Test of Russian K004M and K008 image converter cameras when recording trigger lightning in Florida

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ABSTRACT

There has been presented a brief description of test equipment and instrumentation for recording spatial-time parameters of a lightning at the International Center for Lightning Research & Testing (ICLRT) in Camp Blanding that belongs to the University of Florida as well as the first results of Russian image converter cameras test when recording a trigger lightning.

Key words: image converter camera, electrical discharge, strimer, lider, velocity, lightning, stroke, brightness.

1. INTRODUCTION

The main advantage of a trigger (artificially triggered) lightning consists in the fact that 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 attached (so-called attachment process) that is practically impossible to be done in case of a natural lightning. This allows, in its turn, to study regularities of lightning discharge development and to solve more scientifically-grounded the tasks of lightning protection of various and, first of all, lively important objects. These objects are as follows: powerful high-voltage electric power lines and their substations, nuclear and other electric stations, storehouses of nuclear, chemical and other ammunition, oil tanks, ground and sea oil-extracting installations and complexes, other civil and military objects of state importance, aircrafts and space vehicles, floating means and many-many other things.

The losses caused by lightning all over the world are colossal, sometimes are non-filled up and come to astronomic sums. A latest example: a lightning was one of several equivalent versions of the reason for a failure of energetic network of the East seacoast of the USA and Canada on the 14th of August 2003. Then an extremely hard situation took place in these regions deprived of electric power. This case which has occurred, perhaps, because of lightning cannot be called otherwise as a technogenic catastrophe. It took from one to several weeks in different regions to restore a quickly destroyed energetic network. 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.

2. THE INTERNATIONAL CENTER FOR LIGHTNING RESEACH &TESTING (ICLRT)

The proving ground in Camp Blanding is the only Research Center in the world where lightning is artificially triggered on a regular basis. Lightning triggering is performed with the aid of a small rocket (Fig. 1) launched vertically upwards from a stationary (Fig. 2) or mobile (Fig. 3) launcher.

A coil with a thin wire of about 700 m length is fastened to a rocket's tail plumage. An outer end of the wire is connected with the ground, i.e. is grounded. During a thunderstorm at those moments when electrical field strength near the ground becomes pre-critical equal to not less than 4 kV/m a rocket is launched. When in (1.5 to 2) seconds the rocket reaches a height of ~ 200 to 300 m an upward discharge is developed from it that burns out the wire. After its explosion-shaped burning electrical communication with the ground is kept by means of a plasma channel formed due to wire explosion, and the upward discharge is continued. After its completion up to two tens of discharges called trigger lightning components (Fig. 4) may occur during 1 to 2 seconds in result of subsequent leak of electrical charges from other cloud's places or neighbor clouds to that cloud's place from which the first discharge was started.

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Fig. 1. A rocket of about 1 m length with a coil of wire on its tail used for lightning triggering

Fig. 2. A stationary 12-channel launcher in the form of a tower (a height of an upper tower landing is 11 m)

Fig. 3. A mobile 6-channel launcher

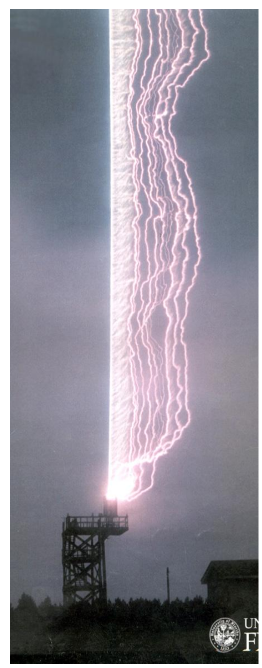

Fig. 4. A series of 11 components of trigger lightning triggered by the rocket launched from a stationary launcher (a channel length seen along the vertical is ~ 60 m).

A photo given in Fig. 4 was taken with the aid of an ordinary photographic camera at exposure of several seconds. A direct vertical channel on the left is a trace from the exploded wire. The wire burns out and is substituted with a plasma channel during the first 10 ms. It is well seen that products of wire combustion (the first lightning channel) were carried away to the right by the wind which was practically always present during a thunderstorm (in this case the wind blew from left to right). The next discharge occurs in a 0.3 s at an average including a noncurrent stage. It is due to the wind that a spatial-time sweep (from left to right) of a series of trigger lightning discharges was obtained in Fig. 4. In spite of the fact that the channel was constantly carried away to the right all discharges reached the target and struck the tower (one can see that the channels of later discharges were strongly bent to the left when approaching the tower).

These components observed after burning out the wire and after completion of the upward discharge are very similar (by physics of their development) to those of natural lightning. It is these next discharges that are usually the main object of investigation.

The tower of the stationary launcher is fully made from wood, i.e. from insulator. A unit of 12 metallic launching tubes in which rockets are installed is connected to the earth with a thin wire that, like the rocket wire, burns out at the initial stage of trigger lightning. The next discharges are accepted by one of three connected with each other metallic tubes (ø 25 mm) placed horizontally above (~ 3 m) the launching tubes between four six-meter vertical plastic masts (see Fig. 2). These current-receiving tubes are connected by a bus with a low-resistance shunt signals of which are recorded with digital oscilloscopes. Identification of oscillograms allows to evaluate electrical parameters of the series of discharges that took place. A replace of the burnt out wire that grounded the unit of launching tubes at the initial stage is performed automatically. Therefore, the next rocket launch can be carried out 2 to 3 minutes after the previous one if during this time electrical field strength is increased to a required level. Starting setup control is carried out from a control panel room (~ 50 m apart from the tower) by means of pneumatics (through plastic hoses). Fiber optic transmission lines are used to transmit signals from sensors to oscilloscopes. Thus the control panel room is electrically isolated from the starting setup.

A probability of lightning triggering with the aid of a rocket is equal to ~ 60 % at an average. During a successful thunderstorm season which continues from May till August inclusive the number of rocket launches resulting in lightning triggering is usually not less than 40.

With the aid of a mobile launcher mounted on an automobile (Fig. 3) trigger lightning can be directed to that object lightning protection of which is necessary to develop or it is necessary to test efficiency of already existing lightning protection developed before the appearance of a trigger lightning method. It is usually a partial or full-size and, to some or other extent, real model of this object.

An underground launcher is available at the proving ground; it is intended for investigation of electromagnetic situation near the channel of lightning not distorted by the launcher and is situated on a strip with grubbed up and exterminated vegetation (Fig. 5 and Fig. 6).

Fig. 5. An underground launcher

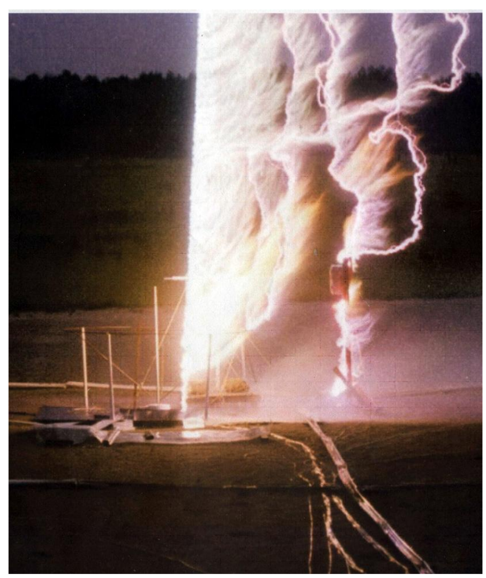

Fig. 6. A series of discharges of trigger lightning triggered with a rocket that is launched from an underground launcher.

It is seen from Fig. 6 that two discharges struck on a rack (with a piezosensor) standing on the right side and having a 1.9 m height.
In Fig. 7 one can see a runway portion with light-signal lamps on both sides along it. A power cable protected with the aid of a rope and earth rods is placed underground. Lightning strikes “well” underground objects (cables, pipe-lines and so on) in dry ground and permafrost. Two full-size fragments of local three-wire electric power lines of about 600 m length are built near the runway. Wires of one line are lying in a horizontal plane (without taking account of a sag) and wires of the other line are lying in a vertical plane.
Fig. 8. shows a setup that was used for tests of lightning stability of ammunition detonators including nuclear. In this case lightning struck exactly a detonator. It should be noted that all tested detonators turned out to be lightning-stable and none of them was come into action.

Fig. 7. Fragments of the runway and two electric power lines.

Fig. 8. A setup for tests of lightning stability of ammunition detonators.

Lightning triggered with rockets launched from the starting tower are usually photographed from a laboratory house that is 475 m apart from the tower (Fig. 9).
A test house is seen near the tower at the foot of the Fig. 9 on the right side; this house was used for tests of lightning protectors of different kinds of buildings including dwelling houses.
A thunderstorm situation above the USA is controlled by a national lightning detection system (NLDS). Artificial Earth satellites are used for data transmission. A thunderstorm situation above Florida and, in particular, around the proving ground is displayed on a computer display (Fig. 10) with periodicity equal to several seconds.
The places where negative lightning happened are marked with blue color and the places where positive lightning happened are marked with red color. An analysis of information gained for a time period that is interesting allows to control dimensions of a thunderstorm zone, a speed and direction of its movement. A black bold point in the center of Fig. 10 represents the proving ground in Camp Blanding; four circumferences (with a radius equal to 5, 10, 15, and 20 km, respectively) around the proving ground represent those zones for which some or other degree of readiness for launching a rocket is declared when thunderstorm approaches them. A part of the Gulf of Mexico is at the foot on the left side and the Atlantic Ocean is on the right side.

Fig. 9. A view of a laboratory house from the tower (at the top in the center of the photo, at a border of the forest).

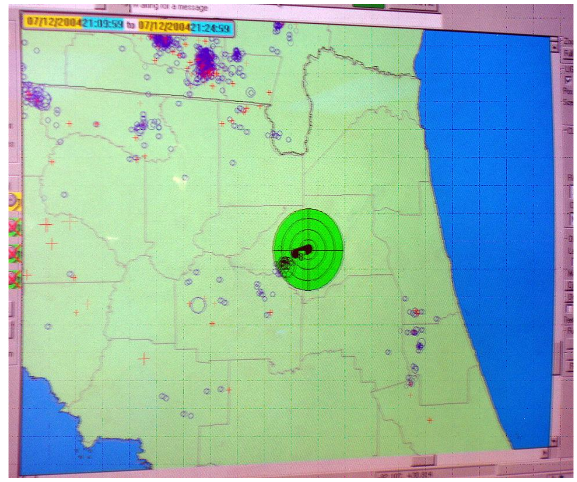

Fig. 10. A fragment of a current thunderstorm situation above Florida.

3. RECORD OF TRIGGER LIGHTNING

Permanent instrumentation used at the proving ground for recording spatial-time lightning parameters is presented by high-speed optico-mechanical cameras of the CORDIN American Company, by digital photo-and videocameras as well as by a four-channel photosensor the channels of which are aimed at different heights. From oscillograms of photosensor's signals it is possible to determine direction of glow propagation (upwards or downwards), an average speed of propagation on 3 portions and relative glow brightness at controllable heights.

Another recording instrumentation is often used. The fact itself that this instrumentation is used and tested at this unique proving ground and, all the more, a positive opinion of the University of Florida about it is a rather prestige moment for designers of such instrumentation.

In summer 2004 record of trigger lightning was tested with the aid of two image converter cameras simultaneously: the K004M camera [1, 2] that was acquired by the University of Florida specially for this purpose and the K008 camera [3]. The K004M camera with 8 x 8 mm^2 image converter tube (ICT) photocathode dimensions can be operated in a streak mode (duration is from 0.355 μs to 10.65 ms) and in a framing mode (from 2 to 9 frames; frame duration is from 0.1 to 10 μs, pause duration is from 0.5 to 999.9 μs) with stepwise reduction of image intensification during a process of recording. The K008 camera (photocathode dimensions are 15 x 20 mm^2) can be operated in a streak mode (duration is from 2 ns to 600 μs) and in a single-frame mode (frame duration is from 10 ns to 600 μs). The main parameters of these cameras are given in [1-3].

The necessity to use simultaneously several cameras operated in different modes is due to the following circumstances. A framing mode of record allows to obtain information on the process to be studied by two spatial coordinates but only at separate discrete time moments. A streak mode allows to obtain only one-dimensional spatial information but this information is continuous in time.

Image brightness of an electrical discharge in long air gaps is subjected to very strong fluctuations as the discharge develops. Therefore, short flashes during a streamer-leader stage may fall into interframe intervals (pauses) when a framing mode of record is used. In this case important information may be fully lost. It will not be lost if a streak mode is used. But if at some time moments two or more adjacent flashes appear simultaneously in a spark gap, then in case of a streak mode their images may be superimposed and spatial information will be either lost or distorted. When two cameras are used simultaneously one of which is operated in a multiframe mode and the other is operated in a streak mode, the data obtained will be added to each other and will allow to avoid a mistake.

Besides, a lightning or discharge channel in a long gap is not a straight line like a slit in the streak camera which is perpendicular to a sweep direction. The channel has a complicated broken shape. In a linear sweep this channel or its parts may have both positive and negative projections on a time axis. It is impossible to obtain, from photochronogram processing, reliable data on a speed of glow propagation if there is no exact information on a channel shape (and in case of a linear sweep it remains unknown in most cases). Only in case of combination with a camera operated in a framing mode exact information on a channel shape and reliable data on a speed of glow propagation can be obtained.

The K004M camera together with the PS001 photosensor, the K008 camera and an interlock designed by American specialists for preventing the cameras against premature and repeated start were mounted on a stand platform (Fig. 11).

Fig. 11. The K004M camera is on a bottom platform of the stand; the K008 camera, the PS001 photosensor and the interlock are on an upper platform.

After explosion of the rocket wire a relatively low (hundreds of amperes) current fluctuating by the value passes through a formed ionized channel during several tens-hundreds of milliseconds. The PS001 photosensor is adjusted so that its starting (first) channel would come into action from glow of exploded wire or from glow of a downward lightning leader.

However in the initial state the interlock keeps the output of this channel closed. The interlock unlocks the channel in a time that somewhat less than a statistical mean delay (equal to ~ 300 ms) of the next discharge taking place after wire explosion. This excludes an opportunity of unexpected start of the cameras before the next discharge. When the next discharge that is to be recorded with the cameras takes place and a photosensor pulse is applied for starting the cameras the interlock again closes this channel for a period of 10 seconds. In this case it doesn't react to photosensor's pulses from new discharges that may occur during 1-2 seconds and thus prevents a possibility of superimposing several sweeps images on the same frame of the CCD readout television camera (a time of readout and subsequent record into a computer is equal to 0.5 to 1 s). The second photosensor's channel which sensitivity is deteriorated with the aid of light filters must come into action only from a very bright discharge stage, namely a so called return stroke. Since brightness of the return stroke is several orders of magnitude higher than that of a leader stage it may lead not only to saturation of a recorded image of the return stroke (disappearance of brightness gradations) but also to a loss of a leader image on a previous sweep portion. By a pulse of this channel an image intensification coefficient in the K004M camera is decreased (is reset) by one step with short fall time during a sweep. A degree of reset can be smoothly adjusted from a zero up to full lock of the ICT.

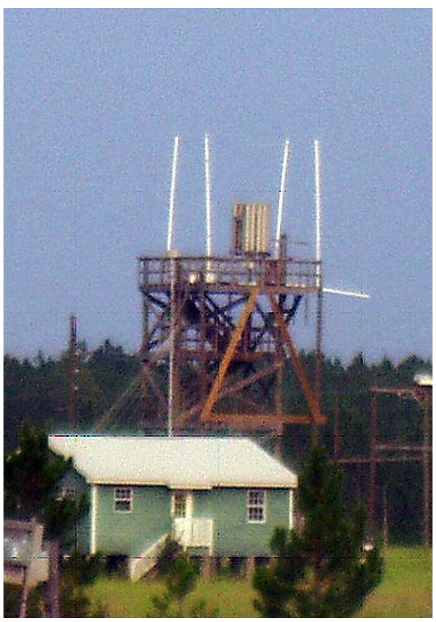

Fig. 12. A view of the tower from the place where the K004M, K008 cameras and the PS001 photosensor are installed.

When testing the cameras it was necessary to obtain (with high spatial and time resolution) pictures of lightning discharge streamer-leader stage development on a portion of a ~ 50 to 100 m height above the launching tower when a channel of a downward lightning leader approached the object to be attached and to measure a speed of return stroke glow propagation. In this case three above-mentioned metallic tubes connected to each other and grounded through a current-measuring shunt were an object to be attached; these tubes were placed between four vertical plastic masts at a 3 m height above the unit of 12 launching tubes; the unit was mounted in the center of the upper tower landing (see Fig. 2 and Fig. 12).

According to evaluation of the return strike glow propagation speed obtained here in 1997 [4] when testing a Japan high-speed (up to ~ 10^7 frame/s) matrix register, namely ALPS (16 x 16 pin-photodiodes), it is comparable with the velocity of light. It was principally impossible to obtain a high-quality image with the aid of the above-mentioned ALPS because of a small number of pin-photodiodes in the matrix. Spatial resolution on the ICT photocathode of the K004M and K008 cameras is not less than 10 l.p./mm. As to the number of resolved elements on a photocathode working area, it is by a factor of 25 and 150, respectively, greater than for the ALPS.

An essential advantage of the K004M camera in comparison with the ALPS is also the possibility of recording in the ultraviolet spectral range. Therefore, apart from recording in the visible light, it was supposed to carry out recording in the ultraviolet range with the aid of the K004M camera and in the hard X-ray radiation with the aid of the K008 camera containing a lead obscure projecting an X-ray image on a quick-response (0.1 μs) luminophor-converter deposited on a fiber disc jointed with a fiber disc of the ICT photocathode.

In a thunderstorm season of 2003 X-ray radiation of trigger lightning was already reliably recorded with the aid of X-ray sensors (based on a NaJ crystal that was set at the PMT input) set in duralumin containers (3 containers were by the starting tower foot, see Fig. 13, and one container was on the upper tower landing). Each container contains 3 sensors tuned to different spectral ranges of X-ray radiation. Each container is aimed to a certain height above the tower. Radiation with quantum energy in the range of 30 to 250 keV was turned out to be the most intensive.

Fig. 13. Containers with X-ray sensors.

Now it was expected to see, with the aid of K008 camera, both fragments and the full image of the channel of the downward leader of lightning in the hard X-ray (in a single-frame mode of recording) and continuous X-ray dynamics of the leader (in a streak mode).

It was supposed that the most difficult problem (when recording trigger lightning) would be synchronization of the cameras, i.e. their start with the aid of the PS001 photosensor with a necessary delay that takes account of "a dead time" of the cameras. For this, the first (triggering) channel of the photosensor was focused, by moving its input lens along the vertical, to a height ~ 70 m above the tower. A slit set in its optical system allowed " to see" at this height a horizontal zone of a 15 m height and a 150 m width. The leader, while intersecting this zone, was to start the photosensor and the latter was to start the cameras. When a statistical mean velocity of the leader was equal to 10^7 m/s it took 7 μs to traverse a distance of 70 m. A height of a field of view for the K008 and K004M cameras above the masts was 80 m and 40 m, respectively. Then the K008 camera operated in a single-frame mode with 6 μs frame duration (a camera "dead time" is 0.2 μs) should record a channel of the leader that had not yet reached the tower masts by approximately 10 m. A 3 μs/cm linear sweep range was set in the K004M camera (in this case full sweep duration was 10.65 μs). It was expected that an image of the downward leader on a sweep would occupy about 4 μs if a camera "dead time" was equal to 1.9 μs. Further, at the beginning of the return stroke the second channel of the photosensor was to come into action and was to decrease quickly high initial image intensification of the K004M camera. Thus an image of the return stroke must also be recorded without saturation (excessive exposure).

Of course, due to leader speed fluctuation from lightning to lightning a length of the leader channel recorded with the K008 camera may vary. For the same reason both location of the image and its dimensions along the time axis on a sweep of the K004M camera may vary. But it was supposed that by making photosensor focusing to a required height more precise, by selection of K008 camera frame duration, K004M camera sweep duration, and image intensification of the cameras high-quality images of the process of leader approach to the tower could be obtained after recording several lightning.

However, insuperable difficulties took place not at all there where they were expected. The weather above the proving ground gave a surprise. It gave no possibilities for any subsequent approximations and refinements. Thunderstorms rumbled in the vicinity of the proving ground almost every day and sometimes several times a day. In this case readiness for launching the rocket and readiness of all numerous recording instrumentation was declared every time. But thunderstorms that came close to the proving ground either stopped not reaching it or suddenly passed by. Only several times electric field strength above the proving ground achieved a pre-critical value that was necessary for launching the rocket. In this connection the proving ground collaborators joked with bitterness saying that in this leap-year Camp Blanding is "the area of lightning protection".

If in the previous years up to 50 – 70 rocket launches were carried out during a thunderstorm season (from May till the middle of August), then only 8 launches were made during a thunderstorm season of 2004. In this case 3 launches were made in the middle of a period since July 6 till August 6, 2004 when V.B. Lebedev, a designer of the K004M, K008 cameras and the PS001 photosensor was present. But in the first case no subsequent discharges occurred after the initial stage (rocket wire explosion). Therefore, the cameras were not started. In the second case a leader speed evidently turned out to be greater than 10^7 m/s. As a result, the K008 camera recorded a channel of the leader when the leader had already reached the tower (and not when it was approaching the tower); a brighter channel of the return stroke (Fig. 14) was imposed on the leader channel.

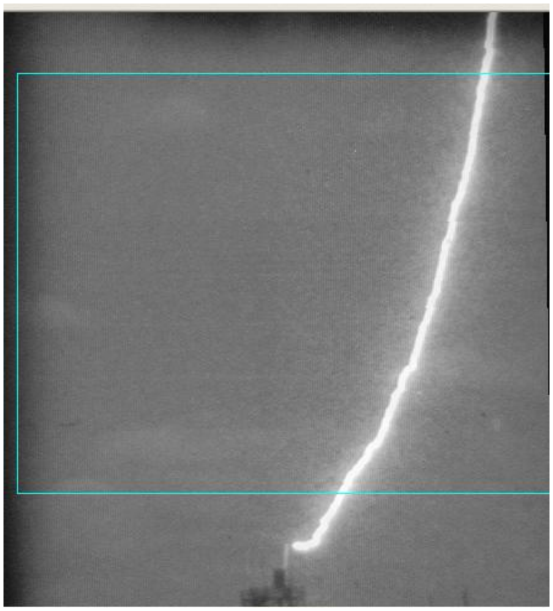

Fig. 14. Trigger lightning recorded with the K008 camera (frame duration is 6 μs, a channel length seen along the vertical is ~ 80 m).

In spite of the fact that the K004M camera came into operation but what was recorded with it could not be written into a computer since literally several seconds before rocket launch the computer hung-up.

In fact the K008 camera recorded only an image of the discharge channel and a mast nearest to it and illuminated with the discharge. This photo was superimposed on a tower image recorded earlier what resulted in a composition shown in Fig. 14. If it could only be supposed that the experiments of the season of 2004 would be completed on this, then with a downward leader speed fluctuation by a factor of 2 than a statistical mean value, of course, for reliable record it was necessary to set considerably lesser frame duration of the K008 camera, i.e. 2 μs instead of 6 μs. Then, if the photosensor would come into operation from downward leader it would be possible to have the picture similar to one of the pictures in Fig. 15 [2], where leader streamers as octopus tentacles seek the easiest way to the aim (weak in the sense of electrical strength) for the leader channel.

The frames in Fig. 15 show the following pictures: (a) the channel and the negative streamers at the beginning of the leader; (b) a stage l of the negative leader with a powerful flash of streamers; (c) a passing of the process to a through streamer phase owing to a junction of negative and positive streamer zones; the channel of the negative leader already occupies a half of the discharge gap length and the channel of the positive leader only begins to form; (d) a meeting of the channels of the negative downward leader and the positive upward leader. In case of d image intensification was strongly decreased. That's why the streamers are not seen; only the channels of the negative and positive leaders are seen.

Earlier, when testing the photosensor and the K004M camera R.K. Olsen has succeeded in obtaining (in a streak mode with 10.65 μs duration) several frames on one of which there has been recorded glow of the exploded, under lightning stroke, rocket wire and wire which grounds the unit of launching tubes (Fig. 16).

It is the beginning of the explosion process and substitution of the wire with the luminous plasma channel. It is seen that not yet the full channel shines but only its separate portions. Three light strips at the bottom of the frame represent glow of channel's portions substituting the grounding wire; this glow is seen by the camera above a roof of the one-storey test house (see Fig. 16a) that closed a view of the rest part of this wire. A width of a middle dark zone above these strips is equal to a distance from an upper end of the unit of launching tubes in Fig. 16a to an automatic grounding device from which a thin wire further descends to the ground. Glow of separate channels substituting the rocket wire is seen above the middle dark zone up to the top of the frame. Even during such a short sweep the increase of brightness and the width of luminous strips in sweep zone occupied by the rocket wire is noticeable. Further, judging by Figs. 4 and 6, separate luminous strips must merge together. Slightly to the right of the sweep middle one can see a very short spike of glow brightness of the channels substituting the rocket wire and the grounding wire as a stop-frame that visualizes a spatial position of these channels, may be, under the action of a discharge current spike.

On the second frame (Fig. 17) one can clearly see superposition of four sweeps on the same frame of the CCD television camera. At that time the interlock preventing the cameras against premature and repeated start has not yet come into action. One would think that information is fully lost because of superposition. However, it is not the case. The return stroke was still recorded on one of the sweeps.

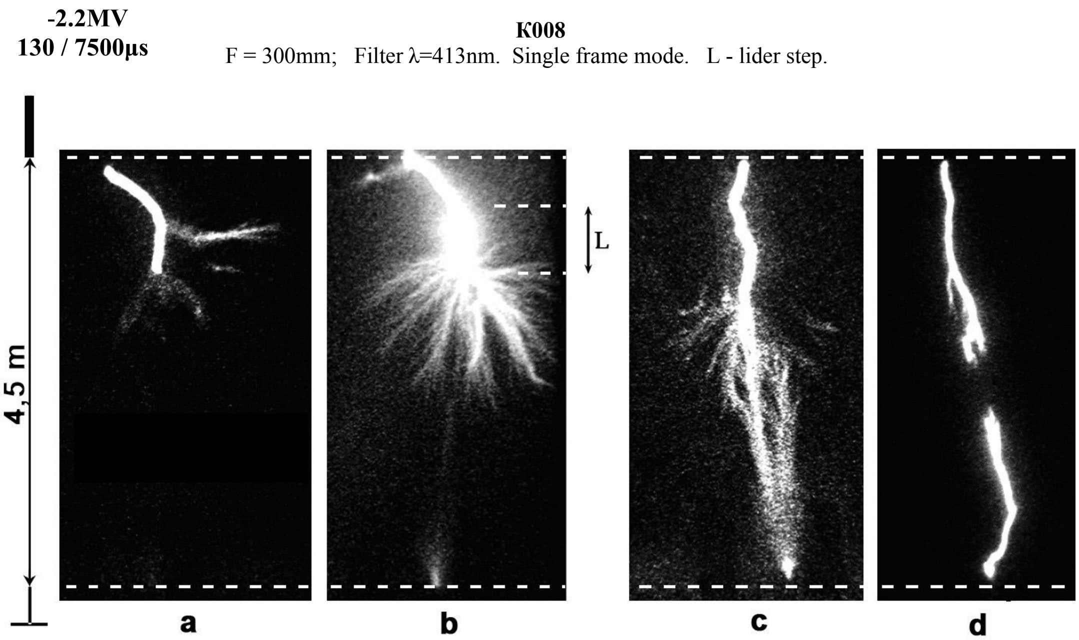

Fig. 15. Pictures of development of a streamer-leader stage for a negative discharge in a “rod-to-rod on plane” air gap (gap length is 4.5 m, pulse amplitude is 2.2 MV) obtained when testing the K008 camera in July 2002 in VNITS VEI (Istra near Mosdow) in a single-frame mode (2 µs); a camera start delay was consequently increased from frame “a” to frame “d”.

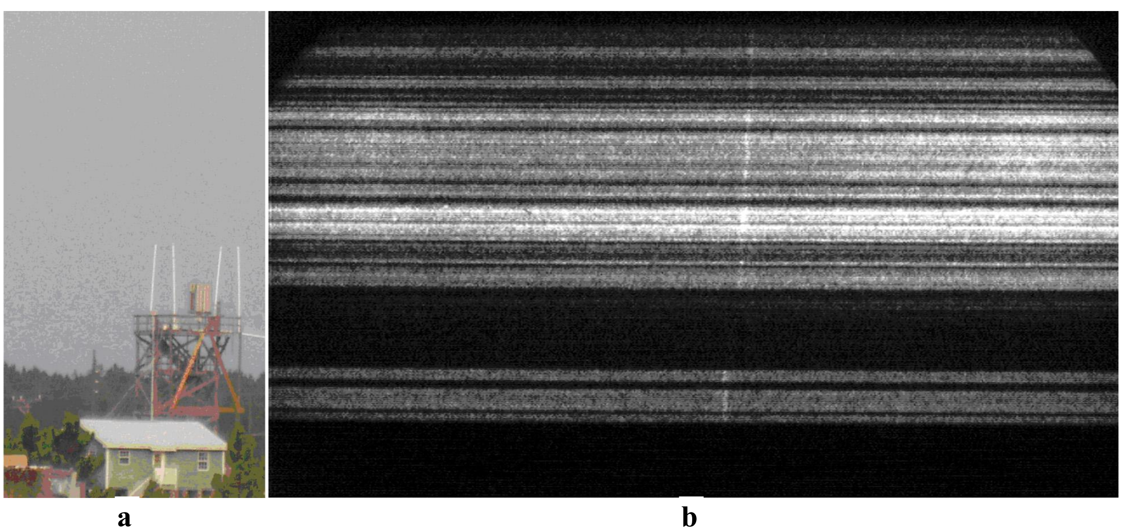

Fig. 16. **a –** A view of the tower in the same scale as it is seen by the K004M camera; **b -** A sweep (full duration is 10.65 µs) of the images of the exploded rocket wire and grounding wire of the unit of launching tubes.

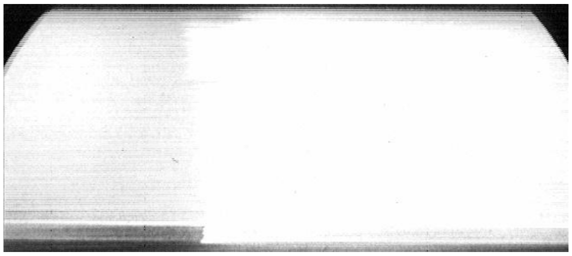

Fig. 17. Superposition of four sweeps of 10.65 μs duration on the same frame of the television camera.

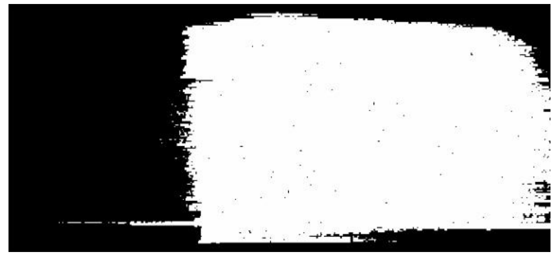

Fig. 18. The beginning of return stroke channel glow obtained by contrasting the image of Fig. 17 (sweep duration is 10.65 μs).

Fig. 18. shows the image (given in Fig. 17) processed so that only its very bright fragments should be marked. It is, first of all, an abrupt brightness change with a slightly broken front reflecting a shape of the discharge channel.

Judging by a very sharp front of channel glow in Figs. 17 and 18 time resolution on this sweep range is obviously insufficient for measuring the return stroke glow speed. Therefore, sweep duration must be decreased by not less than an order of magnitude.

The third frame of a sweep of the return stroke beginning is shown in Fig. 19.

Image intensification was relatively low; that's why downward leader's glow is not seen. Image intensification reset start was turned off. Image brightness is saturated. There is photocathode overload with an input signal, but it is low (the image was slightly compressed along the vertical at the beginning of the return stroke and then it was increased, i.e. was restored; see the analogues effect of overload at Fig. 5 in [5]). A shape of the broken front of the glow beginning reflects a channel's shape. A narrow light strip at the bottom represents a gleam from handrails of the upper tower landing.

The fourth frame is shown in Fig. 20. In this case an input objective lens diaphragm was fully opened, image intensification reset start was turned on, and a big reset amplitude was set. It is seen that the image (it is apparently the leader) is strongly saturated (due to this the leader is not seen) and by the end of the sweep it begins to be compressed due to photocathode overload by a large input signal. At the end of the sweep at the beginning of the return stroke image intensification reset was almost equal to zero. As a result, a shape of the return stroke channel is drawn.

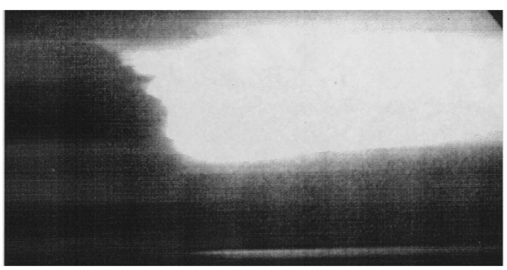

Fig. 19. The K004M camera: a sweep (10.65 μs duration) of the return stroke beginning.

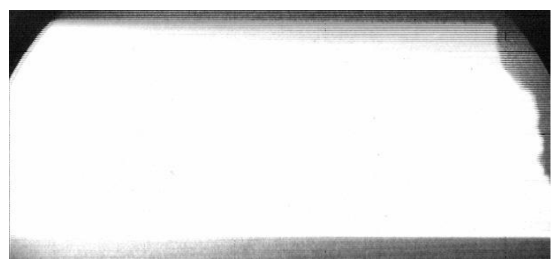

Fig. 20. Image intensification reset at the sweep end (sweep duration is 10.65 μs) where the leader has passed into the return stroke.

4. BRIEF DISCUSSION OF THE FIRST RESULTS

The results of the first trial experiments given here indicate that the high-speed record of trigger 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 trigger lightning discharge.

Most probably that the sensitivity of start channel of PS001 photosensor was turned out not quite enough for distance 457m between photosensor and lightning. It is five times more than the distance to discharge gap at tests of PS001 and K004M in [1, 2]. Because of this in our case the intensity of light signal on PMT input of PS001start channel was at least 25 times less than in [1,2] (at the same brightness of the lightning leader and brightness of the leader in discharge gap in [1,2]).

So, in [1,2] 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, photosensor start thresholds, 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 trigger lightning.

Regarding the possibility of the return stroke recording with necessary temporal resolution when the full time of multiframing or streak sweep will be equal of ones or part of microsecond correspondently so it seems quite real with the present PS001 sensitivity.

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. It is just a pledge and not a guarantee since there is such a circumstance as good luck. The latter is rather important as it follows from described above.

5. CONCLUSIONS

As to preparation for recording trigger lightning in the future thunderstorm seasons, the following actions are considered to be advisable:

1. The essential rising of the sensitivity of photosensor start channel (it is achieved by simple voltage increasing of PMT power supply) that will allow to synchronize the cameras surely with leader stage of the lightning discharge.
2. Development of CCD television cameras' software that will be more fast-response and will allow to record the image of each trigger lightning discharge that follows after the initial stage of trigger lightning. In so doing the interlock must be reprogrammed so that after each case of coming the image converter cameras into action it should lock the possibility of their start only for a time period that is necessary to readout the recorded image with the television cameras and to write it into a computer.
3. 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) that control glow at different heights and, therefore, to identify more exactly the obtained images.

In spite of the fact that the first results of recording the trigger lightning image turned out to be modest and did not give anticipated satisfaction, it in no way means that the image converter cameras were operated unsatisfactorily.

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REFERENCES

1. Y.V. Shcherbakov, V.B Lebedev et al., "High-speed optical studies of long spark (Istra, Russia) and triggered lightning (Camp Blanding, Florida): Initial results", *Proceedings of the 25th International Congress on High-Speed Photography and Photonics (France, 2002),* SPIE, **4948**, 837 – 845 (2003).
2. V.B. Lebedev, G.G. Feldman et al., "Features of Application of Image Converter Cameras for Research on Lightning and Discharges in Long Air Gaps", *Proceedings of the 26th International Congress on High-Speed Photography and Photonics (Alexandria, 2004),* SPIE, **5580**, 887-897, 2005.
3. V.B. Lebedev, G.G. Feldman, "Super small single streak and single frame image converter camera", *Proceedings of the 23th International Congress on High Speed Photography and Photonics, Moscow, 20-25 September, 1998,* SPIE, **3516**, 85-91 (1999).
4. V.A. Rakov et al, "Lightning properties from triggered – lightning experiments at Camp-Blanding, Florida (1997-1999)", *Proceedings of the 25th ICLP*, *Rhodes, 2000*, 54-59..
5. V.B. Lebedev, G.G. Feldman et al., "Test of K004M Russian image converter camera when recording natural lightning in Florida", will be presented at this Congress, Paper No. 036.