Investigation of influence of model hydrometeors on characteristics of electromagnetic radiation impulses registered near to artificial thunderstorm cells

A G Temnikov*, O S Belova, T K Kivshar, L L Chernensky

Russian Federation, Moscow, 111250, Krasnokazarmennaya str. 14, National Research University "Moscow Power Engineering Institute"

E-mail: a_g_temnikov@mail.ru

Abstract. Results of the experimental investigations of the influence of the model hydrometeor arrays on the characteristics of the electromagnetic radiation of the channel discharges between the system of the artificial thunderstorm cells of a negative or positive polarity and the ground have been presented in the paper. Parameters of the impulses of the electromagnetic radiation registered by the wideband plate antennas for the first and subsequent return strokes are under a consideration. Significant influence of the array of the large model hydrometeors on the probability of a subsequent stroke initiation and on the parameters of the corresponding electromagnetic radiation pulses has been established and discussed. Found dependencies between the characteristics of the current impulse of the first and subsequent return strokes from the system of the negative and positive artificial thunderstorm cells and the parameters of the impulses of the corresponding electromagnetic radiation have been analyzed. Comparison of the received results with processes of the electromagnetic radiation of a natural lightning has fulfilled.

Introduction
Electromagnetic radiation of lightning in thunderclouds are in very wide spectral range [1]. Correct interpretation of the parameters of this radiation is an important factor for the understanding of the lightning physics, for the effectiveness improvement of the functioning of the systems of a lightning stroke detection, and for the determination of the lightning discharge parameters [2, 3]. It is necessary to note that the cloud discharges and the intracloud discharge processes during the downward lightning appearance could form and develop in the regions of thundercloud characterized by the large concentration of the hail. So, the hail arrays could play a significant role on the different stages of the lightning development [4]. Last years, more and more attention has been directed on the possible influence of the regions with a large concentration of hail in thunderclouds on the appearance and development of the discharge phenomena in thundercloud, and on the characteristics of its electromagnetic radiation registered on the ground surface [5].

Methodology
Results of the experimental investigations of an influence of the arrays of the large model hydrometeors on the characteristics of the impulses of an electromagnetic radiation of the discharges appearing between the system of the negative (positive) artificial thunderstorm cells and the ground have been presented in a paper. Main parameters of an experimental complex for a creation of the artificial thunderstorm cells and an investigation of the electrical discharges from them has been presented in [6, 7]. Characteristic experimental scheme used in the presented experimental investigations has shown in Figure 1.

Some groups of the large model hydrometeors of the centimeter sizes (hail analogs) have been introduced in a space between the charged clouds, inside the clouds, and near its boundaries. Common potential of such charged aerosol cloud system could reach up to one thousand and five hundred kilovolts. Discharge current between the artificial thunderstorm cells and the ground and its electromagnetic radiation have been registered during the experimental series. Characteristic picture of a formation of the channel discharges between the system of the negatively charged artificial thunderstorm cells and the ground has shown in Figure 2. Disposition of the wideband plate antennas A1-A3 relative to the places where the discharge phenomena have formed has shown in Figure 2 too. Antenna A1 has been disposed on the ground near the place where the channel discharges have occurred. Antenna A2 has been disposed on the ground too but “far” from the place of the discharge formation. Antenna A2 has been disposed on a side wall of an aerosol chamber on a height that has correlated to the heights where the model hydrometeor groups being in the artificial thunderstorm cells. All antennas registered the velocity of the electric field strength change in the places of their disposition.

Figure 1. Experimental setup: charged aerosol generator, 2 – electrostatic screens, 3 – charged cells, 4 – rod electrode, 5 and 5* – channel discharges, 6 – shunts, 7-9 – antennas, 10 – digital oscilloscopes, 11 – digital camera, 12 – photomultipliers, 13 – CCD camera, 14 – model hydrometeor arrays

Figure 2. Characteristic picture of the channel discharge development between the system of the artificial thunderstorm cells of a negative polarity and the ground (symbols A1, A2, A3 show a disposition of the plate antennas relative to the regions of the channel discharge formation)
Experimental results and discussion
Results of the series experimental investigations for the system of the negatively or positively artificial thunderstorm cells have been generalized. A probability of the subsequent stroke appearance has been considered. Experiments have shown that an introduction of the model hydrometeor arrays has significantly increased a probability of the subsequent discharge formation for the artificial charged cells of both polarities. For these cases, the characteristic discharge current impulses and the corresponding electromagnetic radiation registered by the antennas have been shown in Figure 3 and in Figure 4, for negative and positive artificial thunderstorm cells correspondingly.

Figure 3. Oscillograms of the current (curve 1, shunt of 0.5 Ohm) and the signals registered by the antennas A1-A3 (curves 2-4) for negatively charged artificial thunderstorm cells.

Figure 4. Oscillograms of the current (curve 1, shunt of 0.5 Ohm) and the signals registered by the antennas A1-A3 (curves 2-4) for positively charged artificial thunderstorm cells.

The following parameters of the first and subsequent impulses of a discharge current have been under consideration: the impulse current amplitudes, the velocities of impulse current rise, the impulse current durations. The following parameters of the impulses of a corresponding
electromagnetic radiation registered by the antennas have been under consideration: the signal amplitudes, the impulse durations.

Impulses of the electromagnetic radiation registered by the antennas during the first and subsequent strokes from the system of the artificial thunderstorm cells of the negative and positive polarity had the forms of the very high frequency oscillations and were partly similar on the signals registered of the natural downward lightning [2, 8, 9].

Generalization of the experimental results for the case of the negatively charged artificial thunderstorm cells has shown that the impulse current amplitudes and durations and the corresponding durations and amplitudes of the impulses of an electromagnetic radiation for the first stroke were in average in 1.7-3.5 times more than the same parameters for the second stroke from the charged clouds. These results correlate with the results of the similar observation on the natural lightning in Florida [10]. For the case of the positively charged artificial thunderstorm cells, the opposite tendency has been established. The values of the parameters of the subsequent strokes were in 1.25-1.45 times more than the analogues parameters for the first strokes.

Dependencies between the parameters of the impulse currents of the return stroke and the characteristics of the impulses of the corresponding electromagnetic radiation registered by the antennas have been established. In particular, the clear dependence between the impulse amplitudes of a discharge current and the maximal values of the electromagnetic radiation impulse amplitudes registered by the antennas has been observed for the both systems of the negative or positive artificial thunderstorm cells (Figure 5 and Figure 6).

Pronounced correlation between the impulse amplitudes of an electromagnetic radiation and the velocities of impulse current rise for the first and subsequent return strokes has been observed too (Figure 7 and Figure 8).

![Figure 5](image)

**Figure 5.** The dependence of the amplitude of the signals of the antennas A1-A3 on the amplitude of the current pulse of the first discharge
Figure 6. The dependence of the amplitude of the signals of the antennas A1-A3 on the amplitude of the current pulse of the subsequent discharge.

Figure 7. The dependence of the amplitude of the signals of the antennas A1-A3 on the steepness of the current pulse of the first discharge.
Figure 8. The dependence of the amplitude of the signals of the antennas A1-A3 on the steepness of the current pulse of the subsequent discharge

Experimental results have shown the contradictory influence of the place in the system of the artificial thunderstorm cells where the model hydrometeor array have been introduced of the characteristics of the discharges and its electromagnetic radiation. As for the first strokes between the artificial thunderstorm cells and the ground, the impulses of the electromagnetic radiation registered by the antennas had the enough close values out of dependence of a position of the model hydrometeor arrays. At the same time, when the hydrometeor arrays have been disposed near the bottom boundaries of the bottom charged cell the impulse current amplitudes and the maximal values of the electromagnetic radiation impulse amplitudes registered by the antennas for the first stroke were on 10-20 % higher.

As for subsequent strokes, the impulse current amplitudes of the discharges passing through the model hydrometeors disposed between the artificial thunderstorm cells of the same polarity exceed on 20 % the impulse current amplitudes of the discharges passing through the model hydrometeors disposed near the bottom boundaries of the bottom charged cell. Possible such results could connect with the following. When the model hydrometeor arrays dispose between the artificial thunderstorm cells in the most cases such hydrometeors provide the conductive channel between the cells supporting the discharging of the upper cell forming the subsequent stroke. At the same time, the maximal values of the electromagnetic radiation impulse amplitudes registered by the antennas for the subsequent strokes were in 1.7-5.5 times higher.

Experimental results have shown the influence of the quantity of the model hydrometeor arrays of the characteristics of the first and subsequent strokes. When a single array of the model hydrometeor has been disposed near the bottom boundaries of the bottom cell the impulse current amplitudes of the first and subsequent strokes were on 30 % higher in comparison with case of two model hydrometeor array application. A similar picture has been observed for an electromagnetic radiation of the first and subsequent strokes too.

Summary
Experimental investigations of the influence of the model hydrometeor arrays on the channel discharges appearance between the system of the artificial thunderstorm cells of a negative or positive polarity and the ground have shown the significantly increase of the probability of the subsequent stroke formation. It was established that parameters of the impulses of the electromagnetic radiation registered by the wideband plate antennas for the first and subsequent return strokes differ for the cases of the negative and positive charged cells. For negative artificial thunderstorm cells, practically all parameters of the electromagnetic radiation impulses corresponding to the first stroke had more higher values than for the subsequent stroke. At the same time, the opposite picture has been established for positive artificial thunderstorm cells. However, dependencies between the characteristics of the current impulse of the first and subsequent return strokes from the system of the negative and positive artificial thunderstorm cells and the parameters of the impulses of the corresponding electromagnetic radiation have as whole a similar character.

The reported research has fulfilled due to the grant of the Russian Science Foundation (project No. 16-19-00160) and fellowship president grants (projects No. 2173.2019.1 and 2022.2019.1).

References

[1] Rakov V A 2013 Electromagnetic Methods of Lightning Detection (Surveys in Geophysics) 34-4.
[2] Betz H D, Schumann U, Laroche P 2009 Lightning: Principles, Instruments and Applications (Review of Modern Lightning Research. Springer, Dordrecht).
[3] Nag A, Murphy M J, Schulz W, Cummins K L 2015 Lightning location systems: Insights on characteristics and validation technique (Earth and Space Science) 2 65-93.
[4] Changnon S A 1992 Temporal and spatial relations between hail and lightning (Journal of Applied Meteorology) 31-6 587-604.
[5] Wapler K 2017 The life-cycle of hailstorms: Lightning, radar reflectivity and rotation characteristics (Atmospheric Research) 193 60-72.
[6] Temnikov A G 2012 Using of artificial clouds of charged water aerosol for investigations of physics of lightning and lightning protection (IEEE Conference Publications: Lightning Protection (ICLP), 2012 International Conference). DOI: 10.1109/ICLP.2012.6344279, 2012.
[7] Temnikov A G, Orlov A V, Bolotov V N, Tkach Y V 2005 Studies of the parameters of a spark discharge between an artificial charged water-aerosol cloud and the ground (Technical Physics) 50-7 868-875.
[8] Sharma S R, Cooray V, Fernando M, Miranda F J 2011 Temporal features of different lightning events revealed from wavelet transform (Journal of Atmospheric and Solar-Terrestrial Physics) 73 507–515.
[9] Zhu Y, Rakov V A, Tran M D, Lu W 2016 A subsequent positive stroke developing in the channel of preceding negative stroke and containing bipolar continuing current (Proceedings of 33rd International Conference on Lightning Protection, Lisbon, Portugal) p. 202.
[10] Hill J D, Mata C T 2016 Close observations of forked and upward-illumination return strokes at the Kennedy Space Center/Cape Canaveral Air Force Station (Proceedings of 33rd International Conference on Lightning Protection, Lisbon, Portugal) p. 283.