Photography of Lightning

Results from Monte San Salvatore, Switzerland

K. Berger

a) General appearance of a lightning flash

It is well known that by moving a camera with its shutter open during night time, a lightning flash very often is traced as several distinct strokes. A classical example is given in fig. 1 (Prof. Walter in Hamburg, about 1900).

According to Schonlands definition the single luminous streak is called a stroke (a component stroke); all strokes together constitute the flash (the multiple stroke).

More than 1'000 oscillograms and fotos from San Salvatore show, that splittering up of a flash into several strokes happens only when a negatively charged cloud is discharged to ground. Positively charged clouds discharges in a single stroke. The total duration of a flash is within the range of about 0,01 to 2 seconds. The duration of one stroke is from less than one to several ms (milliseconds) for high current values (impulses) or of tenths of a second for low current values (continuing currents).

b) Electric current of lightning strokes

Fig. 2 shows examples of long-duration low-current strokes without impulse currents.

Fig. 3 shows examples of multiple strokes. The first stroke is a long-duration low-current one, the consecutive or following strokes are short-duration high-current strokes; some of them are followed by a tail of long duration and low current.

The shape of typical short-duration high-current impulses is shown in fig. 4 for negative, and in fig. 5 for positive cloud discharges. This very short survey of results of electrical research work done on Monte San Salvatore since 1943 puts the question about the physical reason of these very different shapes of lightning currents.

c) Photography of lightning strokes

To answer this question a photographic installation was erected on top of San Salvatore in 1950. In the first instance there are 8 normal cameras with still 35 mm film. The purpose of these cameras is to get exact localisation of strokes around San Salvatore and to study lightning strokes to and from the two towers of 70 m high each, where the lightning currents are measured in all details Another photographic station is about 3,2 km from the mountain in Lugano-Breganzon from where both towers can be observed photographically. In principle the photography with still films shows 3 types of strokes:

Strokes without any branching (Fig. 6)
Downward branching strokes (Fig. 7)
Upward branching strokes (Fig. 8)

d) Fast moving film

The problem is now to know the mecanism of each single stroke. To this purpose BOYS invented his cameras 40 years ago. The BOYS camera was modified by Malan and later by the author and his assistants.

Fig. 9 gives the principe and Fig. 10 a foto of the cameras used on Mount San Salvatore. The film moves at about 27 m/s around two wheels and before the objective with 1:3,5 aperture. It is a kind of smear camera, where the film moves continually. The practical problem with this camera is to avoid oscillations of the film before the objective. This is done by 4 small jewels which touch the film on both sides. To the same scope the glueing of the film loop must be done with much care, to get a homogenous thickness and sufficient mecanical strength.

e) Examples of photograph

The results by this camera with fast moving film and the comparison with the corresponding electrical current measurements in the lightning towers are given in the following examples, Fig. 11...14 and 15...19.

In these figures the time scale is indicated in ms in the abscissa from the left to the right, the height scale in the vertical in m above the tower top or above ground.

f) Downward strokes

In Fig. 11...14 the first sign of a stroke within the field of the camera is at the upper corner at the left. The light progresses downwards by steps until the tower top or the ground is reached. In this moment a very bright light appears along the channel which was prepared by the steps. This bright line corresponds with the discharge of the negatively charged cloud to the earth. The weakly luminous downward progressing channel is called the leader stroke, which in this case is a stepped leader. The bright line indicates the main stroke. Both together constitute the simple stroke. The first leader progresses at about 100...300 km/s. A 5 km stroke therefore needs about 1/20...1/60 of a second to its formation. The main stroke progresses much faster, at about 1/10...1/3 of velocity of light. Electrically this velocity corresponds to a discharge duration of the 5 km-channel of about 50...150 µs in the first approximation.

The leaders of following strokes in a multiple stroke progress at least 10 times faster; they do not show stepping, but progress continouesly. Schonland called same dart leaders.Their front duration is of the order of 1 µs, sometimes less, whereas the first leader has about 5 to 10 µs front duration. The physical reason for this front duration will be discussed at the end of this paper.

g) Upward strokes

Fig. 15...18 show examples of strokes progressing from the tower top upwards. This case is very useful for research because it allows simultaneous measurement of current into the Leader and photographs of its progression. Such comparative research work is done on San Salvatore since 1950, when the second tower was erected.

Fig. 15 and 16 show upward leaders from the negative tower top ,
Fig. 17 and 18 from the positive tower top towards the cloud.
There is a well remarkable difference in the manner of progessing. Negatively charged leaders only show the very distinct stepping with luminous streaks, whereas positive leaders show continuous luminosity with periodically varying intensity.

Fig. 19 shows the discharge of a positively charged cloud to Campione, at the border of lake of Lugano. This photo is taken at the photostation 3,2 km from

San Salvatore, therefore we get the stroke visible to a greater height.

h) <u>Conclusions</u>

The comparison of hundreds of flashes has led to the following principal conclusions:

1. Downward branching is always identical with downward progressing; these strokes are <u>downward strokes</u>.

2. Upward branching is identical with upward progressing; such strokes are called <u>upward strokes</u>.

3. Downward strokes produce impulse currents when they reach the ground. Current values are between 2 kA and 200 kA.

4. Upward strokes produce continuing currents at the ground. These leader-charging currents are of about 100...300 A amplitude.

It is therefore possible to distinguish downward- and upward strokes also in the current oscillogram without photography.

i) <u>4 types of strokes</u>

Regarding progression and polarity of the leader charge there are 4 types of possible lightning strokes. They are represented by <u>Fig. 20</u>. On Mount San Salvatore all 4 types exist and can be measured, if we don't loose patience. In the last years there are about 90% upward strokes from and only about 10% downward strokes to the measuring towers. Regarding polarity there are much more negatively charged leaders(downward from negatively charged clouds or upward from the positiv tower top) than positively charged leaders.

Many upward leaders show continuing current only, as in Fig. 2. Others produce impulse currents if there are consecuting strokes as in Fig. 3, 4, 5, or sometimes after several ms as in Fig. 16.

k) <u>Upward connecting leaders</u>

16 This last figure leads to the observation of the so called "<u>connecting leaders</u>" or "joining leaders". The photograph shows at the beginning an upward leader from the negative tower top. After 11,6 ms at once there is an impulse current of 27 kA. It must be assumed that the upward leader met an already

charged leader into the cloud. This kind of upward leaders is called an "upward connecting leader" (2). It connects an existing leader in the cloud to the ground. The evaluation shows longer front duration (less steepness) of the impulse current for longer connecting leaders. This phenomenon is rather difficult to observe. The reason is as follows:

The luminosity of positively charged leaders (from the positiv tower below a normal negative cloud) is so weak, that it is visible only in a small fraction of all cases. The exact observation of fig. 12 and 13 does not show any upward leader from the tower top. But the figures show clearly that the upward "main stroke" did begin at a distance of 30...40 m before the downward leader reached the tower top. This confirms the usual observation that positively charged upward leaders which are fully measured electrically does not give any trace on the fast moving film. Only negatively charged leaders do, but this polarity is rather seldom. To get reliable results it was necessary to observe all kind of stroke during many years.

l) Loops in the channel

Fig. 19 shows a loop in the lightning streak near the ground of Campione. Such "loops" cannot be observed in a progressing stroke, but are caused by an "upward connecting leader", which does not contact the downward leader at its top, but somewhat later on its side. In the same time the downward leader touches the upward connecting leader also on its side. The effect is the appearance of a loop.

m) Physics of breakdown

The exact analysis of upward connecting streamers show that the electrical breakdown between the downward leader and the ground often (may be always) happens by means of a progressing leader. It is not at all similar to the breakdown in a homogenous field as f.i. between spheres. This "upward connecting leader" may have 10...100 m (fig. 12 and 13) with negativ clouds (the usual case), but it may reach lengths of about 2'000 m with positive clouds (fig. 16). In the latter case the meeting point is invisible within the cloud. Its existence can be proved or by the oscillogram or by the appearance of a sudden increase of brightness in the leader-photograph, as in Fig. 16.

n) Consequences for lightning protection

The lightning stroke mechanism near the ground is of practical importance to all kind of lightning protection, human beings as well as loss or damage of material. The mystery of the non-existing "protection cone" of lightning rods will probably be solved in the future by the better knowledge of the upward connecting leader.

In the technic of very high voltage power installations the formation of "leaders" possibly will set a limit for transmission voltages. This may justify the study of this very interesting and very important physical phenomenon, which seems to bridge the voltage-gap between lightning and power transmission.

K. Berger

Captions to article
Photography of Lightning
by K. Berger

Fig. 1 Photograph of a lightning flash, above with still camera, below with slowly moved camera.
Photo by Prof.Walter, Hamburg, about 1900.

Fig. 2 Examples of current oscillograms of long-duration and low-current lightning strokes (continuing currents, "hot lightning")

Fig. 3 Examples of current oscillograms of multiple strokes. First strokes with continuing current, consecuting strokes with short-duration and high-current strokes

Fig. 4 Examples of typical negative short duration and high-current strokes (impulse currents, "cold lightning")

Fig. 5 As in Fig. 4, but positive polarity impulses, discharging positively charged clouds

<u>Fig. 6</u> Lightning stroke without any visible branching

<u>Fig. 7</u> Downward branching stroke ("Downward stroke")

<u>Fig. 8</u> Upward branching stroke ("Upward stroke")

<u>Fig. 9</u> Design of camera with fast moving film
1 electrically driven pulley, 2 pulley with stretching spring,
3 film, 4 picture limiter with guiding jewels,
5 optical system

<u>Fig. 10</u> Photograph of the camera of fig. 9

<u>Fig. 11</u> First example of a flash with downward strokes to tower 2:

a) photograph by still film: the flash does not touch the tower at its top but below at the end of the frame work. An upward streamer is visible from the tower top,
b) first stroke with stepped leader,
c)
d) consecutive strokes with dart leaders

<u>Fig. 12</u> Second example of photograph of a downward stroke to tower 2:

a) Photograph from top of mountain,
b) corresponding current oscillogram ms = thousandth of a second
µs = millionth of a second

<u>Fig. 13</u> Third example of downward stroke to tower 2:

a) Photograph on fast moving film
b) Photograph on still film of two strokes, time distance 82 ms
c) Current oscillograms of both strokes in b)

A Meeting point of downward leader with unvisible "upward connecting leader"
B Branching point of the upward connecting leader

<u>Fig. 14</u> Example of a downward stroke to the ground near tower 2:

a) Photograph on ~~top of mountain~~ fast moving film
b) Photograph ~~by~~ on still film

<u>Fig. 15</u> Example of an upward stroke from the negative top of tower 2:

a) Photograph ~~by~~ on fast moving film
b) Photograph ~~by~~ on still film
c) Enlarged beginning of a) showing transition from glow to arc discharge

Fig. 16 Second example of an upward stroke from the negative top of tower 2:

a) Photograph on fast moving film, first at the beginning leader, then after 11,6 ms with an impulse current
b) Photograph on still film
c) Enlargement of the beginning of leader to show transition from glow to arc discharge

Fig. 17 Example of an upward stroke from the positive top of tower 2:

a) Photograph on fast moving film from Lugano-Breganzona
b) Photograph on still film " " "
c) Current oscillogram

Fig. 18 Second example of an upward stroke from the positive top of tower 2:

a) Photograph on fast moving film from top of mountain
b) Photograph on fast moving film from Lugano-Breganzona
c) Photograph on still film from top of mountain
d) Photograph on still film from Lugano-Breganzona, showing one stroke from tower 2 and one from tower 1

Fig. 19 Discharge of a positively charged cloud towards Campione on the Lake of Lugano:

a) Photograph on fast moving film from Lugano-Breganzona
b) Photograph on still film from Lugano-Breganzona
c) Photograph on still film from top of mountain

Fig. 20 Presentation of the 4 possible types of lightning strokes:

1) Downward stroke out of negatively charged cloud, leader negatively charged, current negative,
2) Downward stroke out of positively charged cloud, leader positively charged, current positive,
3) Upward stroke from the positive tower top, leader positively charged, current negative,
4) Upward stroke from negative tower top, leader negatively charged, current positive,
v) Direction of progressing of the leader.