Test of the image converter cameras complex for research of discharges in long air gaps and lightning

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INTRODUCTION

Tests of image converter cameras (ICC) designed by the BIFO Company [1] were undertaken with the aim of checking a possibility of ICC application for recording from large distances low-luminous structures and structures existing during a short time period such as a hypothetic leader streamer zone and a return discharge corona.

The main ICC elements are as follows: an image converter tube (ICT) with a microchannel plate (MCP) intensifying an electron image and a digital CCD camera. The ICT forms an image of the object to be recorded on its luminescent screen; depending on a mode of ICC operation this image is subjected to a frame sweep or a linear sweep. In case of two MCP a gain coefficient (a ratio of radiation energy at the ICT output to that at its input) can achieve 10^{6} W/W. By means of voltage variation at the MCP, ICTs allow to adjust gain in both static mode and dynamic mode (in a process of sweep). The CCD camera readouts the image from the ICT screen and enters it into a personal computer (PC) for visualization and digital processing. A photosensor (PS) with two identical channels based on PMT controls ICC operation. The first channel comes into action at the very beginning of a discharge and triggers an ICC sweep and the second channel triggers, in the course of recording, a circuit of fast and adjustable by value gain coefficient reset when discharge brightness is so increased that the image at the ICT output may be saturated and may loose brightness gradations. An optical system of each PS channel can be focused to a required height above the earth. It is equipped with a set of horizontal slits of a various width and an adjustable length as well as with a set of different filters. All this in combination with electronic adjustment of a level of coming a channel into action allows to perform spatial, amplitude and spectral selection of input signals.

LONG SPARK RECORD

Tests were carried out in the VEI on the open “GIN 6 MV” stand. A discharge with a length of up to 6 m was excited in rod-plane and rod-rod gaps. Positive and negative polarity voltage pulses with up to 3 MV amplitude with a rise time 15 and 130 µs and a half-drop time 7500 µs were used. The PS and ICC were set at a distance of ~ 90 m from a discharge gap. The first PS channel was directed to the end of an upper rod and came into action from a weak flash of an initial corona. The second channel (which sensitivity was deteriorated by two orders of magnitude with the help of filters) was directed to a discharge base. In a daytime the PS and ICC were equipped with violet filters for decreasing background influence. As a result of these tests there was formed an album of frames for 600 discharges with different modes of photography at night and in a daytime. Thus, with the aid of the K008 camera operated in a single-frame mode with a start delay increasing from discharge to discharge, a high quality picture of negative discharge development in a rod-rod gap was obtained (Fig. 1). The frames demonstrate, in succession, a) an initial corona, b) a leader stage (L- is leader step) with a powerful flash of streamers, c) a pass of the process to a through phase at the expense of positive and negative streamer zones mergence and, finally, d) a meeting of the channels of negative downward and positive upward leaders.

With the aid of three ICC operated simultaneously a full picture of positive discharge development has been obtained. A linear sweep in the FER-14M camera has shown a spatially one-dimensional continuous picture of discharge development; a 9-frame sweep in the K004M camera has shown a two-dimensional picture of spatial-time leader evolution; and one large-format frame in the K008 camera has shown in details a channel structure and a structure of a leader streamer zone. The FER-14M and K004M ICC have demonstrated sure record (in the course of one sweep) of both initial low-luminous leader structures with about one ampere current and a leader pass to a brighter (by ~ 4 orders of magnitude) arc with a current equal to several kiloamperes. In this case high (centimeters) spatial resolution has retained. The results of recording discharges are more fully presented in [2, 3]. In particular, an optical diameter of the leader channel turned out to be unexpectedly large and fluctuating from discharge to discharge (from 10 cm to 20 cm). It was also found that the streamer zone of each separate positive leader is an area in the form of a cone; a vertex angle never exceeds 90 degrees.

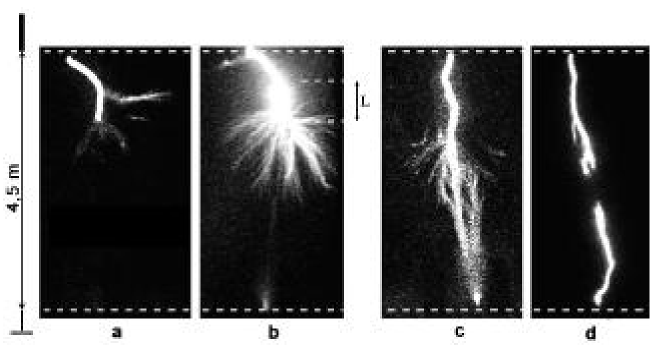

Fig. 1. Development of a negative discharge (-2.2 MV,130/7500 µs) in a rod-rod gap. Frame duration: a, b, c- 2µs; d- 0.5µs.

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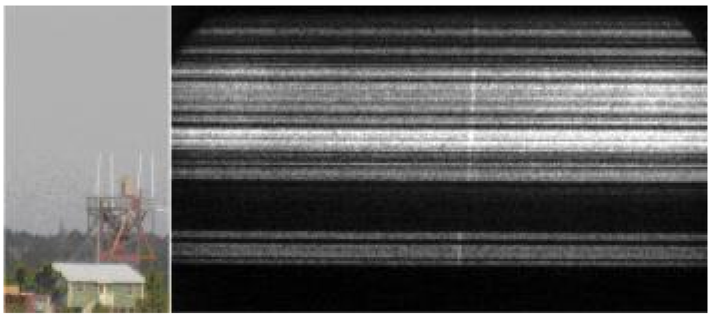
LIGHTNING RECORD

Tests on recording trigger and natural lightning were carried out in a daytime at the Camp Blanding proving ground in Florida [4, 5]. The ICC of K004M and K008 type had a view angle of 10 to 15 degrees and in a lower part of a field of view saw a starting setup (a tower) for launching rockets (it was 475 meters apart from the ICC). The first PS channel was directed to a space area located somewhat higher than the ICC field of view. It was supposed that the PS would generate a pulse for ICC start when this area was intersected by either a downward leader or (if it didn't take place) a bright head of a return discharge going upwards. The second channel was directed to the tower and was to come into action only from a very bright flash of the return discharge.

A. Trigger lightning

Definiteness of a place and time of appearance is an advantage of trigger lightning. Fig. 2 shows a sweep of glow of a rocket wire and a grounding wire (for the unit of launching tubes) exploded under lightning stroke action. It is the beginning of a process of explosion and substitution of the wire with a luminous plasma channel. Therefore, not the full channel glows but only its separate portions. To exclude ICC start from glow of an uninteresting initial lightning phase lasting from the moment of rocket wire explosion to the beginning of a leader-return discharge sequence, the first PS channel output was blocked for a time of ~ 300 ms that somewhat lesser than this phase duration.



a **b**

Fig. 2. a – A view of the tower in the same scale as it is seen by the K004M camera; b - A sweep (full duration is 10.65 μs) of the images of an exploded rocket wire and a grounding wire of the unit of launching tubes. A vertical size of a field of view is 37.5 m.

The K004M ICC in a mode of a linear sweep of ~ 10 μs duration and the K008 ICC in a mode of single-frame of 6 μs duration had a height of the field of view above the tower equal to (15 to 20) m and ~ 80 m, respectively. In Fig. 3 when the PS triggered the K004M camera from a downward leader (the second PS channel was turned off), one could see instant increase in return discharge channel brightness ~ 2.5 μs after the sweep beginning. However, gain that was set in the ICT turned out to be insufficient for recording a low-luminous leader.

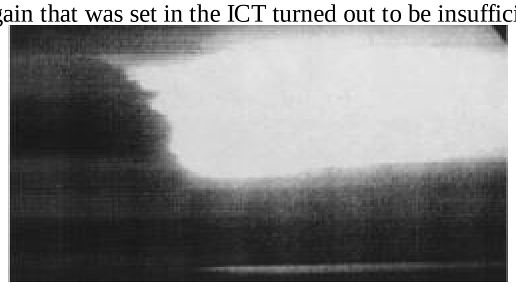


Fig. 3. The K004M camera: a sweep (10.65 μs duration) of the return discharge beginning; a vertical size of a field of view is ~ 20 m

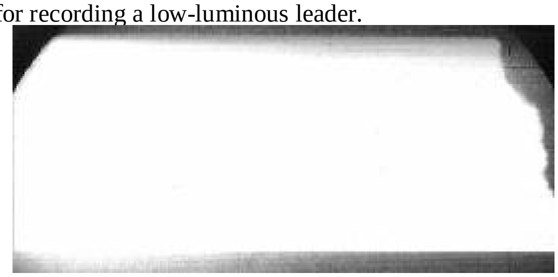


Fig. 4. Image intensification reset at the sweep end (sweep duration is 10.65 μs) where the leader has passed into the return discharge; a vertical size of a field of view is ~ 20 m.

In Fig. 4 when considerably greater gain was set and the K004M camera was also triggered in a leader stage, a spatial leader structure is not seen because the image turned out to be saturated, i.e. without brightness gradations. In return, at the end of a sweep when a return discharge has begun and the second PS channel has come into action, considerable image intensification reset took place, image brightness was sharply decreased; as a result, a channel shape was sharply defined.

In the photo made with the aid of the K008 camera (a vertical lightning size is ~ 80 m), due to insufficient PS sensitivity in this case a leader channel was recorded not at the approach to the tower as it was supposed but when it had already reached it (with a brighter channel of the return discharge superimposed on it). Due to this the image turned out to be saturated, a visible diameter of the channel turned out to be unnaturally great (~ 0.75 m) and, unfortunately, a general view of the photo did not differ from a photo made with the aid of a traditional camera.

B. Natural lightning

In a thunderstorm season of 2005 4 natural lightning that struck the earth in a daytime at a distance of up to 1 km were recorded with the aid of the K004M camera operated in a single-frame mode with frame duration equal to 13.4 μs and ~ 10^4 gain ICC start took place not in the leader stage (sensitivity of the first PS channel with a light filter λ=381 turned out to be insufficient in these cases) but at the beginning of the return discharge. Therefore, the obtained images were created by radiation from lightning processes that took place during 13.4 μs after the return discharge beginning. A picture of lightning discharge (Fig. 5) obtained on the 14th of July 2005 from a distance of ~ 500 m turned out to be most informative. In this case the CCD camera operating in a mode of interlined scanning was so tuned that it had recorded the first semi-frame at the beginning of ICT luminescent screen glow and the second semi-frame somewhat later after essential screen glow fall. In a resultant image one can see a narrow discharge channel (in a delayed semi-frame) and a saturated by brightness "housing" of glow around the discharge channel (in no delayed semi-frame) with sharply defined edges that passes to a smoothly falling glow. In an upper part of Fig. 6 there are shown the profiles of relative glow brightness E in the units of an eight digital ADC at a 17.5 m height above the earth along two neighbor lines (E_1 and E_2 for no delayed and delayed semi-frames, respectively). In the saturated "housing" of a ~ 7 m width with brightness $E_1 \geq 255$ there are no brightness gradations and falling glow is spread by 25 m from the channel converting into optical noise with E ~ 15±5. On the contrary, in the delayed semi-frame E_{2max}~210<255. Therefore, the image is unsaturated and brightness gradations retain even in the center of the discharge channel. It is seen in the brightness profile that at a boundary of a saturated zone, i.e. where E_1=255, E_2 is equal ~50.

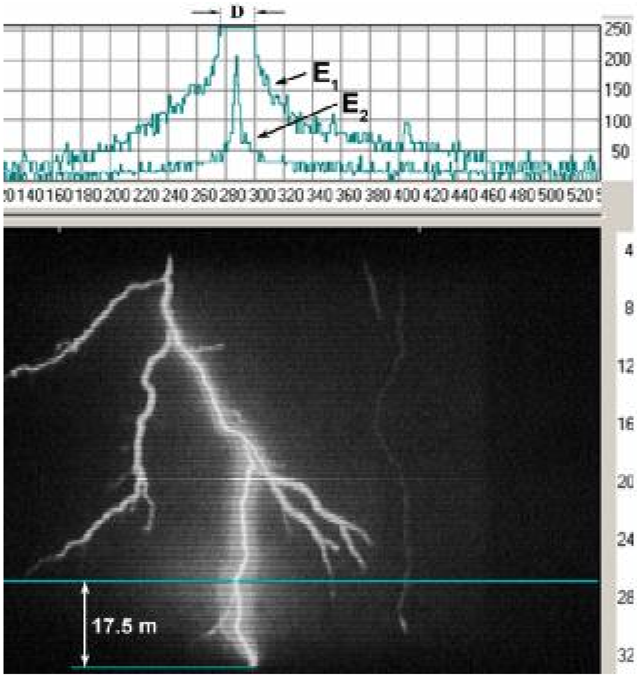


Fig. 5. A natural lightning (at the bottom), a vertical lightning size is ~ 80 m; at the top: profiles of relative image brightness along two neighbor lines of CCD camera.

This means that in the delayed semi-frame discharge image brightness is transferred with attenuation equal to 5. In this case the saturated "housing" is, most likely, caused by excess gain (in the ICC) of light emitted by the channel and scattered in damp air.

An image process with the aid of artificial variations of its brightness, contrast, and a gamma-parameter (Figs. 6, 7) and then reconstruction (Fig. 8) allow to reveal a fine structure of the discharge.

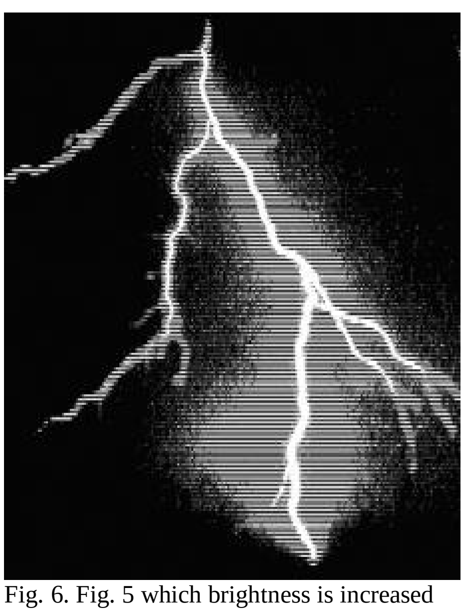


Fig. 6. Fig. 5 which brightness is increased from 50 % to 63 %; contrast is increased from 50 % to 90 %.

Fig. 7. A negative of a channel part from Fig. 6.

Fig. 8. An image of Fig. 7 after its reconstruction.

The leader itself did not fall into exposure but big bright branches and small weak branches created by it were revived by a current of the return discharge and, therefore, they emitted light during exposure. By steep bends of the channel and its large branches it is possible to separate leader's stages; the beginnings of branches coincide with the end of stages. Large branches at stages' ends are distinctly seen in Figs. 5 through 8. Probably, mechanism of branching and mechanism of stages are mutually related. The last large branch from a downward channel lies at a level of ~ 8 m from the earth and a hardly noticeable small branch lies lower by ~ 3 m. This means that a place of a meeting of the channels of downward and opposite leaders (if the latter existed) is lower than (5 to 8) m.

For the first time, there were found weak and short branches (their length was from 1 m to 3 m) around the main channel that were directed not only downwards, in direction of a lightning leader but also in the opposite direction, i.e. upwards. Perhaps, they represent traces of a return discharge corona neutralizing a volume charge of the leader.

The pictures of the next 3 discharges which were took at the day thunderstorm on the 1st of August 2005 basically looks like discharge in Fig. 6. But they are less informative (all images are saturated) because in these cases the CCD camera worked in common mode of operation (without delay of the second semi-frame).

CONCLUSION

The results of experiments presented here confirm great principal capabilities of the ICC but at the same time point to the fact that high-speed lightning record with their help is a much more complicated task in comparison with recording pulsed discharges in long air gaps. A task of synchronizing the moment of coming the camera into action with a lightning leader stage is especially difficult. In most cases sensitivity of the first PS channel that remained the same as in case of carrying out experiments in [2, 3] turned out to be not sufficiently enough for its reliable operation with a 475 m distance from lightning. This distance was by a factor of 5 (and even more) greater than a distance from a discharge gap when the complex of cameras was tested in [2, 3]. Due to this, in case of lightning, without taking account of essential light signal attenuation in water vapors and rain drops its intensity at the input of the first PS channel was at least by a factor of 25 less than that in [2, 3].

In [2, 3] the GIN 6 MV was operated by series with about 2 minutes interval between discharges. At that time more than 1500 discharges were made during a week; most of them were used for PS and ICC adjustment. It is impossible to have the similar number of successful discharges during a thunderstorm season in case of trigger lightning and especially in case of natural lightning. In case of trigger lightning a discharge can be considered to be successful if, firstly, one succeeded in synchronizing with a required discharge stage; secondly, if discharge brightness corresponded to a set gain coefficient and, as a result, the recorded image appeared within a linear dynamic range of the ICC. In case of natural lightning it must fall in the ICC field of view what happens rather seldom. Therefore, a process of collecting necessary statistical materials on lightning record is much more labor-consuming and requires incomparably much time.

As to a possibility of return discharge record with necessary temporal resolution (when a full time of a multi-frame or linear sweep will be equal to units of microseconds or fractions of a microsecond respectively), this possibility is considered to be quite real with existing sensitivity of PS. Reliable synchronization of the ICC with a lightning leader stage is possible if PS sensitivity is essentially increased what is achieved simply by increasing a power supply voltage of the PMT.

If in case of trigger lightning a distance from the ICC to lightning is exactly known, then it is not true in case of natural lightning. In order to measure a distance to natural lightning one should use a timer with a calculator triggered by a pulse of the second PS channel from return discharge radiation and stopped at the moment of arriving a sound wave to a microphone sensor at the place of ICC installation. The calculator must send to the computer the value of a distance to lightning in a digital form. Then it is possible to calculate a scale of photography and to determine actual dimensions of whole lightning or any part of it.

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