Current pulses caused by streamers in sphere-sphere electrode system

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Abstract. Streamer is a channel of a low temperature plasma growing due to ionization in the area of the strong electric field at the tip of the channel. Streamer investigation presents a technically highly complicated task due to fleetingness of the process: growing velocity is 10^6–10^7 m/s and characteristic duration is 10^{-8}–10^{-7} s. The electric current pulse registration is a moderate method for investigating so fast process. However, the major part of streamer current investigations refers to low voltage range (about 10^3–10^4 V) and short streamers length range 10^{-2}-10^{-1} cm. Also positive streamers are usually considered and there is a lack of information about current pulses caused by negative streamers. Both positive and negative streamers and their interaction are considered in the present paper. A multibranch streamer corona emerging at voltages above 250 kV and in long gaps (above 40 cm) was investigated.

1. Introduction

Some experimental investigations of streamers contain electric current oscillograms (waveforms). Current oscillograms of positive streamers in "point/wire" electrodes system with 25 mm interelectrode gap and at voltage 25 kV are presented in [1]: maximal current is 8 A and the pulse half-width is about 10 ns. The current oscillograms of positive streamers in "plane with point/plane" system (gap is 14.3 cm; voltage is 98 kV; working gas is a mixture of "15% O_2 / 85% N_2") is presented in [2]: maximal current is 2 A, the duration of the pulse is more than 300 ns. Current oscillograms of positive streamers in "point/plane" electrodes system with 7 mm gap and at voltage 6–9 kV are presented in [3]: maximal current is about 3–30 mA, the pulse duration is 50–200 ns. Current oscillograms of streamers in "plane with point/plane" electrodes system with 13 mm interelectrode gap by voltage 27 kV in N_2 and N_2/O_2 mixture are presented in [4]. In N_2, maximal current is 14 A, the half-width of pulse is about 150 ns. Pulse duration and maximal current decrease with increasing O_2 concentration. Current oscillograms of streamers in "plane with point/plane" system (gap is 35 mm; voltage is 3 kV) are presented in [5]: maximal current is 60 mA, half-width is about 100 ns. Current oscillograms of negative streamers in "plane with point/plane" electrodes system with 30 mm gap and at 12 kV voltage are presented in [6]: maximal current at atmospheric pressure is about 100 mA. Current oscillograms of streamers in "plane with point/plane" electrodes system with 12 mm gap by voltage 5–10 kV and pressure 0.2–0.5 atm. are presented in [7]. Gas mixture of O_2 and 0–5% H_2 is used. Maximal current is 14–40 mA and pulse half-width is 10–30 ns. Current oscillograms of streamers in "point/plane" electrodes system with 10 mm interelectrode gap at 9 kV voltage are presented in [8]: maximal current is 7 mA, half-width of pulse is 1 μs. Current oscillograms of positive streamers burst from spherical electrode (radius 12.5 cm) at about 600 kV voltage are presented in [9]:

maximal current is 10 A and pulses half-width is about 100 ns.   Thus,   the   major   part   of experimental data on streamer oscillograms refers to voltage values being less than 30 kV, while here a one order higher voltage is considered.

Sphere-sphere electrodes system was investigated. Sphere diameter D and interelectrode distance h were varied. The first sphere was grounded whereas high voltage pulse was applied to the other one. The voltage pulse form was the standard lightning pulse: fore front duration is 1.2 μs, back front duration is 50 μs. Pulses of the both polarities were considered. Current pulse measurement was implemented by observing voltage oscillogram from a shunting resistor that was series-connected to the grounded sphere. The experiments were implemented in air at the atmospheric pressure.

2. Results

Streamers emerge on the high voltage sphere or on the both spheres depending on the voltage and interelectrode distance. Negative streamer current pulses are short (about 0.2 μs) (figure 1) while those of positive streamers are longer (about 0.5 μs). Positive streamers can initiate negative ones from the opposite (i.e., grounded) sphere due to electric field distortion by space charge emerged in air owing to the discharge. The delayed electric current pulse occurs in this case (figure 2).

The correlation between negative streamer intensity and current pulse magnitude confirms the supposition that it is the first pulse that corresponds to the positive streamer current whereas the second one corresponds to the negative one. Compare results presented in figures 2–3.The data were obtained for the same electrode system but for different voltages: 200 kV and 240–250 kV. Positive streamers have similar length and glowing intensity whereas negative streamers are sufficiently longer and brighter in figure 3 in comparison with figure 2. The corresponding oscillograms show that it is the second current pulse that differs in the figures: the maximal current is 0.2–0.3 A at 200 kV whereas 0.8–1.2 A at 240–250 kV. Also the delay of the second pulse regards to the first pulse decreases: it is 1–1.5 μs at 200 kV and 0.4–1 μs at 240–250 kV. It is worth noting that the "meeting" negative and positive streamers and their electrical contact causes neither current leap nor breakdown (figure 3). Apparently, it is due to the high electrical resistance of negative streamer channels [9].
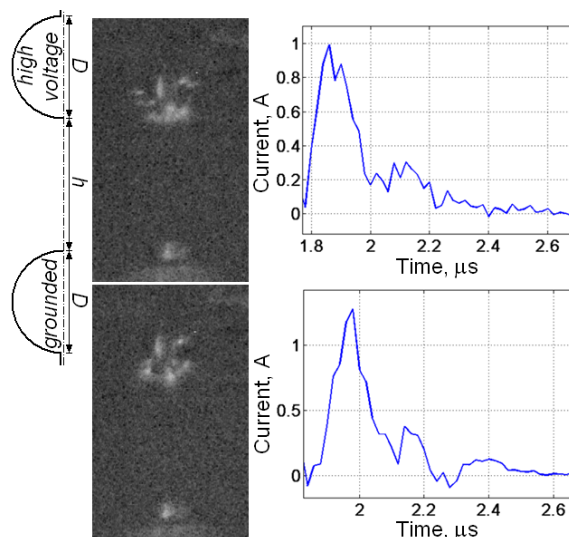

Figure 1. Negative streamer current pulses (on the right) and corresponding pictures (on the left). Spheres diameter D is 4 cm, interelectrode distance h is 5 cm, voltage is 130 kV.
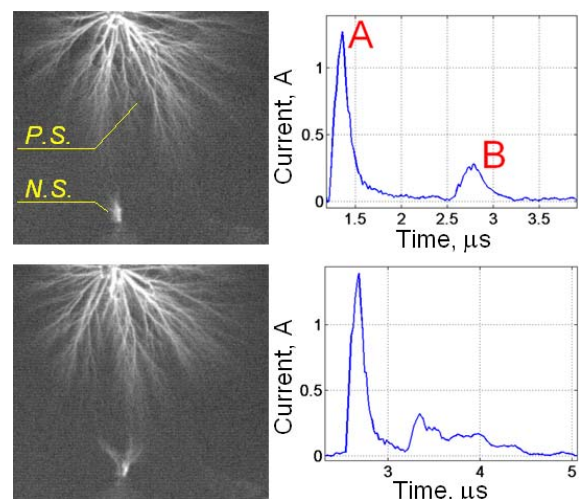

Figure 2. Positive and negative streamers. D is 4 cm, h is 39 cm, voltage is 200 kV. It is supposed that the first pulse ("A") is caused by positive streamers ("P.S.") from the high voltage sphere, the second pulse ("B") — by negative streamers ("N.S.") from the grounded sphere.

Electric current oscillograms preceding a breakdown are presented in figure 4. The same electrode system and voltage is considered in figure 3 where non-breakdown cases are presented. A breakdown oscillogram starts with a pulse that corresponds to positive streamer pulses in figure 3. The distinction is in the following. Streamers preceding the breakdown provide current 1.3–2 times the current of streamers that is not preceding breakdown. Sometimes the second pulse is distinguished (figure 4, "B"); apparently, it corresponds to negative streamers that start from the grounded sphere: there is similarity with the corresponding pulse "B" in figure 3.

The measured current maximums correspond by the order of magnitude to ones measured at the voltage that is 10 times lower [1, 2, 4]; however, pulses duration is 10 times longer. Apparently, the reason is in the following. The streamer velocity and electric field intensity in the channel remain nearly the same at rising voltage whereas streamer length and growing duration increase.

3. Conclusions

Negative streamer current pulses are shorter than those of positive streamers. In the sphere-sphere electrodes system, positive streamers can initiate the emergence of streamers from the grounded sphere; the delayed electric current pulse occurs in this case. Streamers preceding breakdown provide about 1.5–2 times higher current than those that is not preceding breakdown.
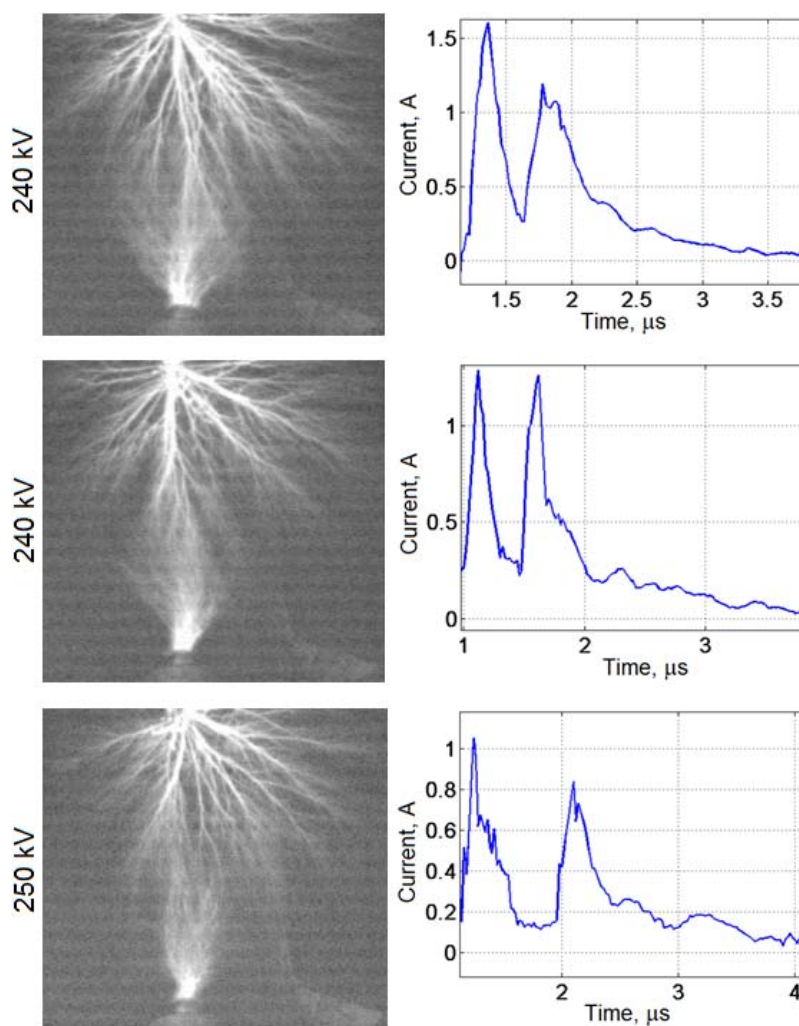

Figure 3. Positive and strong negative streamers. Spheres diameter *D* is 4 cm, interelectrode distance *h* is 39 cm, voltage is 240–250 kV.
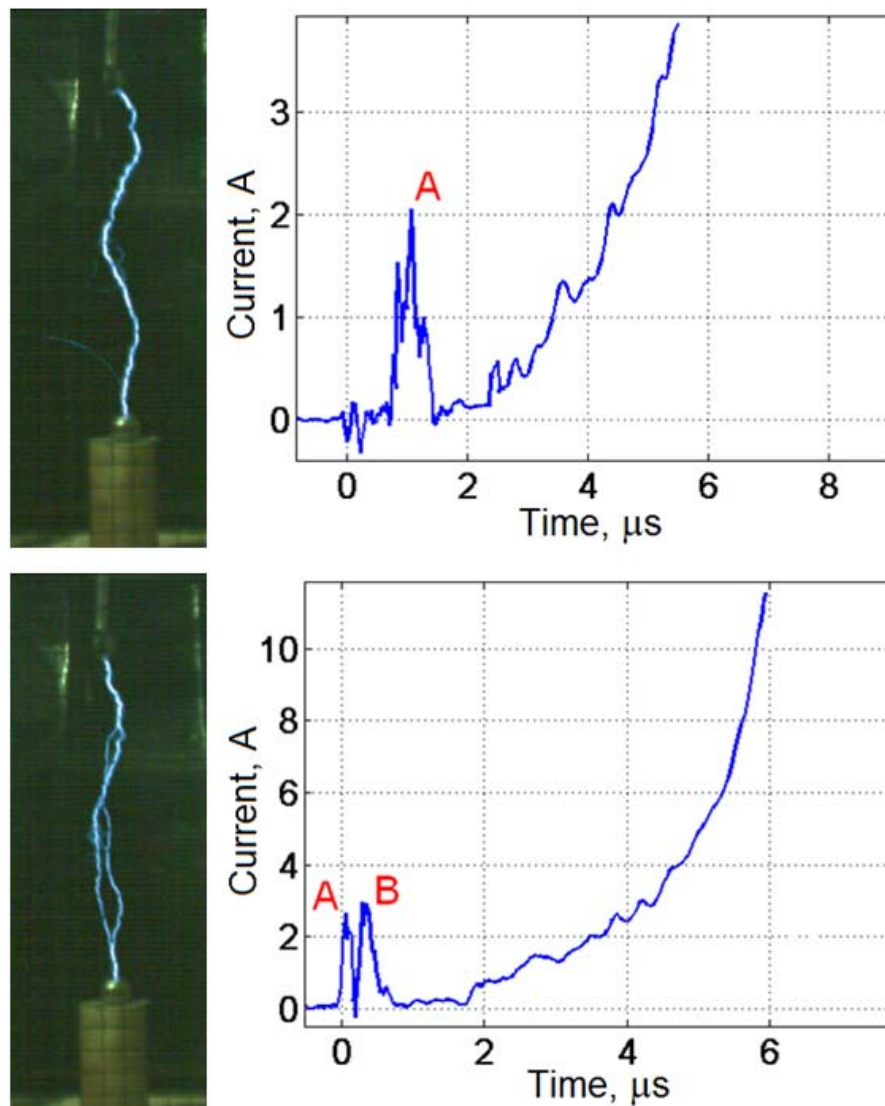
Figure 4. Breakdown. Spheres diameter *D* is 4 cm, interelectrode distance *h* is 39 cm, voltage is 250 kV; "A"—positive streamer current pulse, "B"— negative streamer current pulse.

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