Test of Russian K004M image converter camera when recording natural lightning in Florida

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ABSTRACT

The results of K004M camera tests when recording a trigger lightning are presented in paper [1] at this Congress. This report is a continuation of paper [1] and gives the results of demonstration of the camera functioning when recording a short spark in laboratory of the University of Florida (Gainesville, USA) and then a natural lightning in the University and at the International Center for Lightning Research & Testing (ICLRT) in Camp Blanding that belongs to this University. In so doing it has been shown that, except for luck, important conditions of successful record of a natural lightning are exact synchronization of the moment of camera start with a required discharge stage as well as automatic measurement of a distance to lightning and determination of its polarity.

Key words: image converter camera, electrical discharge, streamer, leader, channel, lightning, brightness.

1. INTRODUCTION

The losses caused by lightning all over the world are colossal, sometimes are non-filled in and come to astronomic sums. It is enough to remember a case of failure of energetic network of the East sea coast of the USA and Canada on the 14th of August 2003 when lightning was also among serial equivalent versions of the reason for occurred technogenic catastrophe. At the end of August, this year, a launch of Atlantis space craft was postponed because lightning struck into a system of lightning protection of starting complex for shuttles. Therefore, a study of lightning nature, investigation of its regularities and creation of efficient means of lightning-discharge protection always was and remains an actual necessity.

In case of a trigger (artificially initiated) lightning a place of its action is exactly known. This allows to record, with high spatial and necessary temporal resolution, a process of lightning approach to the object to be injured by it. In case of a natural lightning it is very difficult to do it. Nevertheless, such attempts were undertaken before and are being undertaken up to now. Record of trigger and natural lightning will allow to compare regularities of their development.

2. CAMERA DEMONSTRATION AT “LIGHTNING RESEARCH LABORATORY”

On September 25, 2003 when a thunderstorm season was already over the demonstration of the K008 and K004M cameras and PS001 photosensor also [1-5] was carried out in operation at the “Lightning Research Laboratory” in the University of Florida for its collaborators, post-graduates, and students (Fig. 1).

In this case a spark from an electroshocker in the air of a ~ 30 mm length (Fig. 2) was a object of record.

Streamers of both polarities and also leaders’ channels appearing by electrodes and germinating into the spark gap are well seen on all photos in the first (upper left-hand) frame. When pressing a lever of the bludgeon, as a rule, a series of numerous discharges follows. It turned out that it is not so easy to learn how to press the lever so that to obtain a single discharge. Not quite a successful attempt is shown on photo of Fig. 2b when two discharges occurred and, owing to a

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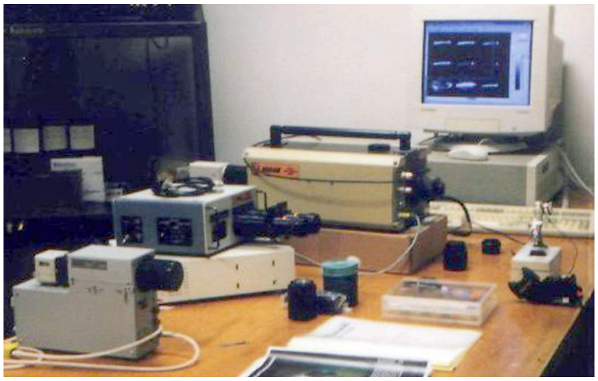


Fig. 1. The demonstration of apparatus. From left to right: K008 camera, PS001 photosensor and K004M camera. The electroshocker lies opposite the photosensor at the right on the brink of the desk.

small interval between them, images of two sweeps fell onto the same frame of the CCD television camera (a frame occupies 40 ms).

Image intensification reset was turned off when two photos are shown in Fig. 2a and b were taken. In this case one can see that, beginning with the second frame when a breakdown happened, a change in time of discharge brightness is of an oscillatory character.

When taking two photos are shown in Fig. 2c and d, image intensification reset happened by a photosensor signal at the beginning of a bright discharge stage in the 2nd frame. In this case it is seen that the second frames on these photos are noticeably less saturated than on photos of Fig. 2 a and b even in spite of the fact that image intensification on the photo of Fig. 2d was essentially increased in order to obtain a brighter image of the initial discharge stage in the first frame. And it

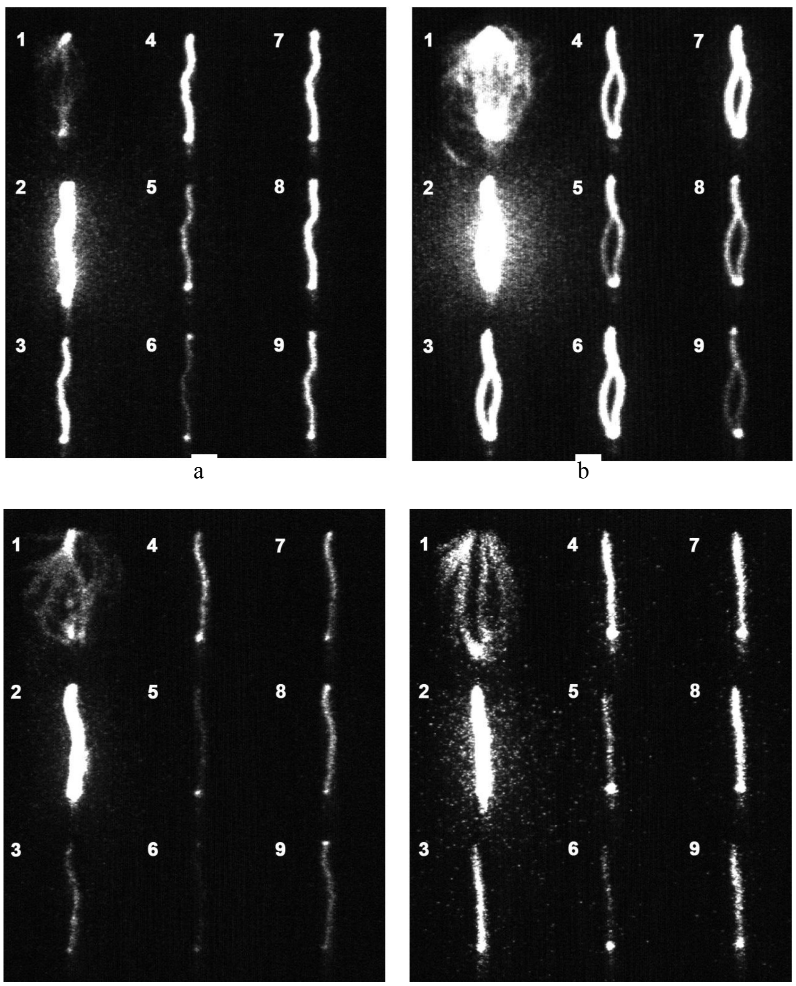


Fig. 2. The K004M camera: 4 photos of a 9-frame sweep of the spark in the air of a ~ 30 mm length (0.1 µs frame duration; 0.5 µs pause duration; frames in columns follow from top to bottom; columns follow from left to right)

was obtained so. Only because of high image intensification (an ICT mode of operation was close to a mode of photon counting) when brightness of image elements consisting of only several dozens of photons converted in several electrons in the ICT almost achieves saturation, an image structure becomes not continuous but point. But here it is nothing to be done; it is a law of nature.

3 photos of a linear sweep of the image of the same spark of a ~ 30 mm length without image intensification reset are shown in Fig. 3; image intensification being increased from photo to photo. On the 3-d picture (3c) one can see how because of high magnification a point structure is appeared evidently. In return, high sensitivity of the camera allowed to measure an average speed of initial process (downward leader) glow that was equal to 6 x 10^7 cm/s).

In Fig. 4 a sweep image is shown with image intensification reset turned on down zero by a photosensor signal. Estimation of speed of response of reset by a brightness profile shows that it is equal to ~ 70 ns.

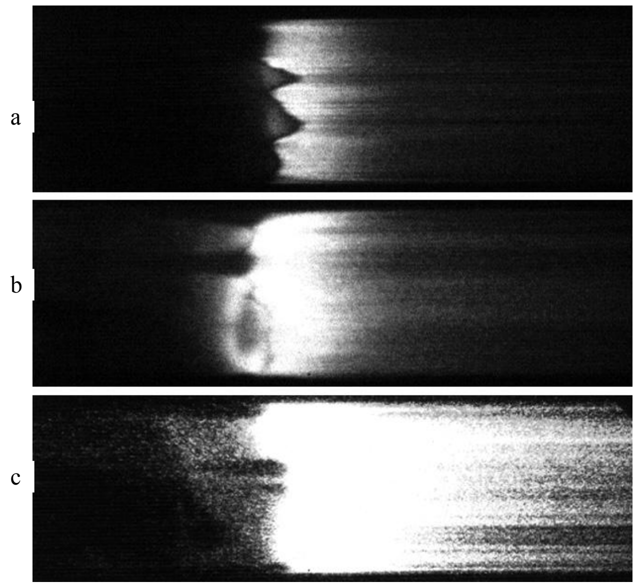


Fig. 3. The K004M camera: linear sweep of a spark in the air (355 ns sweep duration).

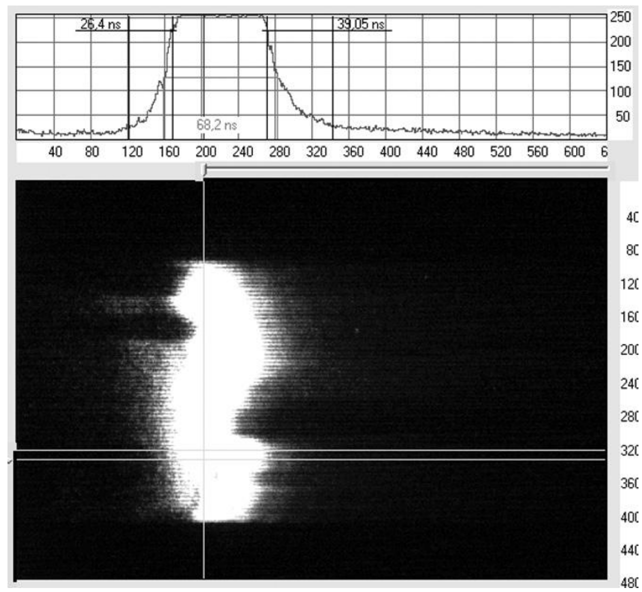


Fig. 4. The K004M camera: a spark sweep with image intensification reset turned on down to zero (355 ns sweep duration, 68 ns delay, 39 ns fall time).

Fig. 5 shows a spark sweep in case of a high input signal of the camera (a diaphragm of the input objective lens was fully opened) and low image intensification. In this case image brightness doesn't achieve saturation but a field of an ICT electronic lens is distorted due to high density of an ICT photocathode current. Depending on a degree of lens field distortion, this results, first of all, in decreasing ICT spatial resolution or (as in case shown in Fig. 5) in both a loss of spatial resolution and strong geometrical and photometrical (wrong transfer of brightness gradations) image distortions. As a rule, the image is compressed as the input signal increase above a critical value, and it restores its undistorted dimensions as the input signal decreases.

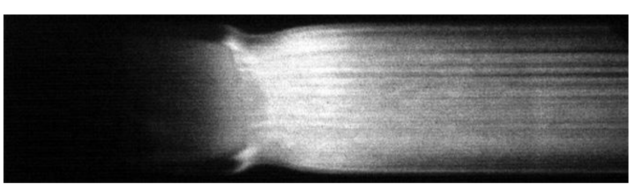


Fig. 5. The K004M camera: spark image distortions (compression) in case of ICT photocathode overload with a high input signal (355 ns sweep duration).

A procedure of checking input signal intensity with respect to the critical value is given in operating instructions for the camera. To do this, a test-object in the form of a slit or a frame (two-dimensional) test-object (depending on a sweep type) must be set at the ICT input and must be illuminated, during a sweep, with the image of the object to be recorded. If in this case spatial resolution complies with Documentation data, then there is no ICT photocatode overload with the input signal (see Figs. 6 and 7). Fig. 7 shows also image intensification reset during a slit test-object sweep.

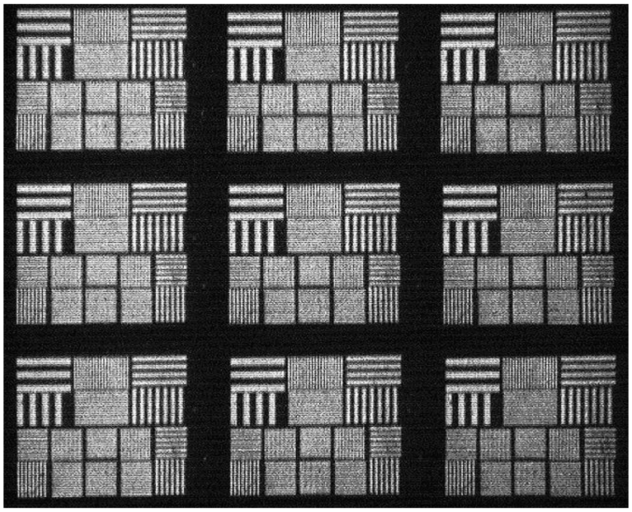


Fig. 6. The K004M camera: a 9-frame sweep of a test-object without ICT overload.

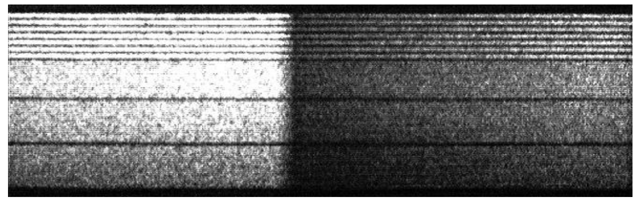


Fig. 7. The K004M camera: a sweep of a slit test-object without ICT overload and image intensification reset in the process of sweeping a slit test-object image (355 ns sweep duration).

Images of the same spark of a ~ 30 mm length obtained with the aid of the K008 camera [2] are shown on the next photos (Figs. 8 through 10).

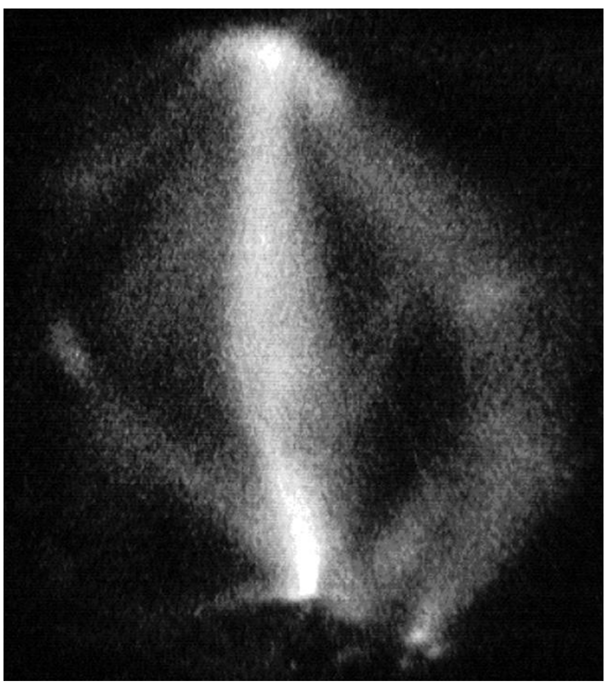


Fig. 8. The K008 camera (single-frame mode): streamers and almost formed through channel of a ~ 30 mm length at the moment just before the beginning of the most bright discharge stage (0.2 μs frame duration)

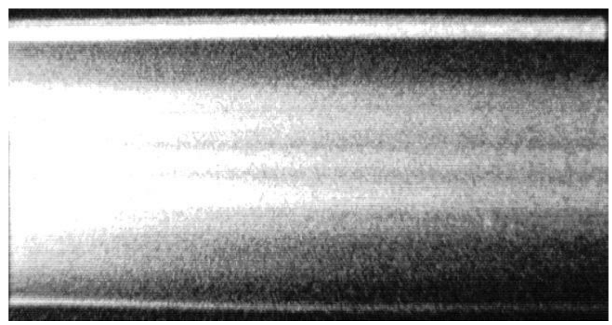


Fig. 9. The K008 camera: relaxation of the first bright discharge flash (0.2 μs sweep duration). The glow of near-electrode's regions of charge one can see above and below of picture.

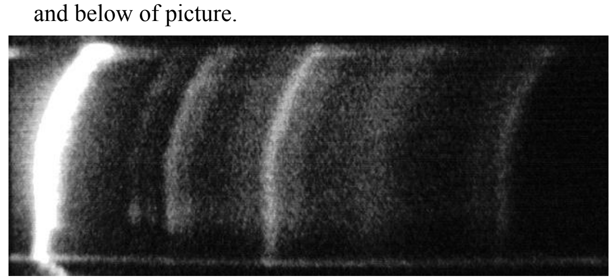
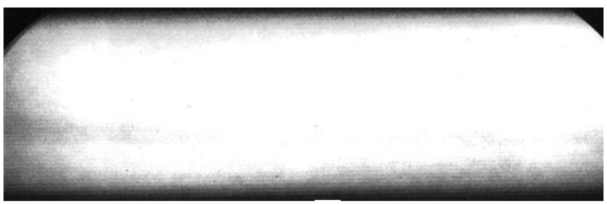


Fig. 10. The K008 camera: an oscillatory character of discharge channel brightness change (6 μs sweep duration).

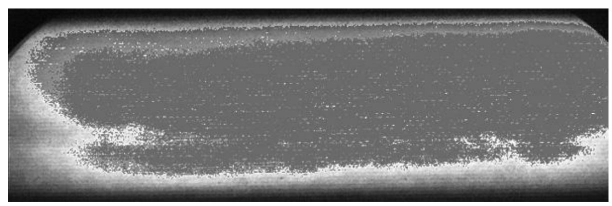
3. RECORD OF NATURAL LIGHTNING

3.1. Streak mode

On completion of the above-described demonstration a rare for this season thunderstorm broke out unexpectedly that lasted about a hour. The K004M camera with the photosensor [1] were urgently lifted to a roof of the building into a glass observatory where about 30 photos of a linear sweep of natural lightning images were made; on 20 photos of them some glow was present. In this case a MIR-10A wide-angle objective lens (a 75 degrees angle of a field of view) was used at the camera entrance; it was intended specially for photography of large-size objects. Sweep duration was equal to 1065 us. Practically none of the photos turned out to be informative enough, i.e. more or less intelligible in spite of the fact that the photosensor that was aimed exactly to the same potion as the camera did, properly reacted to every flash by its starting channel and sometimes by its second channel according to a signal of which image intensification reset took place in the camera in the process of a sweep. The photos in their majority are monotonous, strongly over illuminated (half0tones are almost not seen although initial image brightness and a degree of its reset were adjusted) and represent a sweep of the ICT photocathode uniformly illuminated. Only on several photos (see Figs 11 and 12; a scale along the vertical is the same) images contours are seen. They show through more clearly (see Fig. 11b) when pseudocoloring equal-bright zones of these images.



a



b

Fig. 11. The K004M camera: a – a sweep (1065 μs duration) of natural lightning; b – the same when pseudocoloring equal-bright zones.

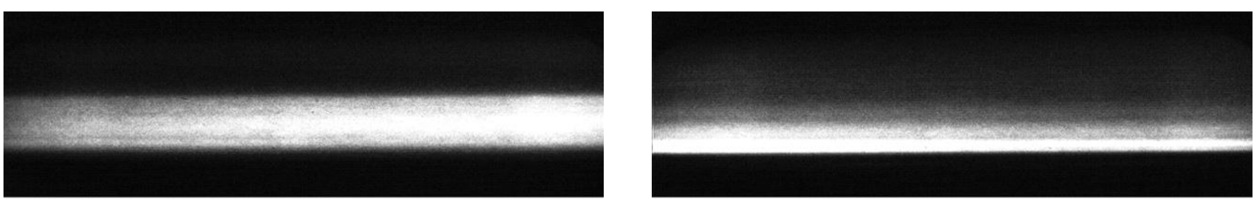


Fig. 12. The K004M camera: a sweep (1065 μs duration) of two natural lightning which channels were oriented almost horizontally.

And only on one photo a white field of a sweep at its end has an oblique (from left to right and from bottom to top) broken cut sharply passing into a dark field (Fig. 13). This time image intensification reset came into action not down to zero; as a result, a lightning channel shape turned out to be recorded at a boundary of white and black fields at the moment of the return stroke beginning.

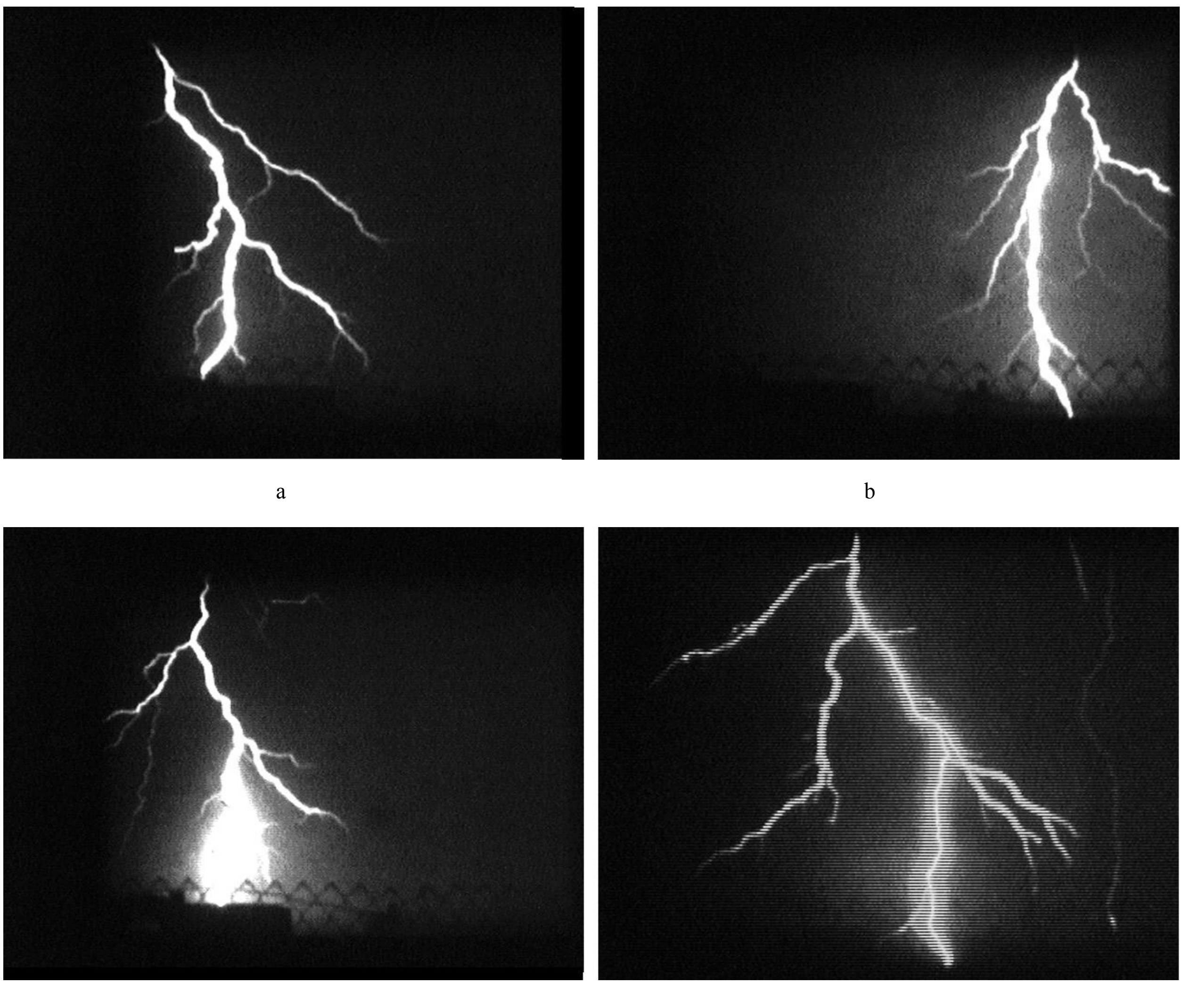
Fig. 13. The K004M camera: a sweep (1065 μs duration) of natural lightning with reset of ICT image intensification at the end of sweep.

The reason for a failure of majority of photos apparently consisted in the fact that sensitivity of the second photosensor channel controlling the moment of image intensification reset was strongly deteriorated with filters. Therefore, image intensification reset did not work in all cases except for one case shown in Fig. 13, and the bright lightning stage, figuratively saying, “flooded” the image on the full sweep. Since the image of the leader stage is also illuminated on the above-mentioned photo, it means that camera sensitivity has been too high and it was to be decreased not only by reducing the initial voltage at the ICT MCP but also by setting light filters or a diaphragm at the input objective lens in order to exclude possible negative effects related to photocathode overload with a high input signal. However in that emergency situation it has not been done because it was the first attempt of natural lightning recording with help of this apparatus.

Since decoding of linear sweeps of natural lightning images is considered to be much more complicated in comparison with a series of photos of framing photography, then it is better to begin the accumulating of experience in recording just from a multiframe mode of sweep.

3.2. Single frame mode

During preparation for recording trigger lightning while correction of camera focusing to the launching tower was being performed (the camera was switched to a single-frame mode in this case) a several natural lightning discharges happened; they were recorded by the camera (Fig. 14).



a b c d

Fig. 14. The pictures of natural lightning of the 2005 thunderstorm season (13,4 μs frame duration, ~ 80 m visible vertical size of lightning).

The pictures are framed (centered) so that slightly visible a shady image of launching tower is on them at the same place (underneath a little bit righter from the middle of each frame). At all pictures were registered the final stage of discharge – return stroke. At Fig. 14a, b, and d one can see that near very ground the width of glow zone around the main leader reached the ground sharply decreased. At Fig. 14c this effect is less visible because of extremely high brightness of lightning flash.
The branching of the main leader almost up to the ground one can see also at all pictures. At that it is possible to say that in most cases the branches are coming out from the places of breaking of leader trajectory. At picture 14d the last two branches are only at distance 15,1 and 7,8 m from the ground. Appearance of the last picture at Fig. 14d is different from the first three so that one can see there both discharge channel of the main leader and the glow around it. In this case TV camera recording the image from the ICT screen and operating in a mode of interlined scanning was tuned so that it recorded the first semi-frame at the beginning of the glow of luminescent screen and the second semi-frame later at the end of screen glow. At that brightness of the image recorded in the first semi-frame turned out so high that 8 bit ADC of readout unit was overfilled and by this reason the image with brightness $E \geq 255$ turned out to be saturated, i.e. gradations of brightness disappeared in it.
Outside a zone of the saturated image, brightness of surrounding glow fluently decreases on a measure of recession from this zone. Brightness of the image recorded in the second semi-frame turned out to be normal, i.e. within limits of ACD dynamic range. That is why in this semi-frame one can see a discharge channel and surrounding glow brightness of which fluently decreases on a measure of recession from the channel. As a result of superposition (addition) of semi-frames a zone with brightness $E \geq 255$ is sensed as a cover with well-defined contour around the channels recorded in the second semi-frame.
The reason of glow surrounded the channel may be as the simple light scattering at the vapors and drops of water and also more complex processes connected with high strength of electric field around the channel.
In Fig. 15 the same picture of Fig. 14 is presented but after artificial increasing its brightness and contrast. At that the channel of the left down leader also surrounded by cover became visible.

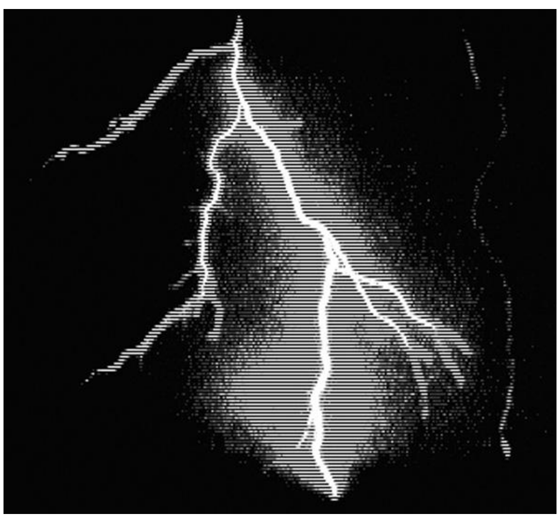


Fig. 15. Processed Fig. 14 (brightness was increased from50 % up to 63 %; contrast was increased from 50 % up to 90 %).

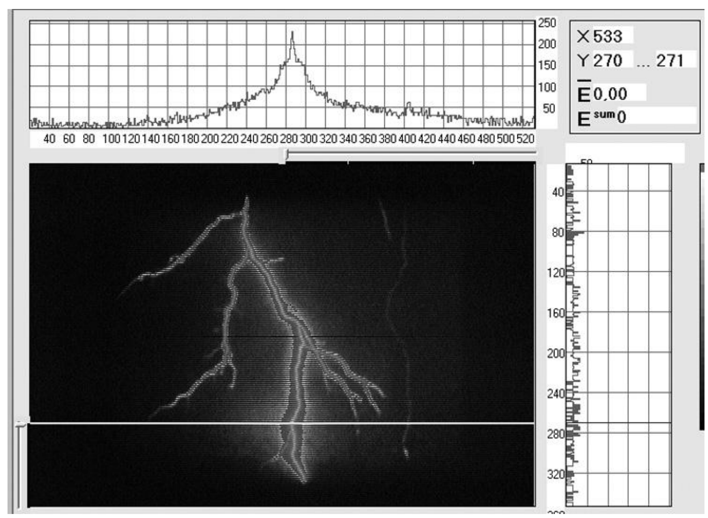


Fig. 16. A profile of the channel and its cover in the widest place of cover. Pseudocoloring equal-bright zones was used for better visual sense of cover contour.

In Fig. 16 a profile of the channel of main leader and its cover are shown at most wide place of a cover. The profile was plotted with averaging brightness E by two neighbor lines (Y = 270…271).
In Fig. 17 it is shown a profile of the channel of main leader and real position of the field of view (17 m x 200 m in the plane of lightning on the height of 128 m) of photosensor.

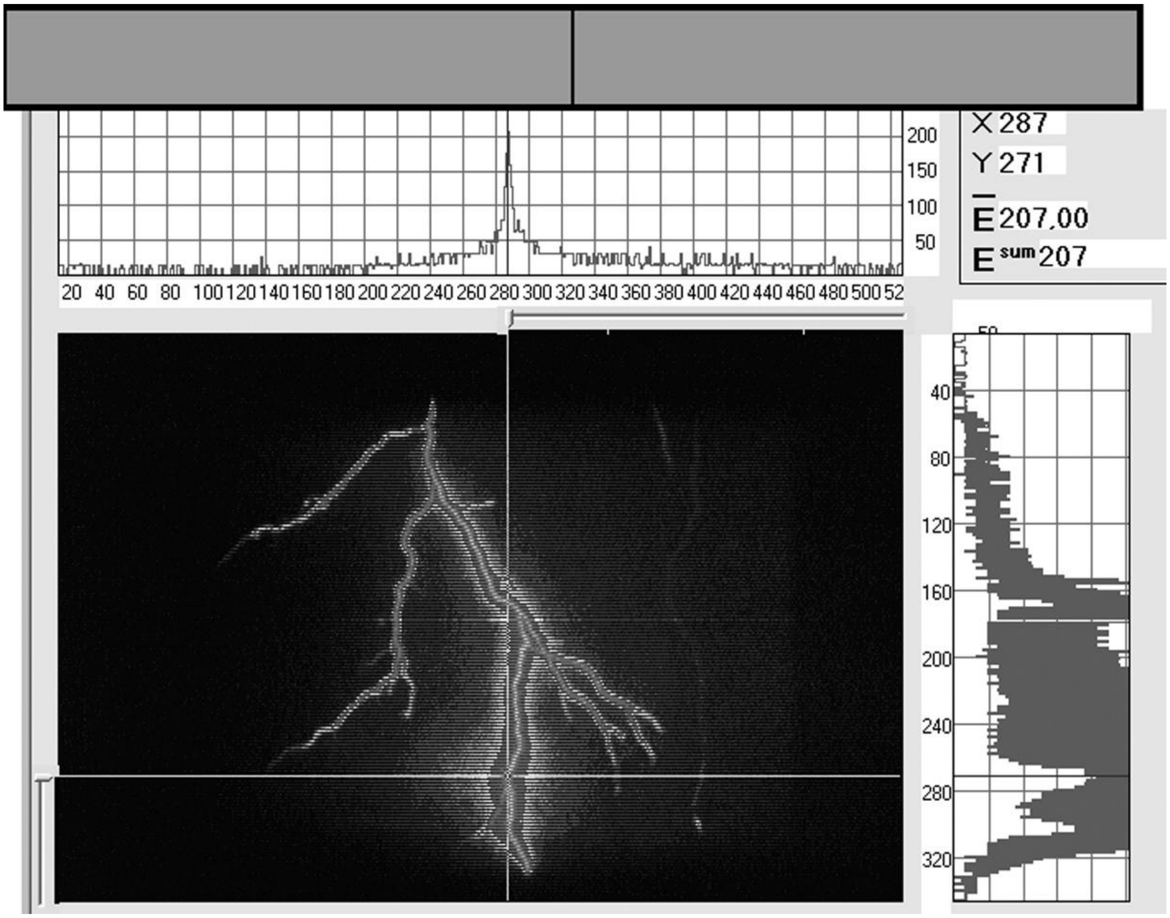


Fig. 17. The profile of the channel of main leader when scanning of image by one line in the second semi-frame at the same place as in Fig. 16. Pseudocoloring equal-bright zones was used for better visual sense of cover contour.

A diameter of the cover in its widest place was equal 7 m and a channel diameter seen by the camera was equal 1.68 m that is near the limit of camera spatial resolution in the plane of the object (lightning) to be recorded. The brightness of glow surrounded the channel is 9 times less than the channel brightness at this place at a distance of 3.6 m from a channel centre.

In Fig. 15 with increased brightness and contrast one can see that diameter of central leader and diameter its cover decrease on a measure of recession from the ground. Perhaps, it is connect with corresponding changing the channel brightness. The results of measuring the diameter of channel and its relative brightness E at different high h from ground level (for which a bottom end of lightning image is taken) are presented in Table 1.

Table. 1

h [м]	0	1,1	1,7	9	17,4	25,8	34,2	42,6	51	59,4	67,8	76,2
E	31	138	160	207	208	207	191	176	176	175	159	111
d[м]	-	1,12	1,12	1,68	1,68	1,12	1,4	-	1,68	1,68	1,4	1,12

One can see from the table that brightness E is increased sharply (almost 7 times) from the beginning up to h ~ 17 m and than up to h ~ 80 m is decreased slowly almost 2 times.

As to channel diameter it is difficult to see some tendency because the diameter's data oscillated by accidental way in limits of 2 CCD TV camera pixel (this is 0.28 m) between 1.12 and 1.68 m but in Fig. 15 with at one's own choosing brightness and contrast one can see that a diameter increase from the beginning up to h ~ 15 m (up to next to last branching) but then almost not changing up to h ~ 40 m (this is the middle of frame) and after this begins to reduce. But, perhaps, it is connected with at one's own choosing brightness and contrast manipulation in Fig. 15.

4. BRIEF DISCUSSION OF THE FIRST RESULTS

The results of the first trial experiments given here and in [1] indicate that the high-speed record both of trigger lightning and particularly natural lightning with the aid of image converter cameras is much more complicated and labor consuming problem than the record of artificial discharges triggered by high-voltage pulsed generators in long air gaps. The most difficult issue is a question of the camera synchronization with leader stage of the lightning discharge.

In our case the field of view (17 m x 200 m) of photosensor's starting channel was aimed on the height of 128 m (it is 48 m higher of overhead lightning end, see Fig. 17 The shot in Fig. 18 recording by ordinary video camera simultaneously with the shot in Fig. 17 confirms that the channel of main leader has crossed the photosensor's field of view.

Fig. 18. The shot recording by ordinary video camera simultaneously with the shot in Fig. 17.

But one can see in Fig.18 that a cloud closed the channel of main leader was found just at photosensor's field of view positionHowever, the channel of the neighbor right leader hits in the mark photosensor's field of view and photosensor must be trigged. But it was not trigged. At that time the reason for which the central leader turned out recorded at all Figs. 14 not approaching to the ground but had time to reach the ground connected with that circumstance that, perhaps, the photosensor not triggered because of its insufficient sensitivity for ~ 500 m distance to lightning. It triggered just from a return stoke glow upward wave running along the discharge channel when it reached a 128 m height.

The photosensor triggered clearly in [3-5] when the distance to leader channel was 90 m. Because of this in our case the intensity of light signal on PMT input of PS001starting channel was at least 30 times less than in [3-5] (at the same brightness of the lightning leader and brightness of the leader in discharge gap in [3-5]). Most probably, this reason (insufficient sensitivity of photosensor) not allowed to trig the K008 and K004M cameras in [1] from downward leader of trigger lightning exept one case shown in [1] in Fig. 19.

The testing of CCD TV-camera operation mode with recording the second semi-frame with delay regarding the first one (it was a result of having unique in one's way picture of lightning in Fig. 14d) run down about expediency of using a high speed TV-camera with framing rate f ~ 1 – 2 kHz. Such TV-camera will allow getting a series of frames of one and the same process from the screen of K004M, but in different moments of time on the curve of phosphor screen glow falling. This will allow in turn in the beginning of the glow at the largest brightness to get on the first frames of TV-camera in unsaturated zones the information about the weakest image. In the following frames within falling of the phosphor brightness it will be recorded the information without saturation about more and more bright images. As a result it will be recorded information about all the image details with extremely high and low brightness.

5. CONCLUSIONS

In [3-5] a generator of voltage pulses was operated by series with an interval of about 2 minutes between discharges. Then more than 1500 discharges (most part of which was used for adjustment of the photosensor and the cameras) were performed during a week. Adjustment consisted in subsequent selection of optics (objective lenses and filters) at the input of the cameras and photosensor, a levels of the photosensor triggering, initial image intensification in the cameras and a degree of its reset in a bright discharge stage and so on). Only about 600 frames (i.e. slightly more than one third part) remained after removing empty frames or frames with a bright final discharge stage only; they contained wide information on the leader stage and on its pass to the return stroke stage.

It is impossible to have a similar number of successful discharges during a thunderstorm season in case of either trigger lightning or especially natural lightning.

Therefore, only a comprehensive and thorough analysis of the described above results obtained, practical steps aimed at every kind of the increase of the probability of successful lightning image record and precise identification of the obtained images are a pledge of the future success in this uneasy affair.

In this connection when preparing to the future thunderstorm seasons the following actions are considered to be advisable:

1. The essential rising of the sensitivity of photosensor triggering channel (it is achieved by simple increasing of voltage of PMT power supply) that will allow to synchronize the cameras surely with leader stage of the lightning discharge.

2. Oscilloscopic record of image converter cameras' control pulses that will allow to compare the moments of coming the cameras into action and the moments of image intensification reset with the records of oscillograms of discharge currents and pulses of the four-channel photosensor (see the beginning of item 2 in [1]) that control glow at different heights and, therefore, to identify more exactly the obtained images.

3Measuring a distance from camera to lightning in order to know a scale (magnification) of potography.

In case of trigger lightning this distance is exactly known and it is not known in case of natural lightning. To measure a distance to natural lightning one should use a timer with a computing device triggered by a pulse of the second channel of the PS001 photosensor from return sroke radiation and stopped at the moment of coming a sound wave to the microphone sensor at the place of camera installation. The computing device must send to a computer the value of a distance to lightning. Then, calculating a scale of photography as a ratio of focal length of the camera input objective lens to a distance from the camera to lightning and knowing dimensions of a recorded image on the ICT photocathode it is easy to determine real dimensions of whole lightning or any its fragments.

4. Control of lightning polarity.

If trigger lightning polarity is exactly known (a sign and a value of field strength before rocket launch is controlled by sensor), then in order to compare a regularities of trigger and natural lightning development it is also necessary to record natural lightning polarity.

In spite of the fact that the first results of recording the natural lightning image turned out to be modest and did not give anticipated satisfaction, it does not mean at all that K004M image converter camera was operated unsatisfactorily.

In [1] and in this paper a phenomenology of recorded images is described in primary. The results of more detailed processing of shot showed on Fig. 14d (unique in its kind) and we hope that the results of new shots and discussion a scientific aspects connected with this will be presented at following publications.

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