig. 7, excepting the voltage polarity. The special features for the positive polarity described



(a) $k=0\%$, $p=1$ ata, $V_p=76$ kV

(b) $k=0\%$, $p=2$ ata, $V_p=106$ kV

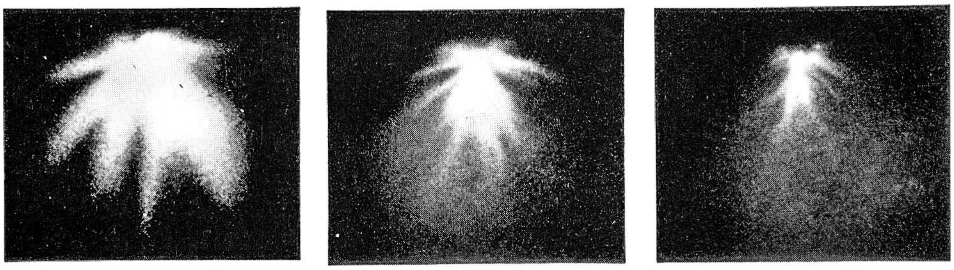
(c) $k=0\%$, $p=3$ ata, $V_p=136$ kV



(d) $k=0.1\%$, $p=1$ ata, $V_p=76$ kV

(e) $k=0.1\%$, $p=2$ ata, $V_p=121$ kV

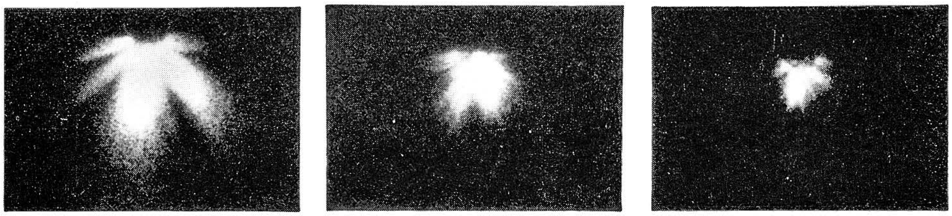
(f) $k=0.1\%$, $p=3$ ata. $V_p=151$ kV



(g) $k=1\%$, $p=1$ ata, $V_p=95$ kV

(h) $k=1\%$, $p=2$ ata, $V_p=166$ kV

(i) $k=1\%$, $p=3$ ata, $V_p=196$ kV



(j) $k=10\%$, $p=1$ ata, $V_p=136$ kV

(k) $k=10\%$, $p=2$ ata, $V_p=136$ kV

(l) $k=10\%$, $p=3$ ata, $V_p=166$ kV

Fig. 8. Examples of corona photographs for negative voltage application. $\phi=4$ mm, $\delta=5$ cm.

above are also applicable for these figures, namely,

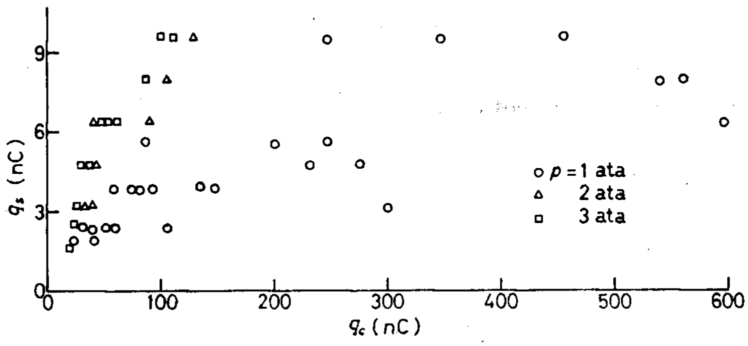
(1) When k is high, the spatial magnitude of the discharge decreases.

(2) When the gas pressure is high, the discharge channel becomes fine and small.

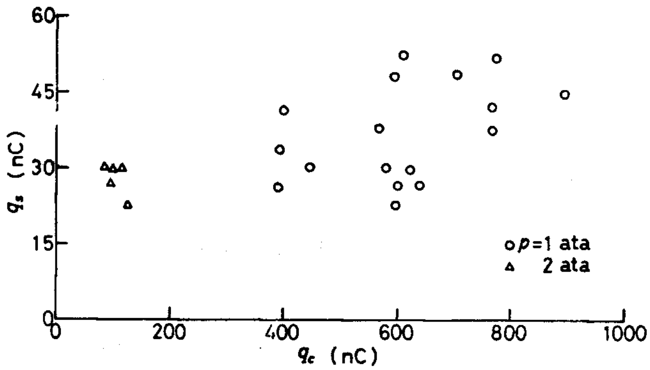
(3) When k or the gas pressure is high, the current pulse becomes narrow and small.

5. Space Charge Characteristics for SF_6–Air Mixture Gas

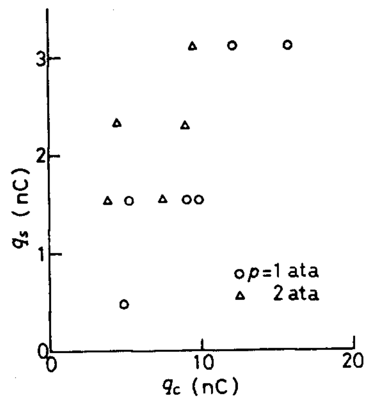
Fig. 9 shows some characteristics between q_c and q_s, where q_c means an integral of the corona current by time and q_s means the amount of space charge measured by the same method used for the space charge measurement in air[3]. In this experiment, results for only the positive voltage application are obtained. From Fig. 9 (a) and (b), it is deduced that q_s has a tendency of extreme saturation against the increase of q_c for $k=0\sim0.1\%$. The reason for this saturation is as follows: When k is small, the corona reaches the cathode very well [see Fig. 7 (a)]. In such cases, the current through the discharge channel continues after the corona reaches the cathode. Thus, q_c increases greatly, but the charge carrier does not remain in gap space. When $k=1\%$ [Fig. 9 (c)], the spatial extent of the discharge phenomena becomes small, and the value of q_s becomes closer to q_c.



(a) $k=0\%$



(b) $k=0.1\%$



(c) $k=1\%$

Fig. 9. q_s vs. q_c characteristics. q_s: space charge, q_c: integral of corona current by time.

6. Conclusion

In this experiment, the discharge phenomena in pure SF_6 and SF_6-air mixture gas were observed by electrical and optical technics. The results obtained are summarized as follows:

(1) Current and light pulses accompanied with the corona discharge in pure SF_6 have very low peak values and a short duration time compared with those in air. When $p=1\sim2$ ata, individual current pulses separate from each other, but for $p\geqq4$ ata, they do not separate.

(2) The velocity of the corona development in pure SF_6 gas is about 10^7cm/s, and is almost the same as that of the leader development in air.

(3) When the content of SF_6 gas against air is high, the discharge channel becomes fine and short, which is the cause of the high insulation ability of SF_6 gas.

(4) The space charge of $1\sim60$ nC is produced by the occurrence of the corona in SF_6-air mixture gas.

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