# Energy deposition in discharge chamber of lightning protection multichamber system

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**Abstract.** The experimental data of energy deposition distribution along discharge chamber of lightning protection multichamber system in initial stage of discharge process aimed to model lightning current impulse up to 10 kA is presented. A multichamber system is a series connection of discharge chambers. According to our experiments the shock wave formation occurs during the breakdown phase between electrodes located at the bottom of discharge chamber. The consequent energy deposition during discharge development goes in the whole volume bounded by shock wave front.

Complexes of special devices are used for the lightning protection of overhead transmission lines [1–3]. Basic elements of the complexes are systems of overhead ground wire [1–3], overvoltage arresters based on metal-oxide varistors [2] and various types of gas-discharge [2,3]. New approaches for improving and updating of surge protection devices of all types take place continuously.

Various types of discharges and methods for overvoltage protection are used in modern gas-discharge protective devices. For example, the active controlled surge protective gas-discharge arresters with tracking system [4–6] has appeared. One of the most perspective elements for lightning-protective complex constructions is a system of multichamber arresters [7,8] designed by Streamer, Electric Company Inc [9]. The multichamber system is a series connection of identical discharge chambers [3,7,8].

Characteristics of these devices satisfy all modern requirements for lightning protective systems [10], and for designing and construction of new transmission lines in many cases the given types of devices has been preferred [3,9].

Design and development of new lightning-protective devices remain rather uneasy and expensive problem. For the process optimization an attempts has been made to develop physical and mathematical models of the discharge for such systems and calculate parameters in the discharge chamber of arresters [11]. In this work the experimental data of energy deposition distribution along the discharge chamber length of the lightning protection multichamber system [3,9] is presented.
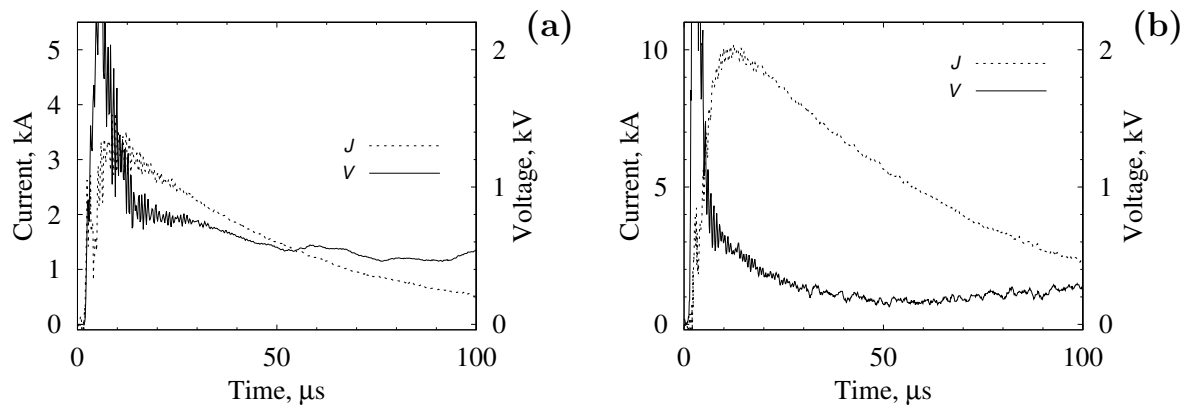
**Figure 1.** Current ($J$) and voltage ($V$) for 3 (a) and 10 kA (b) current amplitude test conditions.

The stimulus for carrying out the presented work was the discrepancy between theoretical estimations of gas flow parameters [12] with experimental data [12] for similar discharge device. Calculated values of shock wave propagation speed are much lower than ones observable in experiment [12]. There are consecutive breakdowns between the electrodes located at the bottom of channels in multichamber system chambers. At a breakdown stage the shock wave is formed which pushes out a significant part of gas from the discharge chamber. Air backflow starts to fill the chamber after current pulse and pressure decrease in the discharge volume. Thus deionization speed of interelectrode gap is governed by speed of backward gas filling which, in turn, depends on amount of gas pushed out from the chamber.

Thus, initial stage of discharge is very important for real work of the arrester. And parameters of a shock wave and gas flow at the initial stage of the discharge mainly define operation characteristics of the given protective device and its ability to extinguish an follow current from transmission line.

In this paper, single discharge chamber of multichamber system [7] was investigated. Experiments were carried out at the stand which detailed description is given in [13]. The brief review of used diagnostics methods one can find in [14]. The first results of energy deposition distribution along discharge chamber for current amplitude of 10 kA are reported in [15].

The chamber construction is described in details in [3], also brief scetch is in [8,15]. The case of chamber is made from silastic. The discharge volume represents the narrow slot-hole channel with rectangular cross-section opened on the one side in an atmosphere with length of discharge volume is of 2 cm. Height of a slot is of 1 cm, width $\sim 0.1$ cm.

Oscillograms of current and voltage are shown in figure 1. The $30\mu F$ capacitor was used for 10 kA current amplitude pulse and 9 $\mu F$ for 3 kA. Initial current-rise rate was of $\sim 10^9$ A/s. The capacitor was charged up to 18–23 kV and then it unloaded on the discharge chamber through the 2 Ohm resistor for 10 kA pulse or 6 Ohm for 3 kA. Thus, the current amplitude was defined by nominal value of the resistor, the time constant of a discharge circuit was $\sim$ 54–60 $\mu$s. The energy input into the discharge was of $\sim$ 100–200 J.

Consecutive frames of high-speed discharge photo in a lateral projection of discharge chamber after ignition of 3 $\mu$s, 5 $\mu$s and 10 $\mu$s are shown in figure 2. An exposition of each frame was of 15 ns. For carrying out high speed photography in a lateral projection of the discharge chamber has been cut off up to border with a discharge slot and instead of a slot wall the transparent polycarbonate sheet has been rigidly fixed [15]. Plain geometry of a discharge slot allows reconstructing a field of energy deposition in the discharge volume according to high-speed photographing.
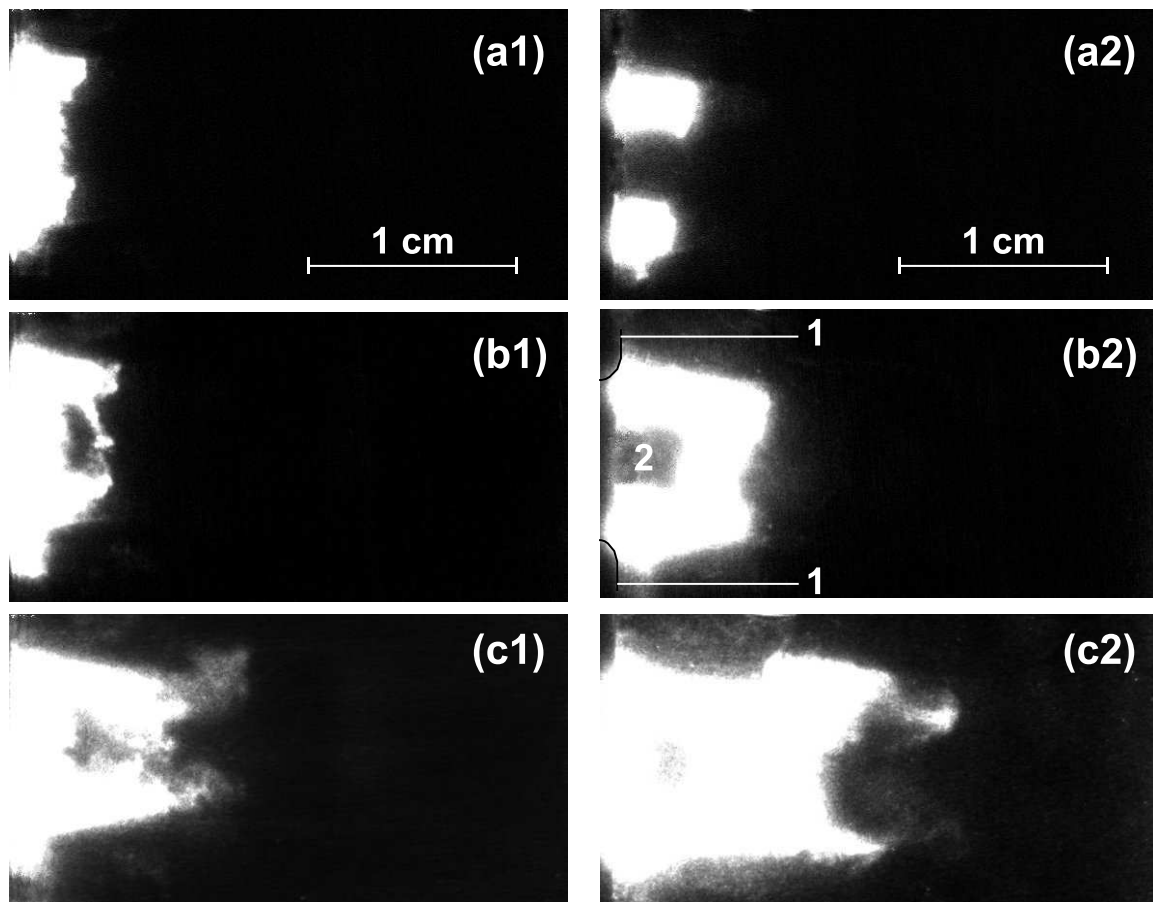
**Figure 2.** High speed photo of discharge for current amplitude 3 kA (a1, b1, c1) and 10 kA (a2, b2, c2): 1—electrodes contour; 2—dielectric peak on discharge chamber bottom; a1, a2—3 $\mu$s after ignition; b1, b2—5 $\mu$s; c1, c2—10 $\mu$s; frame exposition of 15 ns.

For researched object a density of gas was $\rho \sim 1.2$ kg/m$^3$, the characteristic size of gas flow area was $L \sim 2 \times 10^{-2}$ m, cross-section of gas flow was $S \sim 10^{-5}$ m$^2$, a characteristic energy input in initial stage $W_0 \sim 10$–25 J. At breakdown of an interelectrode gap and subsequent formation of the discharge channel the energy $W_0$ was put in rather small area during several microseconds. The front of a shock wave was formed.

For weight of gas in the chamber $m \sim 0.25$ mg, if the energy $W_0$ is fully absorbed by gas, parameters of gas will be as follows: $p \sim 7$–15 MPa, $T \sim 10000$–20000 K. Sound velocity is $c \sim 2.5$–4 km/s. For such parameters it is possible to suppose that plasma is transparent. It is allowable at early discharge stage before massive influx of chamber wall material in the discharge volume and taking into account rather small current density $\sim 10^4$ A/cm$^2$.

Let us estimate characteristic times of a heat transfer: $L^2/4a \sim 0.1$ s, $l^2/4a \sim 250$ $\mu$s, where air thermal diffusivity is of $a \sim 10^{-3}$ m$^2$/s and the wave front size is $l \sim 10^{-3}$ m. Thus, it is possible to suppose that heat is transported with gas flow and neglect transport phenomena.

High-speed photographing was executed in narrow spectral range of 550–650 nm, limited by optical filters. The spectral emissive ability in the spectral range is linearly proportional to temperature $I_\lambda \sim T$ for estimated plasma temperatures. Thus, assuming, that locally deposited energy is spent on temperature increase (with accuracy up to gas kinetic energy), the optical image reflects a field of energy deposition in the plane geometry of discharge volume [15].
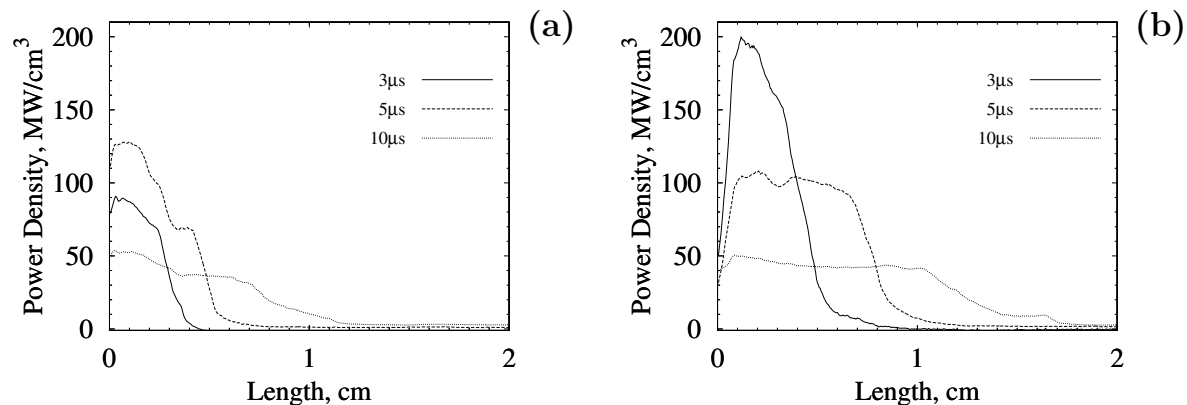
**Figure 3.** Energy deposition distribution along discharge chamber for 3 kA (a) and 10 kA (b) current amplitude test conditions at different time.

Field $I_\lambda(x, y, t)$ actually corresponds to distribution of image intensity of discharge high-speed photo during the same instant in time $t$ (plane $XY$ perpendicular to the direction of the photo shooting and the $X$-axis is directed along the length of the discharge chamber).

So it is possible to restore two-dimensional fields of energy deposition in the discharge volume via high-speed photos. But in our case one-dimensional distributions of power density $P_x(x, t)$ along the discharge chamber length are more indicative (figure 3).

It is clearly visible (figure 3), that energy deposition at the discharge development occurs in the total volume limited by the shock wave. The field of radiation (figure 2) occupies all space from a bottom of the discharge chamber up to moving front of a shock wave in high-speed photos in a lateral projection.

Thus, the shock wave receives energy from discharge all its way out of chamber. The given conclusion confirms assumptions of work [12].

This data can be taken into account for development and updating of physical and mathematical models of the discharge in similar electrodischarge systems.

**Acknowledgments**

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