Application of image converter camera for investigation of discharges from an artificial cloud of charged water aerosol

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ABSTRACT

Results of experimental investigations of optical characteristics of discharges from an artificial cloud of charged water aerosol by using the K011miniature 9-frame image converter camera are presented in the paper. Application of high speed image converter camera has allowed clearly distinguished the peculiarities of a final stage of three types of discharges from the charged aerosol clouds. Each type of final stage is differed not only on optical and current characteristics, but the sequence of formation. It was found that the type of final stage depends on character of development the previous leader discharges in the gap “charged aerosol cloud – grounded rod on the plate”. The most frequently case is the formation of final stage after development of upward leader from the grounded rod and of counterpart negative downward leader from the charged aerosol cloud boundaries. Simultaneously registered current characteristics have shown significant correlation between optical and current characteristics of final stage of discharge. More powerful discharge luminosity the higher current amplitude and the shorter final stage of discharge.

Keywords: Image converter camera, discharge, charged aerosol cloud, frame, leader, final stage

1. INTRODUCTION

Investigation of problems of the lightning discharge initiation and development, streamer and leader discharge propagation inside the thunderstorm cloud and near it, cloud charge neutralization during the return stroke is important as for more deep understanding of the lightning physics as for forecasting of the lightning affection on the ground objects and air vehicles [1]. However, to study the mechanisms of the thundercloud discharge processes (for example, which part of the thunderstorm cloud and in which degree will be discharged, development of the discharges inside clouds, interaction of the return stroke with thundercloud, possibility and direction of the subsequent strokes) in the natural thunderstorm conditions is practically very difficult [1, 2]. There are only propositions about the influence of a cloud structure on the initiation and development of the discharge inside thundercloud and about cloud space charge neutralization [1-3]. Without these data more full and true physical and mathematical model of the lightning initiation and development can not be created [4].

So, an experimental investigation of development of the discharge processes (formation and propagation of streamer and leader discharges, return strokes) in the artificial strongly charged water aerosol clouds (analog of the thunderstorm cells) and near its boundaries could be very interesting and informative, and in fact unique mean for the determination of possible mechanisms of the thunderstorm cloud charge neutralization [5].

However, spark discharges from an artificial cloud of charged water aerosol are temporally fast and very arbitrary phenomenon as in time as in space. It is difficult to obtain a clear distinguished optical picture of all successive stages of discharge development from the charged aerosol cloud, and retrace the single details of every stage especially final stage (possible analog of the natural return strokes of different types). For clear registering of such arbitrary, fast, and having the different luminosity discharge events, the special apparatus has to be used. And, the results of experimental investigation of optical characteristics of the discharges from the charged water aerosol cloud (with emphasis on the fast final stage) received by using the K011 miniature 9-frame image converter camera received simultaneously with current characteristics are presented in the paper.

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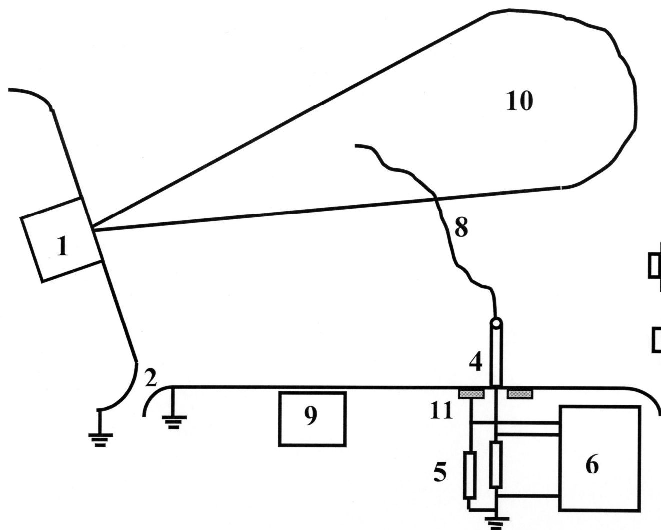
2. EXPERIMENTAL SETUP

The experimental setup consists of 250-m^3 aerosol chamber, charged aerosol generator of a condensate type, an electrode system, and a diagnostic complex. Full parameters of an experimental complex were presented in [6, 7]. It allows to create clouds of charged water aerosol have a potential up to 1.5 MV and could induce the electric fields up to 17-19 kV/cm near its boundaries and up to 6-10 kV/cm under the charged aerosol cloud near the grounded plate. Scheme of experimental setup is shown in fig. 1.



1 – charged aerosol generator, 2 – electrostatic screens, 3 – image converter camera,
4 – grounded rod electrode, 5 – shunts, 6 – oscilloscope, 7 – digital camera,
8 – electric discharge, 9 – electric field meter, 10 – charged water aerosol cloud, 11 – antenna
Fig. 1. Scheme of experimental setup

Experiments were carried out under negative polarity of the artificial charged aerosol cloud as according to [1] the beginning initiation of the discharge phenomena in thunderstorm cloud passes near the region of the negative thundercloud charge. During experiments, outlet current of the charged aerosol generator was in approximately same level of 110 µA. Space charge density inside the cloud of charged water aerosol can be in the range of 10^{-4}-10^{-2} C/m^3. Characteristic distribution of an electric field inside the charged aerosol cloud and in the gap “charged aerosol cloud – grounded plate” has been shown in [8].

For more detailed discharge characterization the rod with sphere tip of 50 mm diameter was installed on the grounded plate. The height of grounded rod was 170 mm during all experiments. Sphere tip was isolated from rod, and current characteristics of discharge developing from the tip were measured using non-inductive shunt of R = 1.39 Ohm. Electromagnetic radiation of discharge was measured using dynamical antenna (displacement current reacting on change fastness of an electric field) connected with the non-inductive shunt of R = 36 Ohm. Isolated metal plate posed around rod electrode on the grounded was used as dynamical antenna. Both current signals were simultaneously fixed by the digital oscilloscope Tektronix TDS 3052. Electric field strength and charge of aerosol cloud were controlled by the string field meter and value of outlet current of the charged aerosol generator.

K011 miniature programmable 9-frame image converter camera (Fig. 2) created by Russian BIFO Company [9] was used by us for registration of optical picture of discharge from artificial cloud of charged water aerosol in spectral range 400–800 nm simultaneously with discharge current characteristics. This camera provided independence duration of each frame and each interframe pause in range from 0.1 up to 102.4 µs with 0.1 µs step. Common discharge picture was fixed by the digital camera Canon PowerShot G1. Angle between the view directions of image converter camera and digital camera on the discharge phenomenon was approximately 30^0.

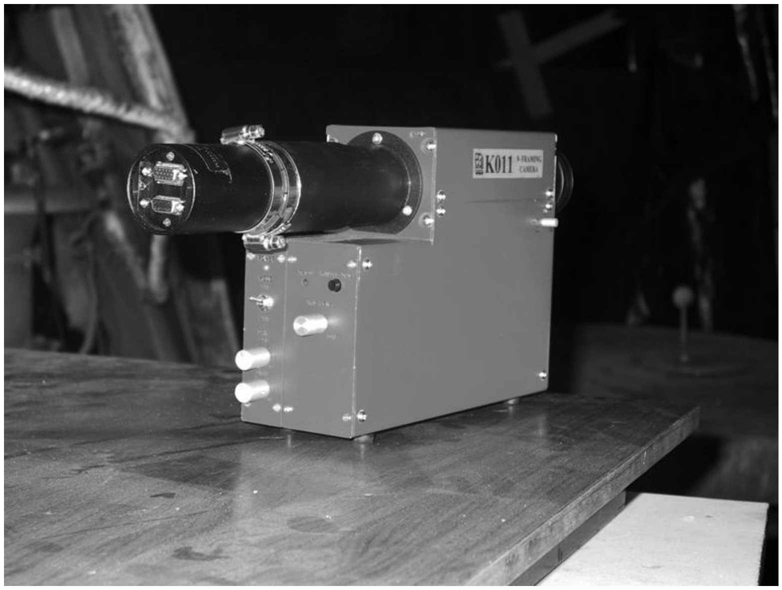


Fig. 2. K011 miniature programmable 9-frame image converter camera

3. EXPERIMENTAL RESUTS

Experimental investigations of the formation dynamics of final stage of discharge from artificial cloud of charged aerosol have shown three main optical pictures of spark discharge development. Paths of formation of final stage and its following development and characteristics of the found optical pictures have been determined by the previous discharge processes in the gap "charged aerosol cloud – grounded rod on the plate": 1 - development from the cloud of negative downward leader, 2 - development upward positive leader from grounded electrode under the cloud only, and 3 - development of downward negative leader from the artificial charged aerosol cloud and counterpart upward positive leader from the grounded rod with the following their interaction.

Detailed analysis of camera frames and current oscillograms has shown that the most powerful and rapid final discharge formed in the case of development from the cloud of negative downward leader. Typical optical picture fixed by the digital camera and by the frame image converter camera and currents oscillograms for such type of discharge final stage are shown in fig. 3, 4 and 5, correspondingly.

Such type of the discharge final stage was rare event. Probability of its formation was sufficiently less than 5 %. However, the maximal optical and current discharge characteristics were in 5-10 times larger than for other types of the discharge final stage. Current oscillograms of the discharge final stage of first type have only one pike, and maximal current amplitudes lie in the range of 15-30 A. Typical duration of final stage is in the range 500-800 ns.

Formation and development of final stage at first one hundred nanoseconds when the maximal current amplitude and maximal luminosity have achieved has been characterized by the fast changing of the electric field near the rod electrode base (large displacement current is fixed). That speaks about two peculiarities of discharge development of the first type. First, space charge neutralization leaved by the negative downward leader passes very fast. And, second, previous downward leader was sufficiently more powerful than upward positive leaders. As a result, we have high current and luminosity final stage of discharge between charged cloud of water aerosol and grounded electrode on the plate that neutralized not only leaved leader space charge, but immediately the space charge of charged water aerosol cloud too. Typical value of the cloud charge that is neutralized by this type of final stage of discharge is 1-3 μC.

Fig. 3. Photograph of final stage of the first type for discharge from an artificial charged aerosol cloud.

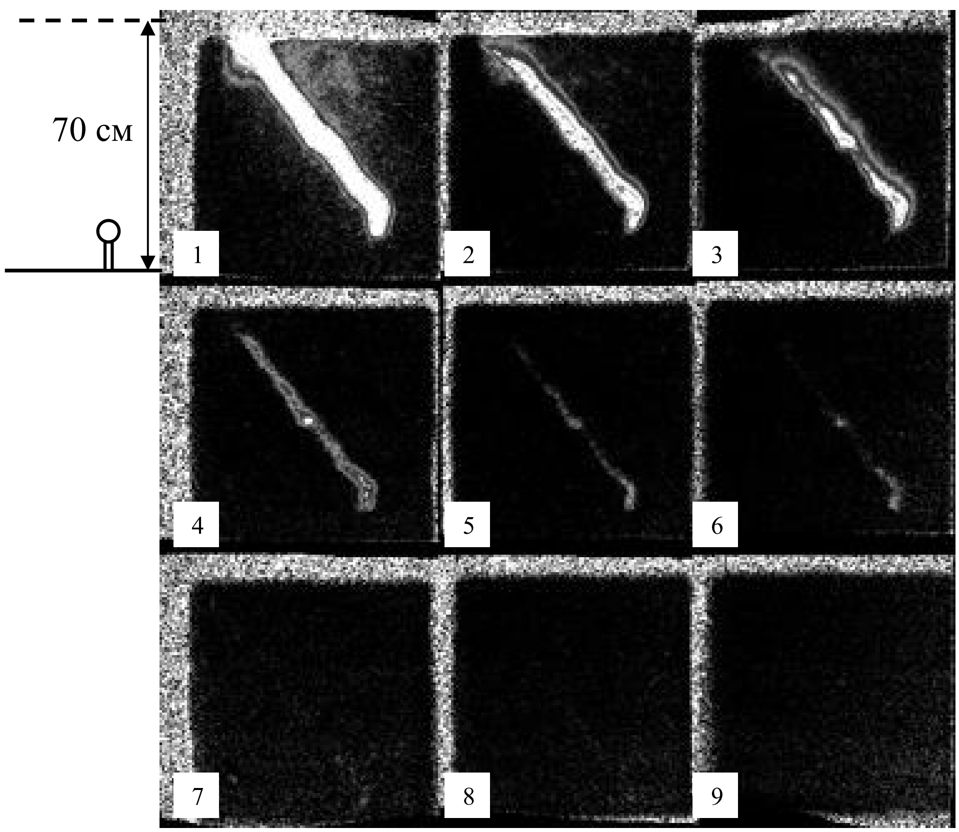


Fig. 4. Formation of final stage of the first type (frame duration 0.1 μs, interframe pause 0.1 μs). Numbers show the frame sequence

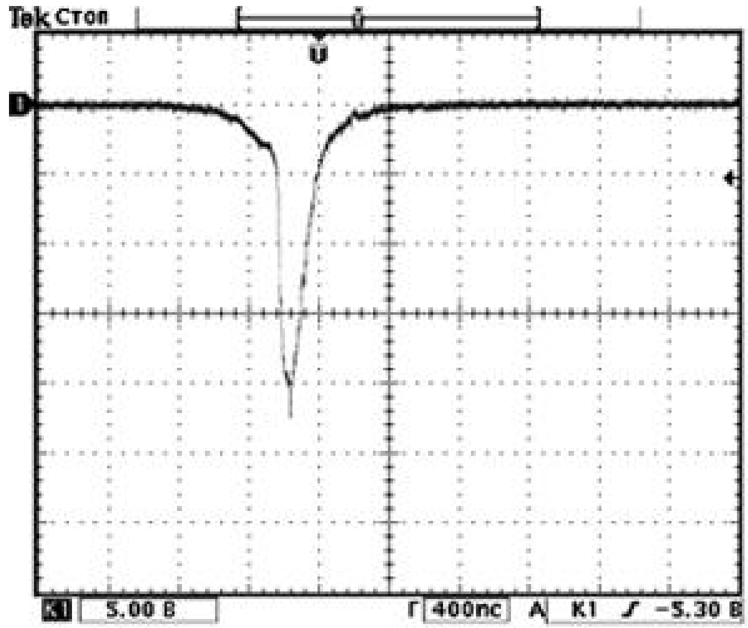


Fig. 5. For the case of first type of discharge final stage, the final stage discharge current (shunt of R = 1.39 Ohm)

Much more frequent occurred variant was the second type of the discharge final stage when only upward leader started from grounded rod electrode under the cloud. It was found that as the upward leader as the following final stage had the less intensive luminosity and current of discharge. Moreover, two possible scenario of the final stage development could be observed after positive upward leader propagation from the grounded rod electrode.

Most of the upward leaders did not achieve the charged aerosol cloud boundaries and did not penetrate inside cloud (uncompleted discharges). In that case the luminosity of final stage of discharge was weak. The maximum current amplitude was not more than some amperes. Duration of the discharge final stage was in the range 1-4 μs. And neutralization of the charged aerosol cloud charge did nit occur during this final stage.

In another case, it was sufficiently rarely observed interaction of upward discharges with the charged aerosol cloud. However, in that case the luminosity of the discharge final stage of the second type and the current amplitude sufficiently increased. Picture of the discharge final stage development and current oscillogram for such type of the final stage are shown in fig. 6 and 7, correspondingly. Current amplitudes are in the range of 5-14 A. Duration of the discharge final stage of the second type was typically some microseconds, but neutralization of the cloud charge occurred in some times less intensive than for the discharge final stage of the first type.

Using K011 camera with frame and pause duration from 0.1 to 2 μs, it was found the main observed variant of the discharge final stage development was the third type when downward negative leader from the artificial charged aerosol cloud interacted with counterpart upward leader from the grounded rod. Typical optical picture fixed by the digital camera and by the frame image converter camera, and also currents oscillograms for such type of discharge final stage are shown in fig. 8, 9 and 10, correspondingly.

Common duration of final stage of the third type is some microseconds. Typical value of the cloud charge that neutralized by this type of final stage of discharge is 0.5-1 μC.

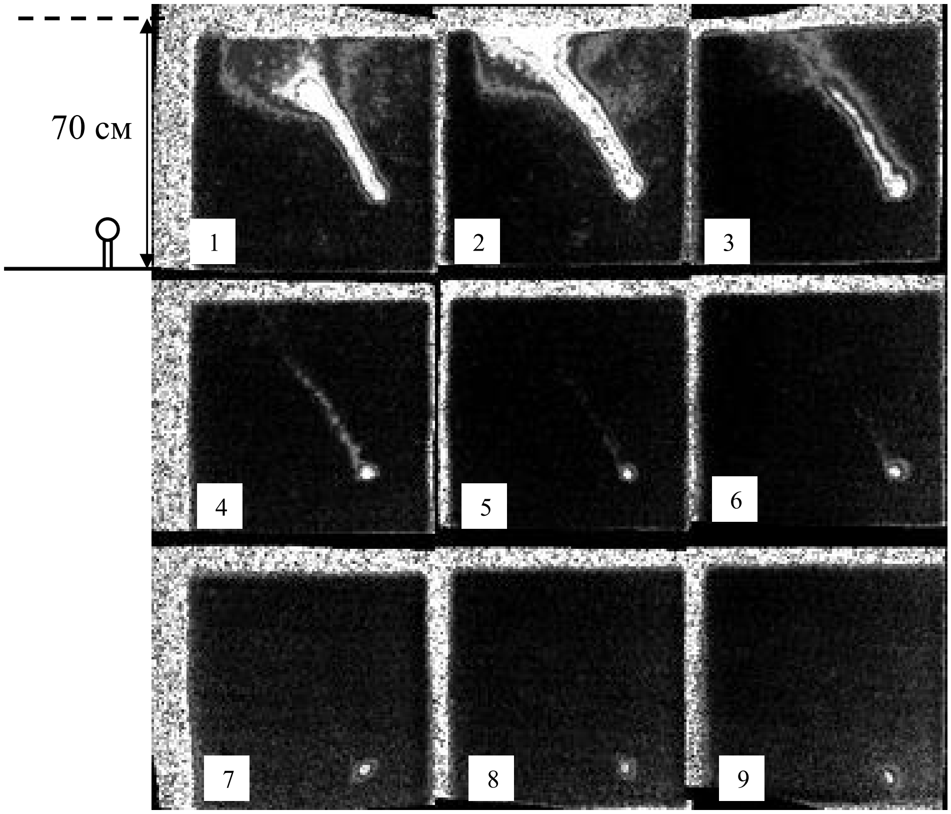


Fig. 6. Formation of discharge final stage of second type when upward leader interacts with artificial charged aerosol cloud (frame duration 0.5 μs, interframe pause 0.5 μs)

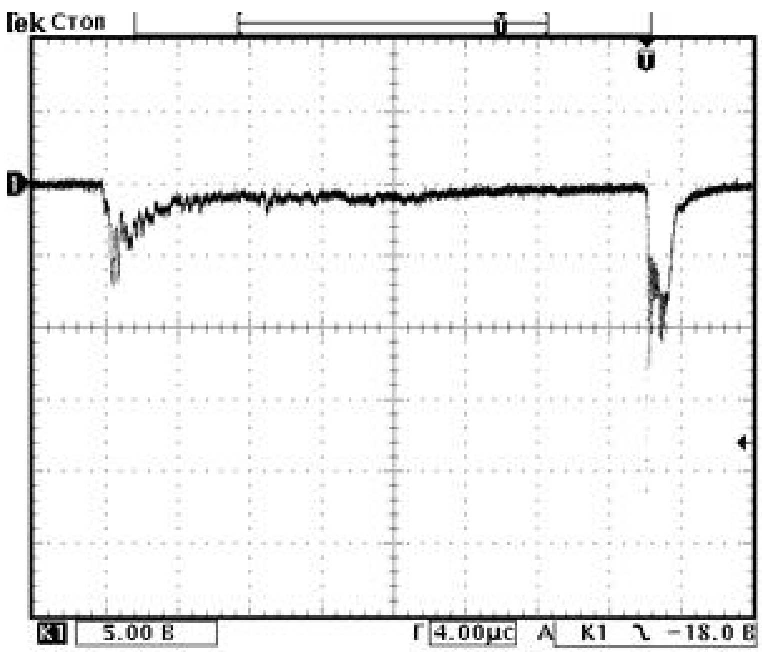


Fig. 7. Current oscillogram of upward discharge from the grounded rod with clear distinguished final stage (shunt of R = 1.39 Ohm)

Fig. 8. Photograph of the final stage of the third type for discharge from an artificial charged aerosol cloud

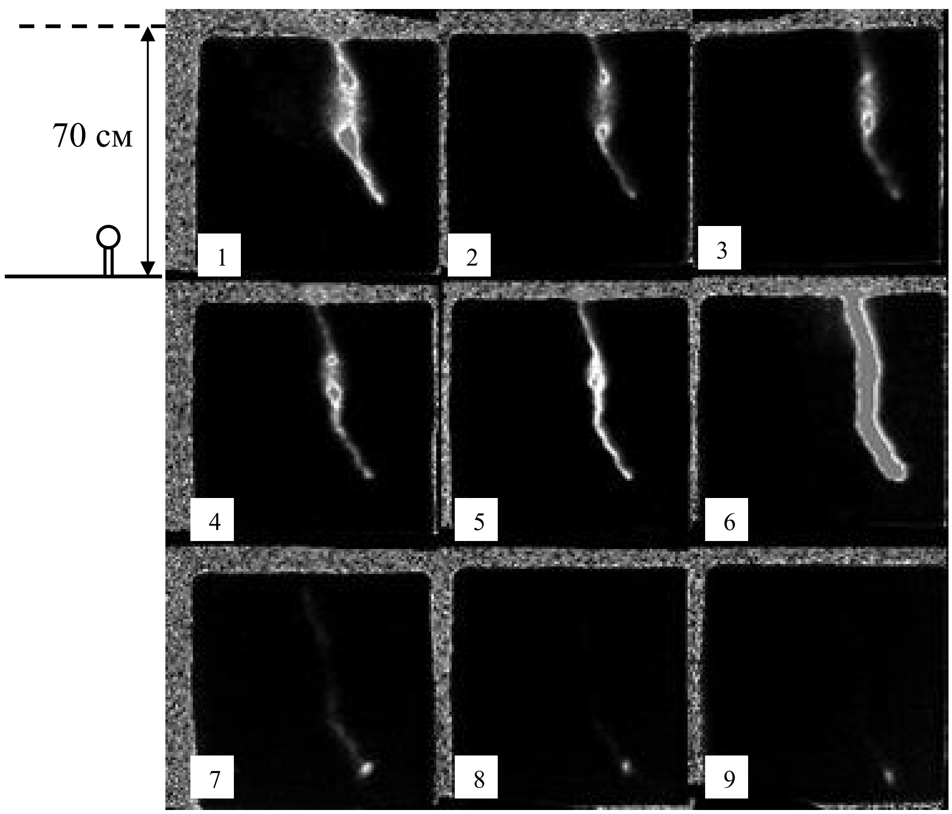


Fig. 9. Formation of discharge final stage of third type when upward leader interacts with downward leader from the charged aerosol cloud (frame duration 0.2 µs, interframe pause 0.2 µs)

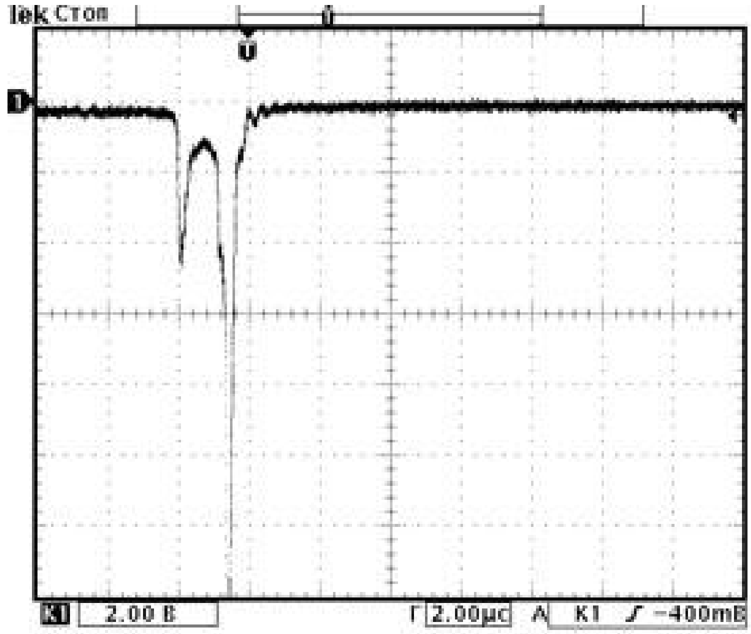


Fig. 10. Typical current oscillogram of discharge final stage of the third type (shunt of R = 1.39 Ohm)

It is interesting to note that when final stage of the third type is forming in the gap "charged aerosol cloud – grounded rod on the plate" current oscillogram usually has two-peak structure (sometimes three-peak structure is observed too when several space leaders form in the discharge gap and than participate in the formation of a final discharge channel). It consists of relative weak first current peak (in the range of 2-8 A) and much more intensive second peak (in the range 7-15 A). First current peak corresponds to formation of the final stage of the upward leader from the grounded rod, and its characteristics (current amplitude, luminosity) significantly correlate with the parameters of discharge final stage of the second type, when upward leader does not achieve of the boundaries of the charged aerosol cloud. Second current peak characterizes the stage of neutralization of downward leader space charge after the meeting of the negative downward leader and the positive upward leader. However, switching on the part of downward leader to the upward discharge does not occur immediately. It is required approximately near microsecond to lunch the second phase of the discharge final stage. It is interesting to note that significant luminosity is observed in the place of interaction of the downward and upward discharges during the pause between the current peaks.

Application of the image converter camera K011 has been allowed to determine some correlation dependences between optical and current characteristics of discharge final stage. Direct dependence between the optical diameter (transverse section at 50 % level of the maximal light signal intensity) of the final stage channel and the maximal current amplitude was established. Dependence between the maximal optical diameter of a final stage channel and maximal amplitude of the discharge current is shown in fig. 11. Analogous but only little less pronounced correlation was found between the optical diameter and the discharge current rise fastness. Dependence between the maximal optical diameter of a final stage channel and the maximal discharge current rise fastness is shown in fig. 12.

It is interesting to note that for the discharge final stage channel of the first type (having the most intensive luminosity and the highest current) the maximal optical diameter increases with the growth of maximal current amplitudes and maximal current rise fastnesses more slowly than for the final stages of second or third type. Such change of a tendency has probably connected with the fact that final stage is almost completely determined by the characteristics of the previous downward leader. As experiments have carried out under approximately similar characteristics of the artificial charged aerosol cloud, the parameters of the developing from cloud downward leaders were close too. So, without influence of the upward discharges we have enough close characteristics of the discharge final stage too.

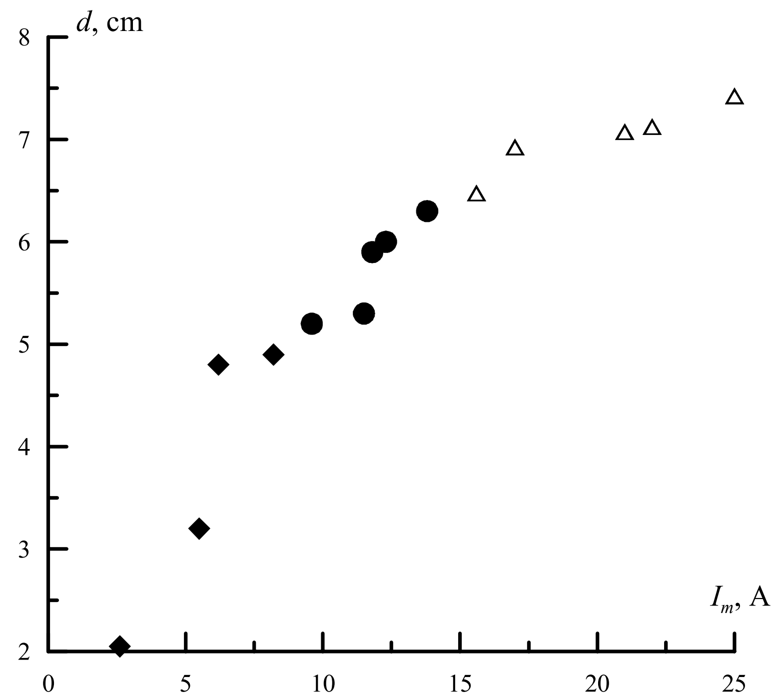


Fig. 11. Dependence between the maximal optical diameter of final stage channel and the maximal current amplitude of discharge: Δ - first type, ♦ - second type, • - third type

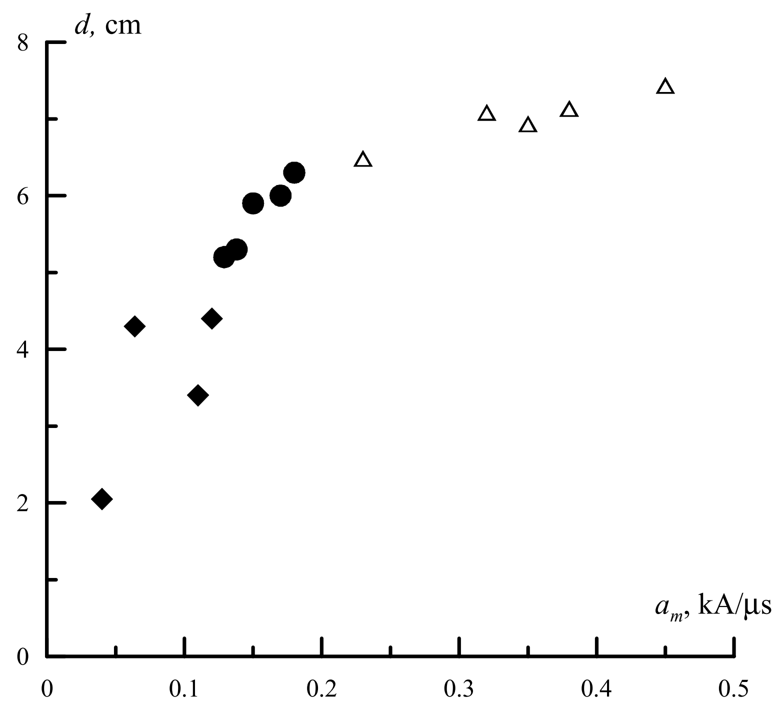


Fig. 12. Dependence between the maximal optical diameter of final stage channel and the maximal rise fastness of discharge current: Δ - first type, ♦ - second type, • - third type

4. CONCLUSIONS

Application of the K011miniature 9-frame image converter camera has allowed to distinguish the detailed optical structure of final stage of discharge from an artificial cloud of charged water aerosol. Three types of final stage were found. First and third types are the most interesting for possible application of received experimental results to real thunderstorm situation.

First type corresponds to the case of immediate connection of the downward leader with grounded electrode and demonstrates the most intensive luminosity and current amplitudes. Probably just for such path of the discharge development the return strokes with maximal currents are formed in real lightning discharge.

Third type corresponds to the case when the downward leader interacts with the counterpart upward leader from the grounded electrode, and optical picture and current shape of discharge final stage have much more complex structure than for the first type. Current oscillograms have multi peak structure with the highest last one, and image converter camera frames show corresponding interaction downward and upward leaders, following processes in the place of its interaction, and the main process of downward leader space charge neutralization. Such situation is considered typical for real lightning discharge. Probably multi peak return stroke current structure is difficult to determine under measurements the real lightning return stroke currents because the first peak dependent on the counterpart upward leader discharge is greatly less than the following main return stroke current.

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