

Features of Application of Image Converter Cameras for Research on Lightning and Discharges in Long Air Gaps

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Introduction

The present report generalizes materials of publication /1-3/. In so doing /1/ and /3/ were presented at appropriate symposiums only as poster reports and were not widely discussed.

Creation of reliable physical and engineering models of sequence of leader-return stroke of lightning (L-RS) and a attachment process is hampered by lack of actual information on the optical picture of low-luminous streamer structures of lightning. Cameras based on an image converter tubes (ICT) /4/ serve as an alternative of traditional optical-mechanical means for recording a lightning image. Such cameras allowed to obtain new results when investigating streamer processes of a long spark what made it possible to formulate a set of hypothesizes relating to a leader process of lightning /5-7/.

Here there are given the characteristics of the image converter instrumentation complex adapted to the work with lightning and a long spark and there are presented the results of its tests in the All-Russian Electro-technical Institute (VEI) named after V.I. Lenin when recording a long spark on the open high-voltage stand in Istra (near Moscow).

Instrumentation parameters and modes of its application

The image converter instrumentation complex consisted of three cameras (K004M, K008 and FER-14M) and a special dual-channel photo-sensor PS001 (Fig.1 and Fig.2).

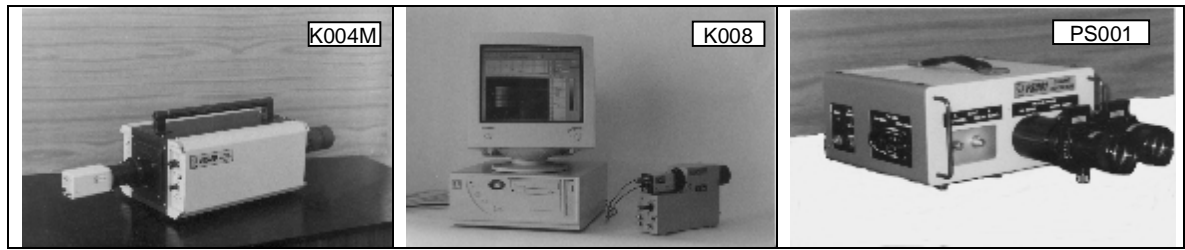


Fig.1. An appearance of K004M and K008 cameras and PS001 photo-sensor.

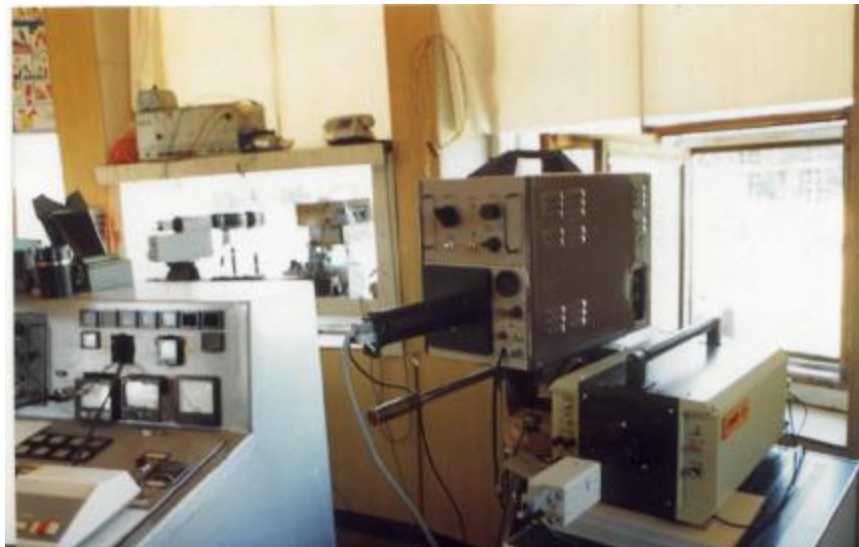


Fig.2. A general view of the image converter instrumentation complex.

Detailed characteristics of the cameras are listed in a table.

Table

1	Camera type	K004M	K008	ФЭП-14М
2	Spectral range, nm	250 ÷ 800	400 ÷ 800	400 ÷ 800
3	ICT photocathode working field, mm x mm	8×8	15×20	8×8
4	ICT screen working field, mm x mm: - for streak mode - for framing mode	35×16 28×28	20×12 15×20	35×16 -
5	Number of micro channel plates (MCP)	2	1	2
6	Conversion coefficient, Wt/Wt	0 ÷ 10 ⁶	0 ÷ 10 ⁴	0 ÷ 10 ⁶
7	Number of CCD TV camera pixels	640×480	640×480	1388×1024
8	Spatial resolution on ICT photocathode, l.p./mm	10	12	15
9	Linear sweep, μs/screen	0,35 ÷ 10 ⁴	2×10 ⁻³ ÷ 0,2 0,2 ÷ 6×10 ²	1,0 ÷ 10 ⁴
10	Single-frame mode, frame duration, μs	0,35 ÷ 10 ⁴	10 ⁻² ÷ 0,2 0,2 ÷ 6×10 ²	-
11	Multi-frame mode, frame duration, μs	0,1 ÷ 10	-	-
12	Inter-frame interval (pause), μs	0,5 ÷ 10 ³	-	-
13	Number of frames	1,2,4,6,9	1	-
14	Mode of image intensification decrease	yes	no	yes

The record was carried out simultaneously with the aid of the three cameras operated in different modes. In this case the K004M camera designed by the BIFO

Company for the University of Florida and intended for recording trigger lightnings was mainly used in a multi-frame mode, the K008 was used in a single-frame mode and the FER-14M camera was used only in a streak mode since it did not have other modes. The FER-14M camera was based on the FER-14 camera that was designed and manufactured in VNIIOFI as long ago as in 1983 /8/. For these experiments a photo-attachment in this old but reliable camera was replaced with an up-to-date CCD TV camera.

The necessity to perform a record simultaneously with the aid of several image converter cameras operated in different modes is due to some circumstances. A framing mode allows to obtain information on the process under study along two spatial coordinates but only in separate discrete time moments. A streak mode allows to obtain only one-dimensional spatial information but continuous in time.

Image brightness of an electrical discharge in long air gaps undergoes a very strong fluctuation as this discharge proceeds (Fig.5a). Therefore, in case of a framing mode short flashes during a streamer-leader stage may fall into interframe intervals (pauses) (Fig. 6b. frame №6). In so doing important information may be completely lost. It will not be lost in case of streak mode. But if in some time moments two or more flashes located near each other occur simultaneously in the discharge gap, then their images may be superimposed in case of the streak mode, and spatial information may be lost or distorted. In case of a simultaneously record with the aid of two cameras one of which is operated in the multi-frame mode and the other is operated in the streak mode the two types of obtained data complement each other and allows to avoid confusion. Besides, a lightning channel or a channel of discharge in a long gap is not a straight as a slit in the streak camera that is oriented perpendicularly to a sweep direction. The channel has a complicated broken form. The channel or its portions may have both a positive and negative projection on the time axis in case of the streak mode. Not having exact information on the channel form (and for the streak mode it remains unknown in most cases) reliable data on a speed of glow propagation cannot be obtained from a processing of a photo-chronogram. Only in combination with the camera operated in the framing mode it is possible to obtain exact information on the channel form and, respectively, reliable data on the glow propagation speed.

The maximum conversion coefficient (image intensification) of the ICT with two MCP is equal to 10^6 W/W. This makes it possible to record the image of the extremely low-luminous streamer stage of discharge. The cameras allow to obtain, during one act of the record, normal images of both the steamer-leader stage of discharge and the stage of subsequent powerful arc discharge (brightness of these stages differ by many orders) due to the fact that the conversion coefficient can be decreased in the process of recording by means of a step-by-step decrease of the voltage at the MCP.

The camera's spatial resolution on the JCT photocathode is not less than 10 l.p./mm. By the number of elements to be resolved in the photocathode working area this is , respectively, 25 times (K004M), ~50 times (FER-14M) AND ~150 times (K008) better than fjr the known instrument ALPS /9,10/ with 16x16 PIN-photo diodes. The possibility of recording in the ultraviolet range is also an

essential advantage of the image converter cameras in comparison with the ALPS instrument.

For cameras control a high-sensitive photo-sensor having two identical channels based on PMT has been designed. Entrance optics allows each channel to be focused, in the vertical plane, to a required area of space. A periscopic device to be inserted in turn into each channel allows performing an aiming focusing of channels. The output PMT signal comes to a comparator with an adjustable level of coming into action and then to a former of output pulses. The photo-sensor's first channel triggers the camera; the second channel triggers in the camera a circuit of decrease in image intensification when brightness of the object to be recorded becomes above critical and an image at the camera exit begins to saturate. A degree of image intensification decrease can be adjusted widely up to full ICT blanking. The sensitivity of photo-sensor's channels is adjusted by both optics (neutral, color, and interference light filters, slits and diaphragms) and electronics (setting of a level of coming a comparator into action). Therefore, spatial, spectral, and amplitude selection of the input photo-sensor signal is possible.

Investigation of a long spark were carried out on a high-voltage stand "GIN 6MV" both at night and in the daytime. An arrangement of the main parts of the "GIN 6MV" is shown in Fig. 3.

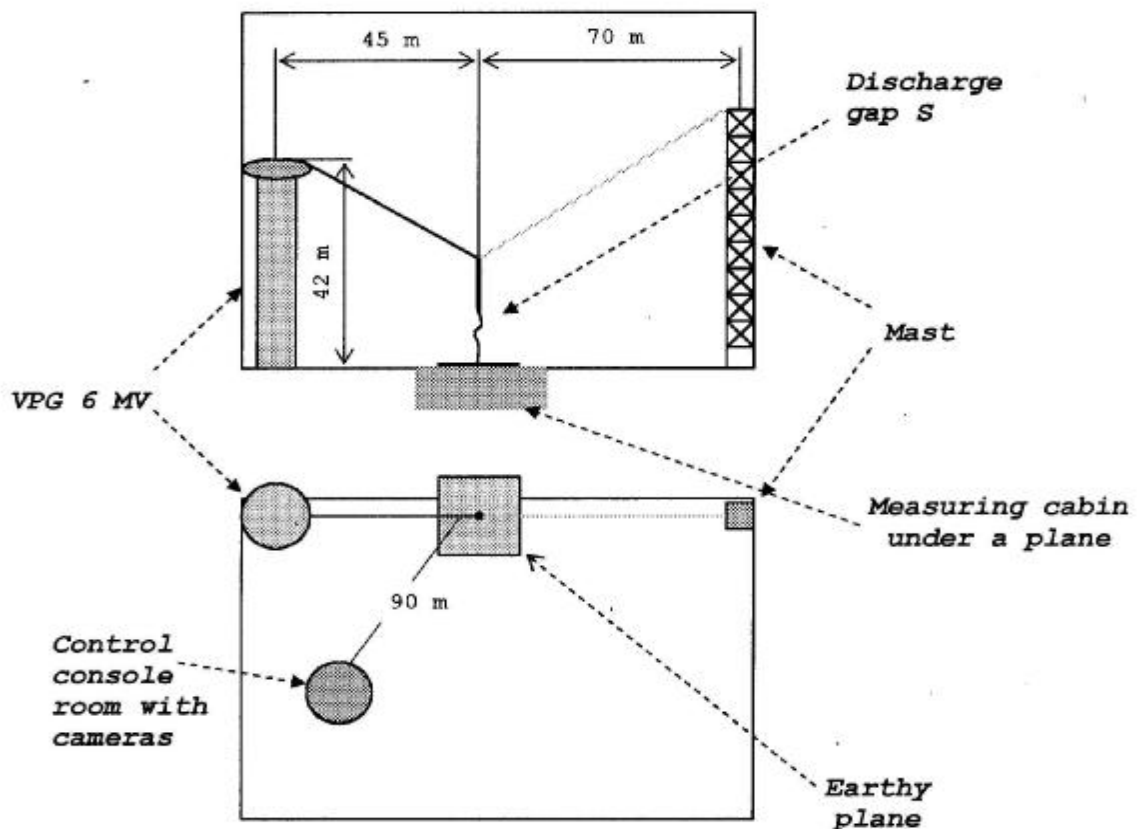


Fig.3. Arrangement of the main parts of the "GIN 6MV"

A spark with a length of up to 6 meters was triggered in the gaps of two configurations; a rod-plane and a rod-rod. In the second case a rod of a ~1m length was set on a plane. Positive and negative polarity voltage pulses with a rise time 15 and 130 μ s and a half-drop time 7500 μ s (± 15 to 130/7500 μ s) were used. Recording

instrumentation complex was set in the control console room at a 90 meters distance from the discharge gap. The cameras were triggered with the help of the photo-sensor only. In the daytime, in order to decrease or to completely exclude the negative influence of a constant light background on instrumentation operation, selection was used: spectral selection for the cameras and spectral and spatial selection for the photo-sensor. Spatial selection consisted following: a field of view of the first channel of the photo-sensor was decreased so that it “saw” only the end of the rod to which a GIN pulse was applied. In conjunction with spectral selection (the use of a interference UV filter), this made it possible to keep the high sensitivity of the channel and to trigger the cameras from a weak flash of the initial corona at the rod end even a bright sunny day.

The results of long spark investigation

Four frames shown in Fig.4 illustrate development of the negative leader during $\sim 20\mu\text{s}$ in the rod-rod gap. They were made with the help of the K008 camera in a single-frame mode of operation. A long focal length ($f=300\text{ mm}$) objective lens and an interference violet filter ($\lambda=413\text{ nm}$) were used. The frames pertain to different discharges. But at the expense of consecutive increase in a delay of triggering a kind of a time scanning of the leader process was obtained. The frames demonstrate the following pictures: (a): the channel and negative streamers at the beginning of the leader; (b): a step “ l ” of the negative leader with a powerful flash of streamers; (c): a pass of the process to a trough streamer phase due to a junction of negative and positive streamer zones; (d): a meeting of the channels of a downward negative and upward positive leaders.

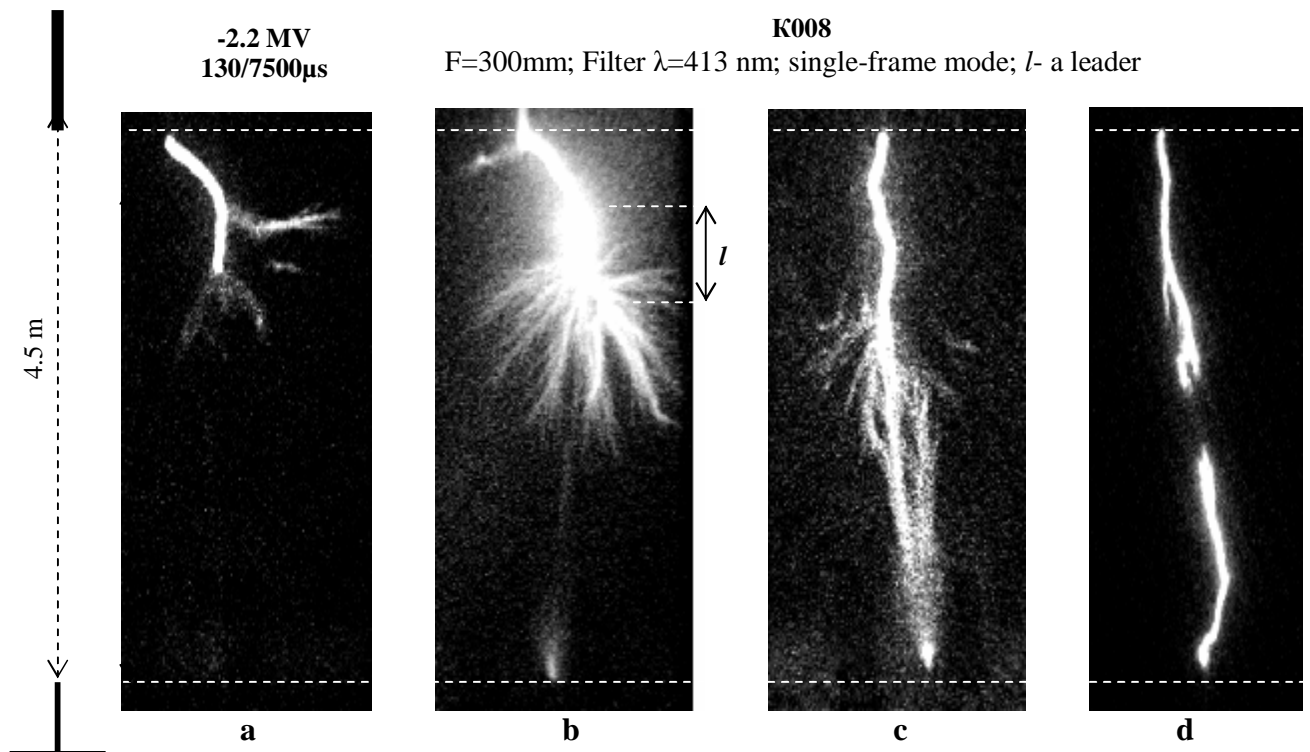


Fig.4. Development of negative discharge in the rod-rod gap. Day photos (positive). Frame duration: a, b, c- $2\mu\text{s}$; d- $0.5\mu\text{s}$.

The positive leader was also recorded. It should be noted that positive leader in a long air gap with a sharply nonuniform field was investigated in many laboratories. It is connected with the fact that the most low electric strength is observed just in such gaps. For example, both electric characteristics of such gaps and a linear sweeps in time of the optic pictures have been investigated in detail in /11-14/. However the image of the same discharge has not been recorded simultaneously in both streak and framing modes.

Fig.5 shows a picture of positive discharge in the rod-to-plane gap obtained with the aid of three cameras that were operated synchronously. The FER-14M camera recorded in a streak mode a continuous picture of discharge development beginning from the corona and finishing with the arc. The K004M camera gave a 9-frame picture of discharge development, in particular, evolution of the streamer zone till the beginning of the arc. The 9th frame was obtained over illuminated since a degree of decreasing image intensification that was set for the arc stage of discharge turned out to be insufficient. The K008 camera gave one large-format frame obtained 110 μ s after the FER-14M and K004M cameras were triggered. It corresponds to the 8th frame of the K004M camera. Let us note that before passing to the arc stage, the leader develops at a current ~ 1 A and a shines very weakly. Nevertheless, its channel and the streamer zone are well recorded with the aid of the three cameras even from a distance of 90 meters.

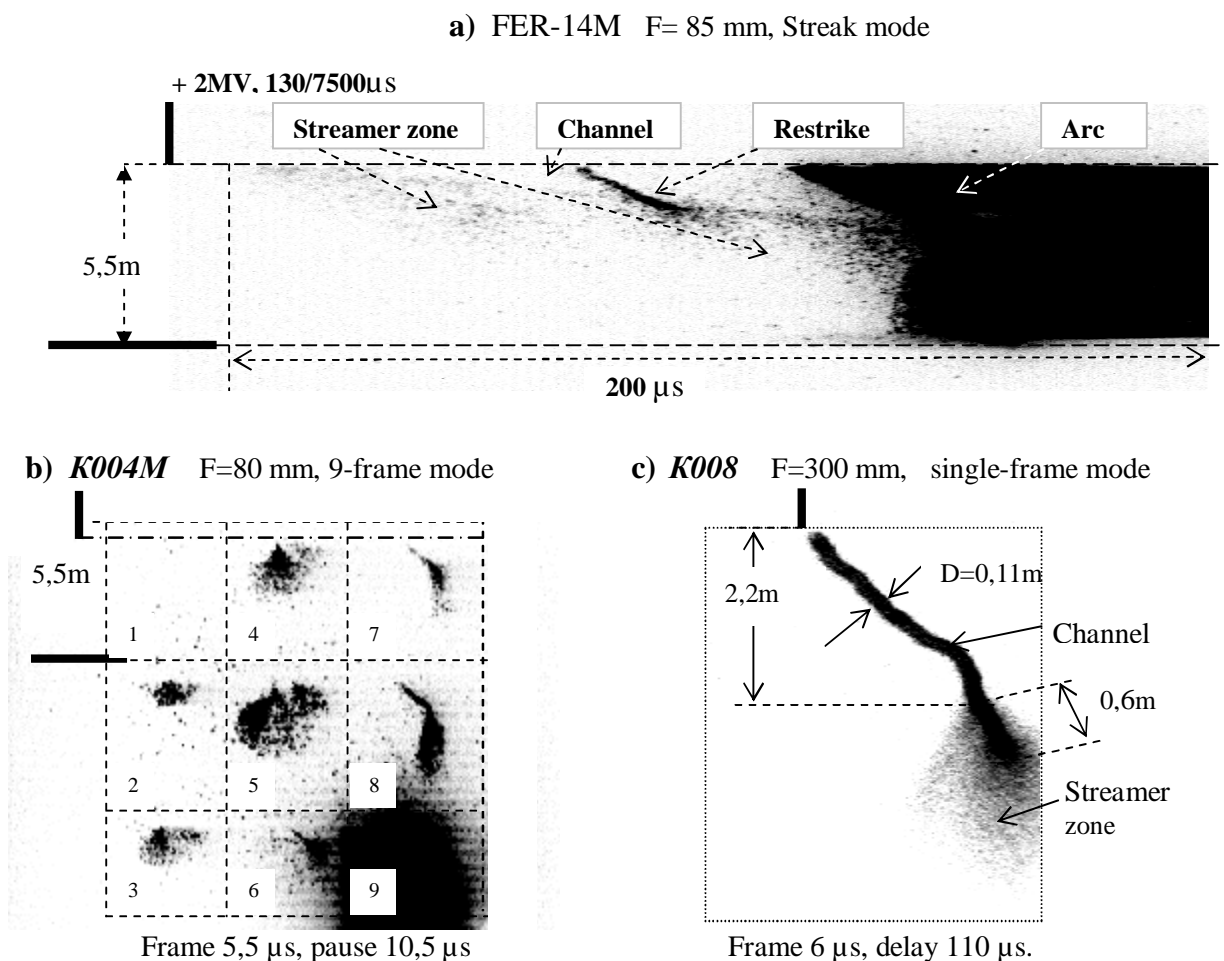
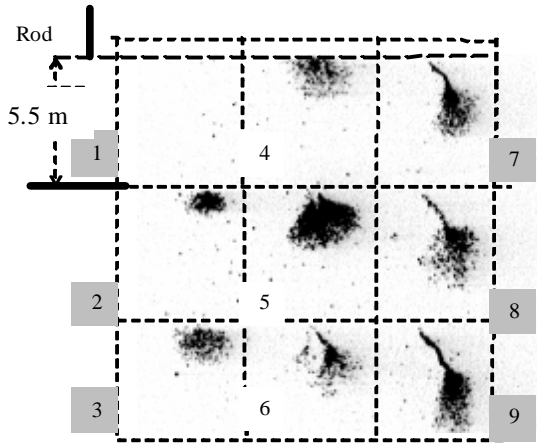
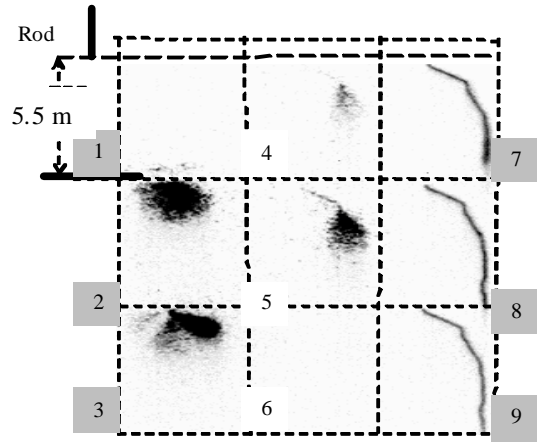


Fig.5. Synchronous photos (negative) of positive leader development in the rod-to-plane gap obtained for the same discharge with the aid of three cameras.

Fig.6 gives typical pictures of positive discharge in various stages. In this case frames 7-9b recorded the arc stage of discharge without image over illumination.



a) Frame $5\mu\text{s}$, pause $8\mu\text{s}$.



b) Frame $8\mu\text{s}$, pause $15\mu\text{s}$

Fig.6. The K004M camera: typical picture (negative) of positive discharge development with a voltage pulse $+U=2\text{MV}$, $130/7500\mu\text{s}$.

Typical picture (positive) of positive leader development obtained in a large-format with the aid of the K008 camera are given in Fig.7.

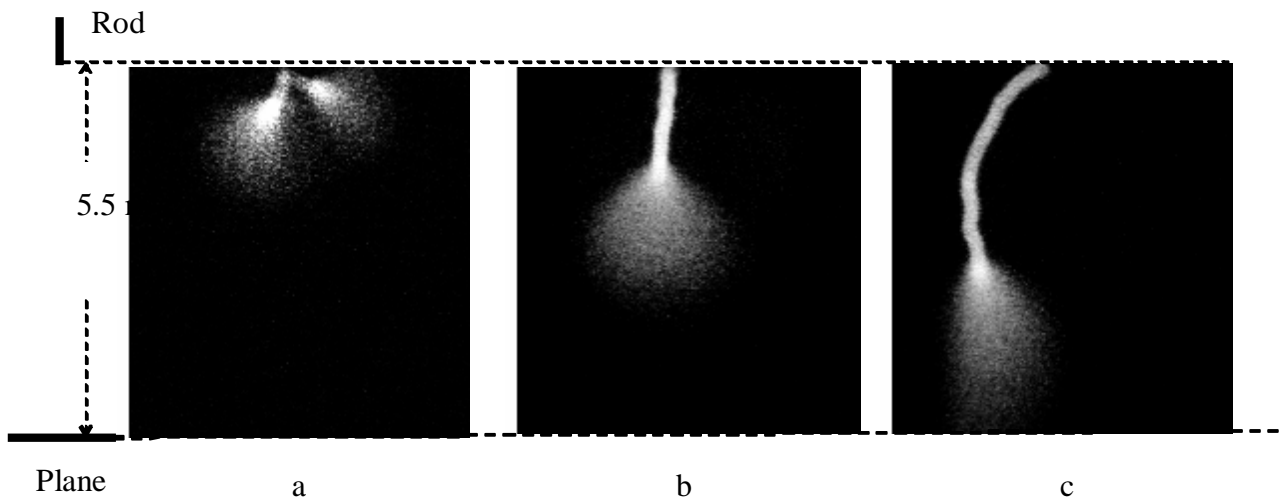


Fig.7. The K008 camera: typical picture of positive leader development with a voltage pulse $+U=2\text{MV}$, $130/7500\mu\text{s}$ (positive image, $6\mu\text{s}$ frame duration). The photos refer to different discharges: a) the beginning, b) the middle, c) the end of the leader stage.

Processing of a collection of such frames shows that at the beginning of the stable development of the positive leader a length of its streamer zone is $\sim 1.5\text{m}$, in

the middle of the gap it is ~2m, at the end of the gap it is ~2.5m. These data correspond to those obtained in /11/.

It should be noted that in photos made with the aid of the K004M camera (Fig.5b and Fig.6) the streamer zone at the beginning of leader movement looks like a conic area with an angle at the vertex of about 180° . However photos with a higher spatial resolution obtained with the aid of the K008 camera (Fig.5c and Fig.7) show that this is due to spatial superposition of the streamer zones of two or more simultaneously developing leader channels which are taken as a single streamer zone because the spatial resolution is insufficient. These measurements allow to confirm that the streamer zone of a separate positive leader channel during all time of its movement in the gap has a conic form with an angle at a vertex being always less than 90° .

In Fig. 5a and 5c an acceleration of leader channel movement in the middle of the gap is fixed. In Fig. 5c the increase in the channel length is ~0.6m for a period of $6\mu\text{s}$. In this case an average speed of channel movement on this portion can be estimated by the value not less than 10^5m/s .

It should be particularly noted that with the aid of the K008 /15/ camera a very sharp optical picture of the positive leader channel with a high spatial resolution (Fig.5c and Fig.7) was successfully obtained. This, in particular, allowed to measure an optical diameter of the channel which turned out to be unexpectedly large and fluctuating from discharge to discharge from 10cm to 20cm.

Deductions

The following deductions can be made on the results of performed experiments.

1. An optical picture of positive leader development in the investigated gap is practically the same for the pulses with a rise time $15\mu\text{s}$ and $130\mu\text{s}$.
2. The streamer zone of every separate positive leader represents an area in the form of a cone; an angle at a cone vertex never exceeds 90° .
3. The optical diameter of the positive leader throughout the gap length is practically the same, lies in the range 10-20cm and fluctuates from discharge to discharge. In this case leader channel brightness does not strongly differ from brightness of the middle part of its streamer zone.
4. Fast variations of the length of the positive leader channel occurring with a velocity not less than 10^5m/s were fixed in the course of positive leader movement.
5. Regularities of negative leader development are more complicated than those of positive leader development and require separate thorough investigation.

Conclusion

A mode of using simultaneously three cameras for recording a lightning similar to that depicted in Fig.5 is considered to be preferable. When recording a natural lightning, a problem will be "to catch" a spatial window with a required portion and a required time phase of lightning. A situation is

essentially simplified when recording a trigger lightning for which a bottom part of the channel is rigidly tied to a certain place and a form of the channel up to a height of several hundred meters is broken essentially less than in case of a natural lightning.

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