AN ATTEMPT TO DETERMINE CURRENTS IN LIGHTNING CHANNEL BRANCHES FROM OPTICAL DATA OF A HIGH SPEED VIDEO SYSTEM

G.Diendorfer[1], M.Viehberger[1], M.Mair[2], W.Schulz[1]
1) OVE-ALDIS, Vienna, Austria
2) Technical University Vienna, Austria

Abstract

Direct measurement of lightning currents is only possible at the point of impact using a shunt or other measuring instruments (e.g. Rogowsky-coil). On the other hand, the brightness of the lightning channel can be determined by means of optical measurements. So, if there is any correlation between lightning current and channel brightness, there is also an option to estimate the channel current from the measured brightness of a lightning flash.

We have developed a software tool Flash Analyzer (FA) to verify the correlation between the lightning current measured at the top of an instrumented tower and the simultaneously recorded brightness changes of the lightning channel. The optical data are taken by a high speed video system that is installed at a distance of about 200m to the tower. The camera system is operated with 500 frames per second i.e. an image of the lightning channel is taken every 2 ms. The mean value of the measured current during the frame exposure time of 2 ms is calculated from the simultaneously recorded current values. The 2 ms exposure time of the high speed video frames only allows analyses of the initial continuing current (ICC) phase of the upward initiated flashes to the tower.

The FA software has the option to specify up to four arbitrary lines per image, defining cross sections of the lightning channel. The basic idea of the analysis is to place the lines across the lightning channel and to determine the brightness along these cross sections. The result is a plot of the channel brightness as a function of time. This sequence is at first sight (purely visually) very similar to the plot of the measured lightning current. Several analyses under most different conditions have proven the usability of this procedure. Different parameters effecting the correlation between brightness and current (e.g. displacement of the lightning channel due to strong wind, the use of different camera lenses or background light on images taken during daylight time have been analyzed and corrected. For most of the examined lightning flashes coefficients of determination $r^2 > 0.5$ were determined for a linear regression between channel brightness and lightning current. By placing the cross section lines across the individual branches of the lightning channel, we were able with this software tool to assess the corresponding lightning current in the individual branches of the channel. In this paper we show some results of the analysis of lightning flashes to the Gaisberg tower in the years 2000 to 2002.

Introduction

The radio tower on Gaisberg with a height of about 100 m is located 1287 m above sea level and about 5 km east of the city of Salzburg, Austria. This tower was selected for lightning experiments because analysis of historical data from the lightning location system ALDIS showed a flash rate of about 40 – 50 flashes to the tower per year.

Lightning photography as a tool for lightning research has been in use for many decades. But today, by using high speed digital imaging and data acquisition it becomes possible to process optical data in a similar way as the digital acquired lightning current data. The characteristics of the lightning channel brightness, to the extent that these characteristics relate to the current flowing in the lightning channel, contain important information for the understanding of the physical processes that occur along the lighting channel at different heights.

An analysis of lightning flashes to the CN Tower in Toronto based on high speed digital camera frames was presented by Janischewskyj et al. (1998) [1]. They give plots for the maximum and the average brightness at a single line on the time series of frames for a flash. One fundamental limitation was that they could use only horizontal cross sections over the entire image width. In this paper we present a more flexible approach to analyse the correlation of lightning channel brightness and current.

1. Lightning current measuring system

For current measurement a current sensor on top of the tower, a fiber optic link for transmission of the measurement data and a recording system are installed in a building next to the tower (Fig.1).

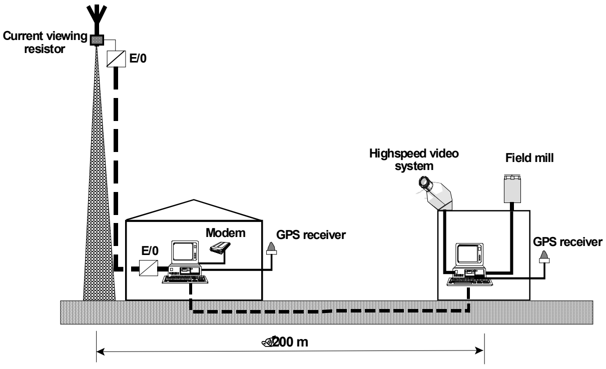


Fig.1: Schematic overview of the experimental setup at Gaisberg tower (E/O: Electrical/Optical signal converter)

The lightning current is measured at the base of the air termination on the tower as the output voltage of a 0.25mΩ current viewing resistor (shunt). Due to the wide range of lightning current peak amplitudes two separate fiber optic channels of different sensitivity are installed. Only data from the channel with the higher sensitivity (0 - 2.1 kA) is used for this study, because the brightness information of the lightning channel at higher peak amplitudes can not be captured appropriate by the video system. The shunt output signal is recorded by an 8 bit digitizing board installed in a personal computer. The digitizing board with a memory of 16 MByte per channel, operated with a sampling rate of 20 MSamples/s gives a maximum recording length of 800ms. The high speed video system is operated at 500 frames per second and therefore about 400 frames with simultaneous current waveform recording are captured.

To be able to compare these data, both data sets need to be aligned to the same “time grid”. Therefore an offset corrected mean value for blocks of 40.000 current data points is computed (2 ms camera exposure corresponds to 40.000 current samples).

By this procedure the current data records are reduced to a total of 392 2-millisecond mean values per lightning impact.

2. High speed video system

For capturing changes of the lightning channel brightness a monochromatic high speed video camera (KODAK MotionCorder Analyzer SR-1000) is installed at a distance of 200m to the tower. The frame rate of the camera is set to 500 frames per second. The internal camera memory for 1092 frames limits the total recording time to 2.1s at 500fps. 1092 individual BMP-images are created and stored on a local PC for each lightning impact with a pretrigger length of 546 frames. These data set provides sufficient time resolution for investigations on the optical development of the entire flash with a total time duration of up to several hundred milliseconds. On the other hand the 2 ms exposure time is insufficient to analyze brightness details of individual return strokes with pulse durations of some tens to some hundreds of microseconds. The images are stored as 8 bit grayscale bitmap files with 240x512 pixels (see Fig.2). For an optimal use of the available display size the camera has been mounted in 90 degree with respect to the natural view.

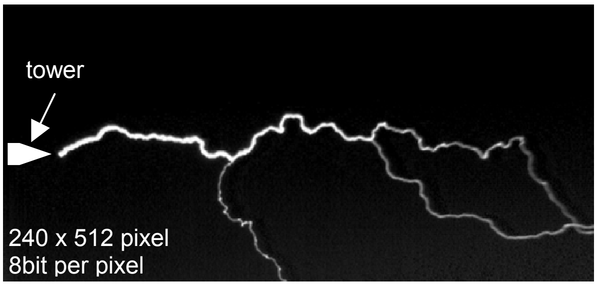


Fig.2: Single frame taken by the high speed video system (original picture, not rotated).

Only for about 10% of all recorded lightning flash current waveforms useful optical information about channel brightness is available. Primarily the local weather conditions at the Gaisberg during the lightning events restrict collection of appropriate video images. Often heavy rain or fog avoid an evaluation of the optical data (see Fig.3).

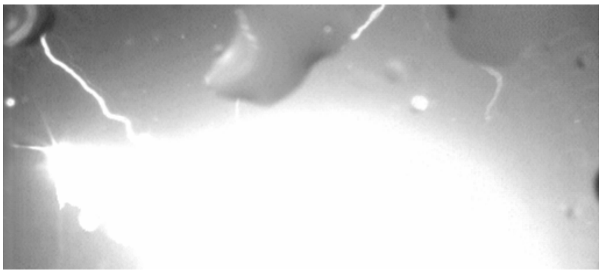


Fig.3: Single frame of the high speed video taken during heavy rain showing light reflections on raindrops on the camera lens – in this case evaluation of lightning channel brightness is impossible

Sometimes the system is triggered by electromagnetic interferences caused by lightning strikes nearby the tower. This results in a video data set without visible lightning channel on a single image. We have developed a software tool for a quick check of a full video image set (1092 images), to select images with any short time brightness changes between individual images.

3. Flash Analyzer (FA)

Only video data sets showing a clear structure for the lightning channel are used for the following analysis. The basic concept is to specify cross section lines across the lightning channel and to determine the brightness along these lines. These cross section lines can be in arbitrary directions to the lightning channel and of different lengths, preferably they are set about perpendicular to the lightning channel. This allows good adjustment of the cross section lines to the structure of the lightning channel. Up to four cross sections can be specified at the same time, allowing simultaneous analysis of different channel branches in relation to the measured total lightning current or in relation to the other branches.

Various tests showed, that for the available data the best measure to describe the channel brightness at a given height (channel position) and time is the sum of all pixels brightness values along the cross section on the time corresponding image [2].

Before we can perform a more detailed regression analysis between the current and the brightness data we have to apply different corrections on the brightness data:

(1) background light offset correction
(2) wind shift correction
(3) elimination of saturated pixels
(4) eliminate below threshold current values

ad (1): background light offset correction is required, when all the video images of a flash show an almost constant background illumination (e.g. when the flash occurred during daylight time). A constant offset value is determined as an average value from the pretrigger images, that show the same area without any lightning, and this value is subtracted from all images,.

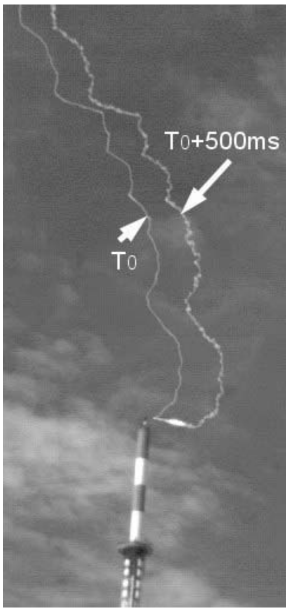
ad (2): Strong wind during a thunderstorm can shift the lightning channel by several meters as shown in Fig.4. With the first and the last image showing a visible lightning channel a total displacement vector is specified. When running the analysis for a set of N images, the cross section lines are moved by the N-th fraction of this displacement vector to ensure that the defined cross section lines stay at about the same channel positions.

ad(3): The 8-bit greyscale resolution may result in saturation of some pixels for very bright lightning channels. For the correlation analysis with the current data, described in the next section, we have eliminated any brightness data including one or more saturated pixels.

ad(4): Longer periods without significant lightning current (i.e. only current noise signal is recorded) and no visible lightning channel in the video frames result in a significant number of data points close to the origin in brightness versus current plots (see Fig.6). Including these data in the regression analysis would bias the results towards too optimistic regression coefficients. In the final analysis we have eliminated data points with currents below a given threshold, where the threshold value was adjusted to the signal noise level of the lightning current data.

After all these corrections we can generate for each cross section of a lightning flash a set of time correlated current and channel brightness data points.

For a flash recorded on June 14th, 2000 an image showing two specified cross section lines is given in Fig.5.



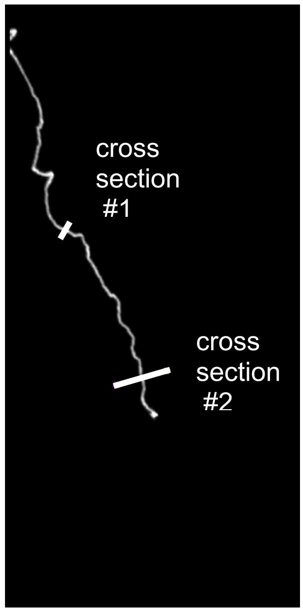


Figure 4:
Overlay of two lightning images separated in time by 500 ms to demonstrate the wind shift of the lightning channel

Fig.5:
Flash recorded on June 14th, 2000 20:19:52 (GMT) using lens Ultrak 8,5mm

An example of brightness versus current data points for the cross section line #2 in Fig.5 is shown in Fig.6. We determined k= 4.00 and r^2=0,96 for a regression line y=k*x forced to go through the origin (no current - no brightness).

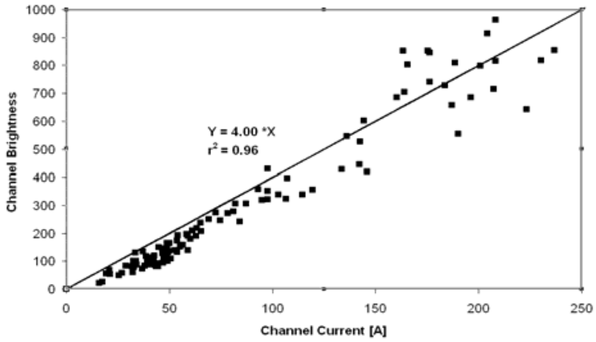


Fig.6: Brightness versus current data for line #2 in Fig.5

4. Results

A total of 9 records of flashes to the tower was analysed as described before regarding the correlation of channel brightness versus measured current. In Table 1 we have summarized the results of our calculations. The regression line slope k and coefficient of determination r^2 given in Table 1 are calculated as the average of four cross sections along the visible lightning channel.

Table 1: Summary of the brightness (y) versus current (x) regression analysis (y = k * x)

Flash #	Date	Time	Lens [mm]	k	r^2
1	14.06.00	19:26:54	8.5	4.03	0.49
2	14.06.00	20:19:52	8.5	2.99	0.93
3	14.06.00	20:30:36	8.5	3.56	0.61
4	17.08.00	19:08:38	8.5	4.48	0.50
5	21.09.00	02:53:29	8.5	3.06	0.81
6	03.08.01	06:58:24	3.5	6.35	0.25
7	08.08.01	16:04:27	3.5	6.08	0.70
8	08.08.01	16:15:55	3.5	5.85	0.98
9	09.09.02	20:35:32	3.5	5.69	0.63

Obviously there is a good correlation between the lightning current and the channel brightness for most of the available flash data.

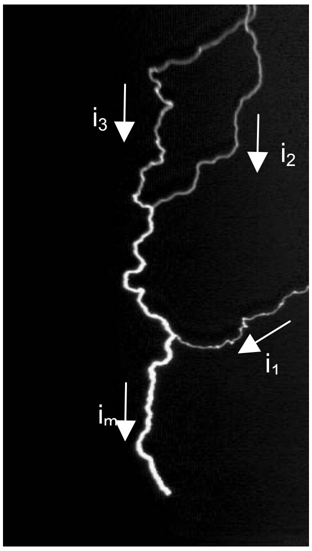


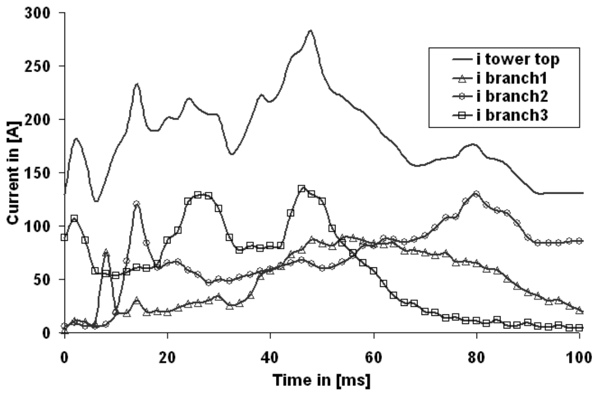
Fig.7: Branched lightning channel (flash #7, t= 40ms)

We can apply the same principle to individual braches of the lightning channel and we assume that the measured total current i_m at the tower top is the sum of currents $i_m = i_1+i_2+i_3$ in the branches (see Fig.7). Based on the proofed correlation between the current i_m and brightness we estimate the current i_{branch} in each channel branch from the ratio of brightness of the branch to the brightness at the tower top, and the corresponding total current i_m (Eq.1).

$$i_{branch} = i_m \cdot \frac{brightness_{branch}}{brightness_{tower\,top}} \qquad (1)$$

Fig.8: Current in the lightning channel branches of flash #7 for the first 100ms of current flow

Obviously the three visible branches contribute uneven to the total current measured at the striking



point at the tower top. During the first few milliseconds current flows almost only in branch 3 and branch 1 and 2 inject a first current peak after about 8 and 15 milliseconds, respectively. A MPEG movie that we have generated from the full set of BMP images provide a good visual impression of these changes in the current distribution among the visible branches.

Summary

Although the presented procedure in the current state is only applicable to the ICC (initial continuing current) sequence of upward lightning because of the limited time resolution of 2 ms of the video system, this method can provide some new insight in the dynamic changes in the contribution of the branches to the total lightning current.

References

[1] Janischewskyj W., Hussein A.M., Wiacek M., Chang J.S.: Details of canadian national tower flashes utilizing a digital high-speed camera, 24th International Conference on Lightning and Protection (ICLP), Sept. 1998.

[2] Diendorfer G., Mair M., Schulz W.: Detailed brightness versus lightning current amplitude correlation of flashes to the Gaisberg tower. 26th ICLP 2002, Cracow, Poland, September 2002