CHARACTERISTICS OF TRIGGERED LIGHTNING OBSERVED IN BRAZIL

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ABSTRACT: Several parameters of return-stroke current waveforms of triggered lightning are discussed and compared to results obtained in other places. The parameters presented in this paper, obtained for the first time in Brazil, are crucial in the lightning protection research. All these measurements were done with a sample rate of 100 ns, enabling us to study rise and decay times of the waveforms. Images from a high-speed camera were also used in this work. The triggered lightning, artificially initiated by the “classical” and the “altitude” techniques, were performed during the summer of 2001 and 2002 at International Center for Triggered and Natural Lightning in Brazil (Cachoeira Paulista, S 22°41.2; W 44°59.0; altitude: 625 m). Most triggered lightning strokes in this study have uncommonly higher peak current intensities. These high peak current values were confirmed by the registered magnetic field in the magnetic cards. Also the average duration of the strokes were shorter than usually reported in literature. Measurements of current and light intensity are also compared in order to find a relationship between them.

1. INTRODUCTION

There is no possible way to predict where and when a natural lightning will strike a given point on the Earth’s surface. This is perhaps the main reason why studying many aspects of the physics of the lightning discharge is not an easy task. In order to measure some of these aspects, different kind of measurement equipment has been placed nearby tall man-made structures or metallic towers located on mountain tops. Although some close range data has been obtained in this way, the analysis of an appreciable amount of data requires years of continuous data recording, even in areas of relatively high lightning activity.

The most effective technique for artificial lightning initiation involves launching a small rocket trailing a thin copper wire toward the charged cloud overhead. The first triggering over ground was accomplished in 1973, at Saint-Privat d’Allier in France [Fieux et al, 1975, Fieux et al, 1978]. Other techniques to stimulate the occurrence of lightning between an overhead cloud and a designated point on the ground are being developed, such as, laser beams and salt water jets going upward.

Some of the research that is being done at lightning-triggering facilities concern the study of: a) physical properties of the lightning discharge such as current intensity and duration of the various phases of a lightning discharge, the electromagnetic radiation, stroke multiplicity, etc; b) evaluation of proposed techniques for the estimation of lightning parameters from remotely measured electric and magnetic fields; c) accuracy and detection efficiency of existing and future lightning locating systems; d) evaluation of various mathematical models of the lightning discharge, the lightning striking mechanism, and lightning induced effects, etc [Rakov et al, 1995].

2. THE ROCKET-AND-WIRE LIGHTNING TRIGGERING TECHNIQUES

The two common techniques used in rocket-and-wire lightning triggering are the classical and altitude techniques.

2.1 - The classical technique.

When the ambient electrostatic field at ground reaches a critical value (which varies from place to place) a small rocket trailing a thin grounded wire is launched toward a charged cloud overhead. The rapid introduction of a long thin wire (typically in excess of 100m) into this intense electric field causes the inception and development of an upward leader. This leader propagates toward the cloud and initiates a continuous current of the order of several hundred amperes, typically for a few hundred milliseconds. After the cessation of the initial continuous current, usually one or more downward dart leader/upward return stroke sequences traverse the same path. Although in this technique the initial processes are distinctly different from natural lightning, the dart leaders and return strokes are satisfactory similar.

2.2 - The altitude technique.

If the trailing wire is not connected to the ground, a more realistic reproduction of the initial processes in natural lightning (stepped leader followed by the first return stroke) can be achieved. The rocket first spools out 50 to 100 m of insulating Kevlar followed by 400 to 600 m of copper wire. When this last wire has been unreeled over a sufficient length, a bi-directional leader initiates from its extremities. As the negative downward leader from the lower end of the triggering wire approaches the triggering facility, an upward positive connecting leader is initiated from the grounded object to be tested (in this case, different lightning rods). Once the attachment between the two leaders is made, the return stroke is initiated.
3 - THE INTERNATIONAL CENTER FOR TRIGGERED-LIGHTNING IN BRAZIL

The International Center for Natural and Triggered Lightning Studies (CIPRIN) is located inside the National Institute for Space Research (INPE) campus at Cachoeira Paulista (S 22°41.2; W 44°59.0; altitude: 625 m), a small city located halfway between São Paulo and Rio de Janeiro, where there are about 80 thunderstorm days per year on average. The research institutes involved in the ICLRT are INPE, UNICAMP from Brazil, CNRS/UPS from France, IREQ from Canada, and the companies INDELEC from France and MAKER from Brazil. The triggering site is located on a flat 120m x 70m area of a hill top. The red laterite soil provides a resistivity equal to about 1000 ohm.m (Figure 1).

3.1 - LAUNCHING SYSTEM

The instrumentation and control container is located 45 m away from the rocket launcher that has a capability of launching up to 12 rockets during the same event. The rocket is ignited through a battery connected to a switch that is turn on via air pressure from the control room. The ambient electric field, a crucial parameter to decide if lightning triggering is viable, is monitored by a field mill connected to the control room via fiber optic link. The plastic rockets are 0.85 m long and carry the wire spool with them. They reach the speed of 200 m/s in about 1s from ignition.

Around the launcher system there are three different lightning conductors (two Early Streamer Emission rod and one conventional rod tip) connected to ground with a grounding resistance of 29 ohms. All lightning conductors are at the same height.

3.2 - VIDEO AND STILL PHOTOGRAPHIC CAMERAS

Two standard video cameras are manually activated using air pressure switches and are located about 50 m from the launch pad and lightning rods.

Two lightning activated cameras, manufactured by Power Technologies Inc (PTI), are located approximately 75 meters and 1 kilometer away from the launch pad and lightning rods. These cameras are standard VHS camcorders controlled by an electronic circuit board. The system can be triggered either by magnetic field or optical sensors. It is completely self-powered and automatic, which allows lightning observation even when there is no human presence at the test site.

A high-speed digital camera, manufactured by RedLake Imaging, allows the acquisition of high-speed sequences up to 8000 frames per second. This camera is controlled by a portable computer and can be moved easily to meet observation requirements (lightning rods tip observation, rocket launcher and lightning rods overview, rocket speed computation, natural lightning observation…). The record memory length is 2 seconds.

3.3 - ELECTRIC CURRENT AND OPTICAL MEASUREMENTS

The current at the bottom of a lightning channel is sensed by a 1-mΩ coaxial current viewing resistor (shunt) manufactured by the Laboratoire d’Applications Spéciales de la Physique, Centre d’Etudes Nucléaires de Grenoble, France. The signal from the shunt is transmitted via a fiber-optic system to a LeCroy 9314 digitizing oscilloscope operating at a 10-MHz sampling rate and with 8-bit amplitude resolution.

The luminosity produced by the lightning channel current is monitored by an optical sensor placed at a distance of 45 meters from the launching system. Its signal output is recorded simultaneously with the current signal in a LeCroy 9314 digitizing oscilloscope operating in “windows” mode. The number of acquisition windows was set at 10. The total acquisition time of each windows was 2 ms, with a 1 ms pre-trigger and temporal resolution of 100 ns.

Peak current values in various places were also estimated using magnetic cards. The magnetic field generated by the lightning return stroke current passing through a conductor erases a portion of a pre-recorded signal on the magnetic card. Knowing the geometrical configuration of the conductor to be monitored, the peak current can then be evaluated.

4 - PRELIMINARY RESULTS

Some partial results for 2 triggered flashes are presented in this section.

The first triggered flash was obtained by the classical method (LRSG) and contained 3 return strokes. The electrostatic field at ground was −7.6 kV/m. The second one, although obtained by an altitude method (LRSA), attached to one of the 11.5-meter high lightning rods, allowing direct current measurements. The electrostatic field at ground for the altitude triggering was higher, −9.3 kV/m.
The simultaneous recordings of current and luminosity of both lightning are presented in Figure 2.

Figure 2 – Current and luminosity waveforms for a classical (right) and altitude (left) triggered lightning.

The altitude triggered lightning had a 30 m Kevlar insulator cable under the copper wire. Seven strokes were registered. It is possible to observe in Figure 2 that the first two strokes waveforms are narrower than the 5 other. In fact, their calculated charge were about 10 times lower than the rest.

From the data recorded several important parameters were obtained and shown in Table 1.

Table 1 – Altitude and classical triggered lightning return stroke values.

<table>
<thead>
<tr>
<th>ALTITUDE</th>
<th>CLASSICAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>stroke</td>
<td>Peak light (relative units)</td>
</tr>
<tr>
<td>1</td>
<td>0,20</td>
</tr>
<tr>
<td>2</td>
<td>0,15</td>
</tr>
<tr>
<td>3</td>
<td>0,15</td>
</tr>
<tr>
<td>4</td>
<td>0,12</td>
</tr>
<tr>
<td>5</td>
<td>0,14</td>
</tr>
<tr>
<td>6</td>
<td>0,15</td>
</tr>
<tr>
<td>7</td>
<td>0,14</td>
</tr>
</tbody>
</table>

Geometric mean parameters frequently used in lightning protection research were calculated and compared to values listed in other papers (Table 2).

Table 2 – Altitude and classic triggered lightning geometric mean values (* discarding the 2 first strokes).

<table>
<thead>
<tr>
<th>Parameters (Geometric Mean)</th>
<th>Altitude (7 strokes)</th>
<th>Classical (3 strokes)</th>
<th>Classical (other papers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Return-stroke current peak (kA)</td>
<td>33</td>
<td>26</td>
<td>12 [Fisher et al., 1993]</td>
</tr>
<tr>
<td>Total stroke charge (C)</td>
<td>0.7 (2.3 *)</td>
<td>1.9</td>
<td>2.5 [Fisher et al., 1993]</td>
</tr>
<tr>
<td>Total stroke action (A².s)</td>
<td>4.5x10³ (12.5x10³ *)</td>
<td>13.0x10³</td>
<td>3.8x10³ [Fisher et al., 1993]</td>
</tr>
<tr>
<td>Peak di/dt (kA/µs)</td>
<td>195</td>
<td>94</td>
<td>91 [Depasse, 1994]</td>
</tr>
<tr>
<td>10-90% di/dt (kA/µs)</td>
<td>107</td>
<td>26</td>
<td>28 [Fisher et al., 1993]</td>
</tr>
<tr>
<td>10-90% current rise time (µs)</td>
<td>0.25</td>
<td>0.79</td>
<td>0.37 [Fisher et al., 1993]</td>
</tr>
<tr>
<td>Half-peak width (µs)</td>
<td>1.35</td>
<td>3.60</td>
<td>18 [Fisher et al., 1993]</td>
</tr>
<tr>
<td>20-80% light rise time (µs)</td>
<td>3.6</td>
<td>1.1</td>
<td>1 – 3 [Idone et al., 1985]</td>
</tr>
<tr>
<td>80% peak current-light delay (µs)</td>
<td>3.0</td>
<td>0.4</td>
<td>-----</td>
</tr>
</tbody>
</table>
5 - CONCLUSIONS
All strokes of the triggered lightning obtained in this study have uncommonly higher peak current intensities. These high peak current values were confirmed by the registered magnetic field in the magnetic cards. The 2 first strokes waveforms of the altitude triggered flash were narrower than the 5 other. The fact that the width of the current waveform produced by the initial-stage return stroke is appreciably smaller than that for the following return strokes is cited by Rakov, 1999. But the fact that the second return stroke of this flash presented the same pattern is surprising.

Except for the 2 first strokes of the altitude flash, the charge destroyed in each stroke was comparable to the geometric mean values usually reported. Considering that the geometric mean current peak is 2 to 3 times higher, this should indicate that the average duration of the strokes is shorter. In fact, they are much smaller than expected. Only one stroke among 41 registered by Fisher et al., 1993 presented a half-peak width lower than 4 µs.

The parameters peak di/dt, 10-90% di/dt, 20-80% light rise time presented higher values for the altitude technique. The 80% peak current-light delay time, which is the time delay between 80% of the peak values, is also higher due to greater values of 20-80% light rise time for altitude strokes.

The values obtained for the classical technique are in good agreement with the literature. Exceptions are the 10-90% current rise time, the peak current and the half-peak width values.

We found no correlation between peak current and peak luminosity values as obtained by Idone et al., 1985.

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REFERENCES