Blitzforschung FKH 1975

DEVELOPMENT AND PROPERTIES OF POSITIVE LIGHTNING FLASHES AT MOUNT S.SALVATORE WITH A SHORT VIEW TO THE PROBLEM OF AVIATION PROTECTION

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The following reflexions are concerned with lightning research on Mount San Salvatore near Lugano, Switzerland, and especially with discharges from positive clouds.

1. Site of observation and frequency of flashes

Site and measuring equipment have been described in some earlier papers, ref. 1...6. During the period 1963 to 1971 (9 thunderstorm seasons) 1026 oscillograms of lightning flash currents to and from the two measuring towers on Mount S. Salvatore have been obtained. 838 of them were negative, 130 positive, 58 of both polarities. Out of these 1026 oscillograms 134 were downward flashes, 106 of them with negative, 28 with positive current. These oscillograms were statistically evaluated and described in ref.1...4.

Statistical evaluation shows clearly, positive flashes are less frequent but more severe than negative ones in mean current peak value, in electric charge and in the integral $\int i^2 dt$, which is relevant for thermal and electrodynamic effects.

To improve the statistical quality of downward positive flashes another evaluation was made for the period 1959...1973 including 48 flashes (15 thunderstorm seasons), with a mean value of 55 kA current peak. The mean frequency of registered positive discharges in the two towers is:

28 : 9 = 3,1 per year in the 9 years period
48 : 15 = 3,2 " " " " 15 " "

Taking in account the missed registrations a mean frequency of about four positive flashes may be assumed. This number of flashes is equal to the number of strokes, because positive flashes (with very few exceptions)have only 1 stroke per flash.

2. Types of lightning flashes

Current oscillograms and photography by means of fast moving film (originating in the Boys-camera) reveal several types of discharges which are represented diagrammatically by Fig. 1.

Polarity of the cloud charge defines also polarity of stroke current. Polarity of electric charge in the leader is the same as for current only for downward leaders, but opposite for upward leaders. Leader photography by means of "Boys"-cameras is well possible for negative leader charge, but very difficult for the faint trace of positively charged leaders. Therefore the indication "Fotos" in Fig. 1.

The classical fotos of leader progression by Sir B.F.J. Schonland (ref. 7) corresponds to type 2 in Fig. 1. Fig. 2 is an analog photograph from Mount S. Salvatore. Point A is the junction point where the negative downward leader met the positively charged upward connecting or junction leader, which is too faint to be visible. But its existence is proved first by the junction point A, secondly by its branching in point B. K. B. McEachron (ref. 8) who first made a simultaneous research by C.R. oscillograph and photography states that "none of 55 strokes to the Empire State Building in New York comes from a positive cloud center. Out of 27 oscillograms all but three were entirely negative." All observartions by McEachron relate to the types 1 and 2 of fig. 1 (negative clouds). There are the first observations of upward leaders. It is astonishing there are no observations of type 3 and 4 (positive clouds), this in contradiction to the observations on Mount S. Salvatore. 102 of the 130 positive currents to Mount S. Salvatore represent upward leaders without any return strokes, type 3 in fig. 1. Their currents are between 100 A and 1 or 2 kA; their electric charge is rather high. The remainder of 28 positive cloud discharges as shown in type 4 of fig. 1 apparently never have been observed before the reseaech on Mount S. Salvatore. These flashes shall be discussed as follows.

3. Typical positive flashes to Mount S. Salvatore : Type 4 of Fig. 1

From the simultaneous registrations of current and progression of leaders it becomes evident that, with a delay of up to abount 25 ms after the inset of an upward leader, a strong impulse current appears together with a bright "return stroke". See Fig. 3 as an example. From this figure emerges some difficulty when defining upward and downward strokes: Regarding leader progression the flash is an upward one, regarding the heavy cloud discharge it is a downward one. In our statistical evaluation we proceeded this way: When the electric charge in the impulse cloud discharge is greater than the upward leader charge we called it as downward flash. This is the usual case with type 4 in fig. 1. Considering this picture it seems justified to denominate the long leader in fig. 3 as an extremely long connecting leader to an already existing intracloud discharge. In this view type 4 corresponds exactly to the classical type 2 of the negative cloud. Instead of about 100 m there are several km length of the connecting leader.

The Fig. 4...10 illustrate some examples of positive downward flashes according to type 4 in fig. 1. The first curves are current curves, traced on the base of electromagnetic oscillograms, the second ones are traced by a special C.R.oscillogram. Fig. 4 is a complete record, where the two current curves are supplemented by 5 field mill registrations: 1 with a classical field mill on Mount S. Salvatore, 4 of a new type, one on a measuring tower and 3 on points at 2,5 - 3,5 - 3,3 km distance (for details see ref. 4 or 5). A first proof of the preexistence of an intracloud discharge just before the beginning of the upward leader is given by the field oscillogram. Another proof of fast field variation is realized by a very sensitive measurement of corona-current to the tower antenna (range 10 to 300 mA), curve C. A third proof is shown by the curve *L* which represents the illumination of the sky even before the leader becomes visible. This curve *L* (light) is produced by an"electronic eye" on top of the mountain church. Fig. 5...8 have in excess of the two current curves a single field curve as measured on the montain. These field curves normally show a sudden charge of field polarity in the moment of upward leader inset, but rather small an effect of impulse current (stroke current) on field.

Fig. 11 shows the time interval T between leader beginning and "return stroke" as abscissa, and current peak as ordinate. Most intervals are between 10 and 25 ms leader duration. If we admit mean leader velocities of 150...200 m/ms according to ref. 4 or 5, the normal height of the junction point with the intracloud discharge is between 1,5 and 4 km. It may be of interest to mention some very high impulse currents together with very short leader durations (T = 1...4 ms), corresponding to very low intracloud branches. Some oscillograms prove the existance of such short or fast connecting leaders.

Fig. 12 answers the question about correlation of current peak and current steepness (di/dt max). There is no evidence of such a correlation.

4. Discussion

A first observation relates to the exceptional long duration or length of the upward leader to the positive clouds above Mount S. Salvatore, with the consecutive impulse discharge. It is interesting to note an observation by Sir B.F.J. Schonland, ref. 7, page 93 "By sending up positive streamers which can travel the whole distance to the cloud, they often actually invite flashes of lightning to occur to them". As Schonland was concerned always with negative cloud discharges he concluded the occurence of positive upward streamers toward negative clouds. These are not sufficient in luminosity for photography. As shown in Fig. 2, short connection leaders below negative clouds do exist; their length is of the order 10...200 m, their duration less than 1 ms. Furthermore there is the big majority of upward leaders or rather "strokes" below negative clouds according to type 1 of fig. 1, which do not show any immediate downward "return stroke". They rather present a single long continuing current, or then after a complete current interruption one or more very steep impulse currents: This is the so-called multiple stroke flash. What Schonland surmised to happen with negative clouds can be observed on Mount S. Salvatore only in the form of multiple flashes with complete current interruption between the strokes to ground. But the Schonland-picture really is observable as in fig. 3...10 for discharges of positive clouds to the towers on Mount S. Salvatore.

A second observation relates to the topographic situation of Mount S. Salvatore. Its peak is 915 m above sea level or 640 m above lake Lugano. Measuring tower 1 is 90 m high (before 1958 it was 70 m), tower 2 is 400 m apart and 70 m high. For comparison the Empire State Building in 1938 was 1250 feet (375 m) high. At the first view both cases should be rather similar. Comparison of results show this is not the case. Many positive cloud discharges could be measured on Mount S. Salvatore which never could be observed on the Empire State Building. The more it seems difficult to transpose results from these to the flat country. What comparison of current and field measurements prove without any doubt that the necessary fields strength for upward leader progression ist caused by just preceeding and still lasting intracloud discharges. The field at the ground before the inset of any discharge may be positive or negative or zero; never the occurrence if a stroke is predictable by the static local field strength one or more seconds before. The most severe case like type 4 fig. 1 seems to happen only at local places with a strong field concentration, and only when the atmosphere is predisposed to intracloud discharges which have the effect to alter the ground field immediately.

A third remark refers to lightning type 5 of fig. 1: Positive downward leader and upward connecting leader. Photography of this type is seldom successful because of insufficient luminosity of positively charged leaders. There is only one undoubtful photograph of this case, with a downward positive leader, not to the towers on S. Salvatore but to the flat border of lake Lugano near Campione. Beyond a relative clear leader photo the picture on still film shows the famous loop of the lightning channel near the ground as a proof for an upward connecting leader.

Some more examples to type 5 of fig. 1 probably are represented by the points with very short leader duration T_e in fig. 11. A possible confirmation would be feasible by field oscillograms showing a fast, trumpet-like field raise curve, similar to that observed with negative clouds of type 1 of fig. 1. But all these examples of Fig. 11 refer to flashes to (or from) the towers on Mount S. Salvatore, not to the flat country.

5. Lightning and Aviation

Planes, helicopters and rockets may be involved in the lightning channel; the full current may pass their metallic bodies. The characteristics of lightning currents are well known if measured at the ground. But these characteristics certainly are functions of hight above the ground. Below negative clouds current peak and steepness are maximum at the ground, corresponding to the travelling wave theory of the upward return stroke. In the case of a long upward leader below a positive cloud the "return stroke" is initiated at the junction point at the intracloud discharge. Highest steepness and amplitude of current have to be supposed at this junction point where the downward travelling wave starts. Instead of the well conducting earth there is now a well conducting intracloud channel which behaves like a surge impedance for the lightning transient. This latter may be the reason for the lower steepness at the ground of the positive stroke of type 4 fig. 1.

The above reflexions are at the base of the strength of planes, helicopters and rockets by lightning. The problem of protection against lightning consists in fixing certain withstand values of its characteristics, which is not within the aim of this report.

List of references

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3) Berger, K.: Novel Observations on Lightning Discharges: Results of Research on Mount San Salvatore. Journal of the Franklin Institute, Vol. 283, No. 6, June 1967.

4) Berger, K.: Methoden und Resultate der Blitzforschung auf dem Monte San Salvatore bei Lugano in den Jahren 1963...1971. Bulletin SEV Bd. 63 (1972) No. 24, S. 1403...1422.

5) Berger, K.: Oszillographische Messungen des Feldverlaufs in der Nähe des Blitzeinschlages auf dem Monte San Salvatore. Bulletin SEV, Bd 64 (1973) No. 3, S. 120...136.

6) Translations of 4) and 5): Methods and results of research on lightning on Mount S. Salvatore 1963...1971. CE Translation 6253.
Oscillographic measurements of field patterns near lightning strokes on Mount S.Salvatore. CE Translation 6254.

7) Schonland, B.F.J. The flight of thunderbolts, Oxford, Clarendon Press 1950

8) McEachron, K.B. Lightning to the Empire State Building. Journal of the Franklin Institute, Vol. 227, No. 2, February 1939.

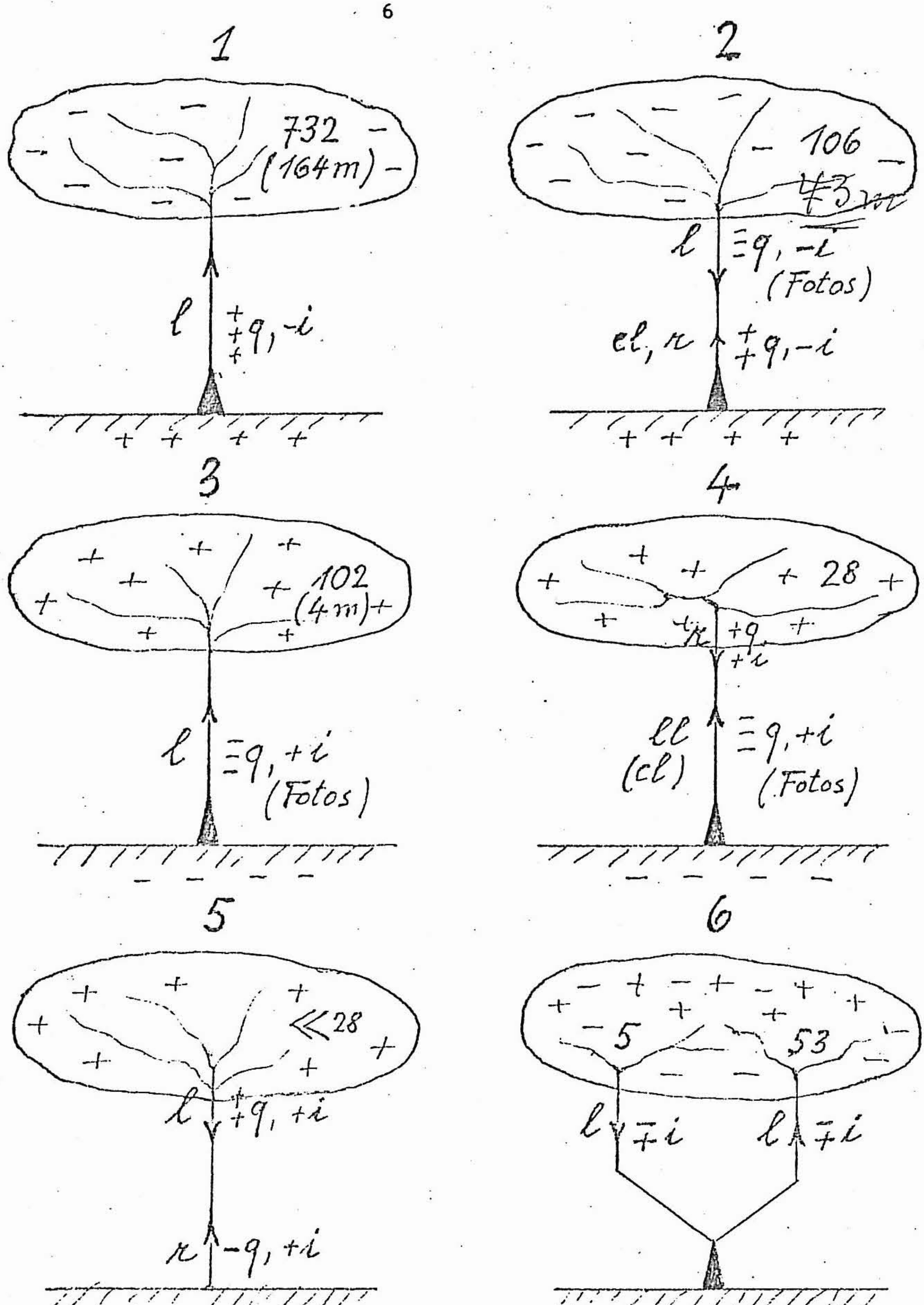


Fig. 1 Types 1...6 of lightning strokes to and from Mount San Salvatore

- *l* leader
- *r* return stroke
- *cl* connecting leader (junction leader)
- *q* electric charge
- *i* electric current

enclosed numbers: Frequency of registered flashes, m : multiple stroke flashes

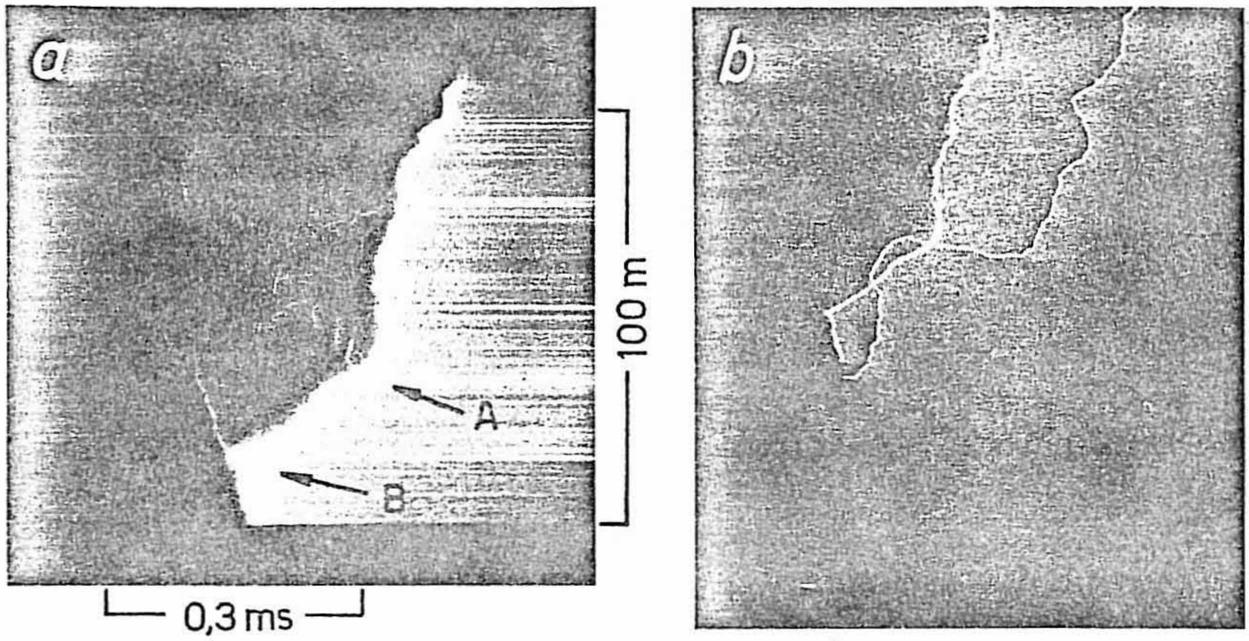


Fig. 2 Downward negative stroke of type 2 with upward connecting leader
A junction point
B branching point of connection leader
a photo on fast moving film
b photo on still film

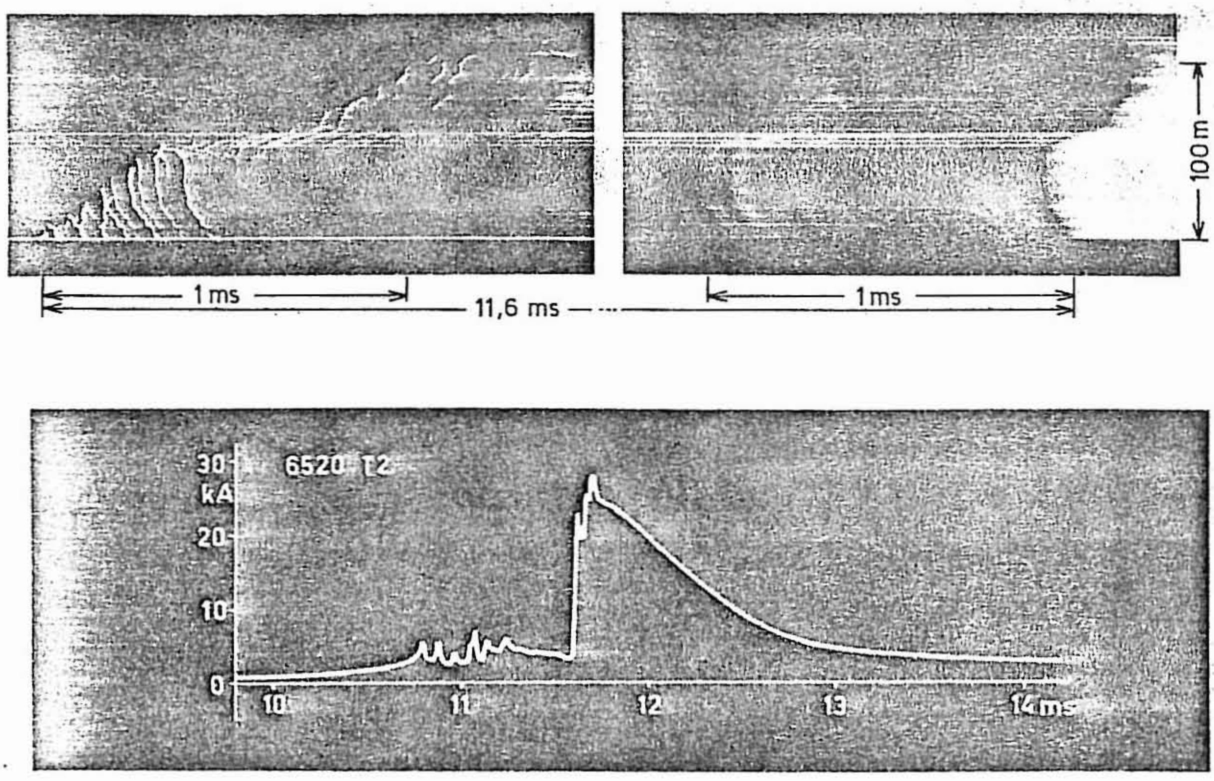
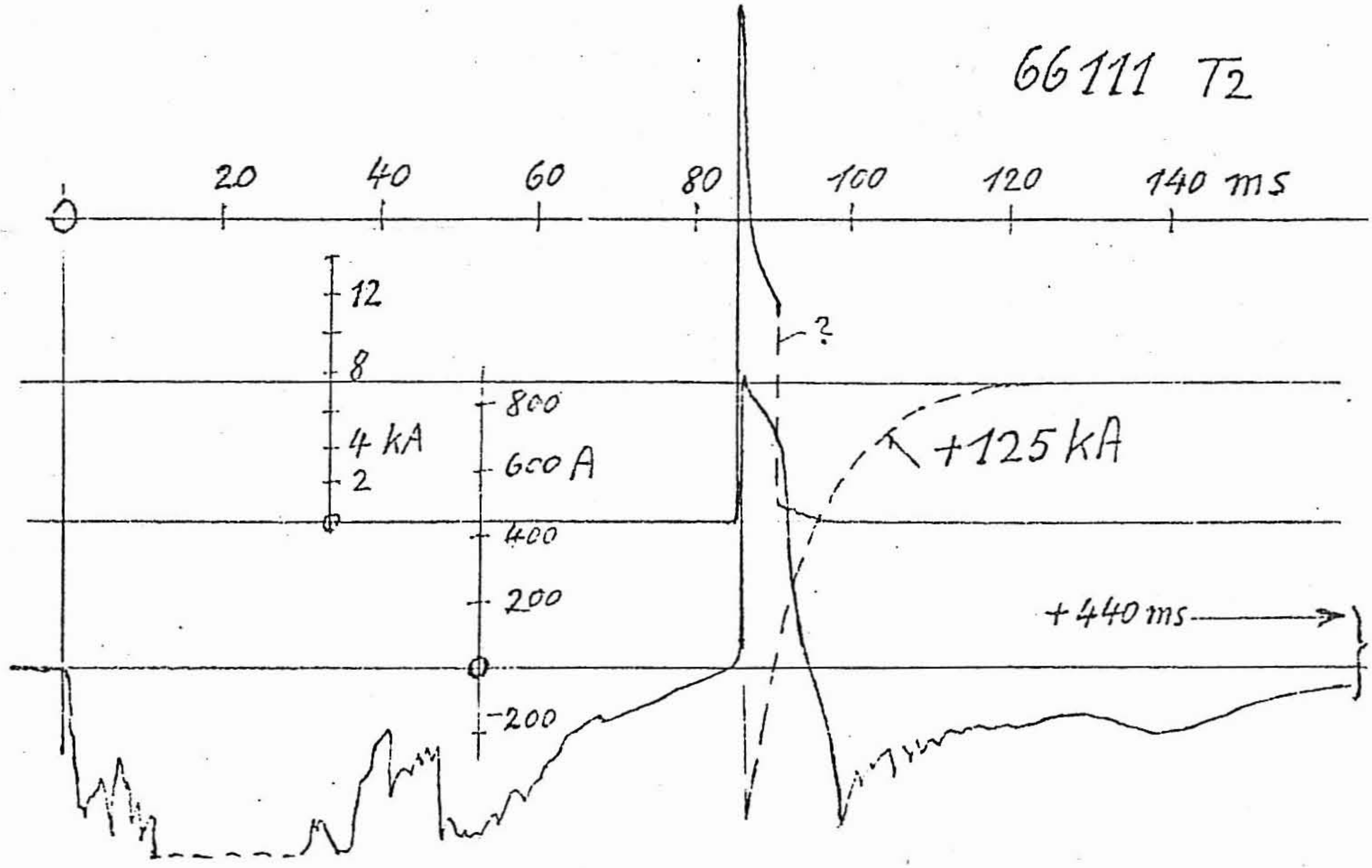


Fig. 3 Positive flash of type 4
above photo on fast moving film
below oscillogram of stroke current



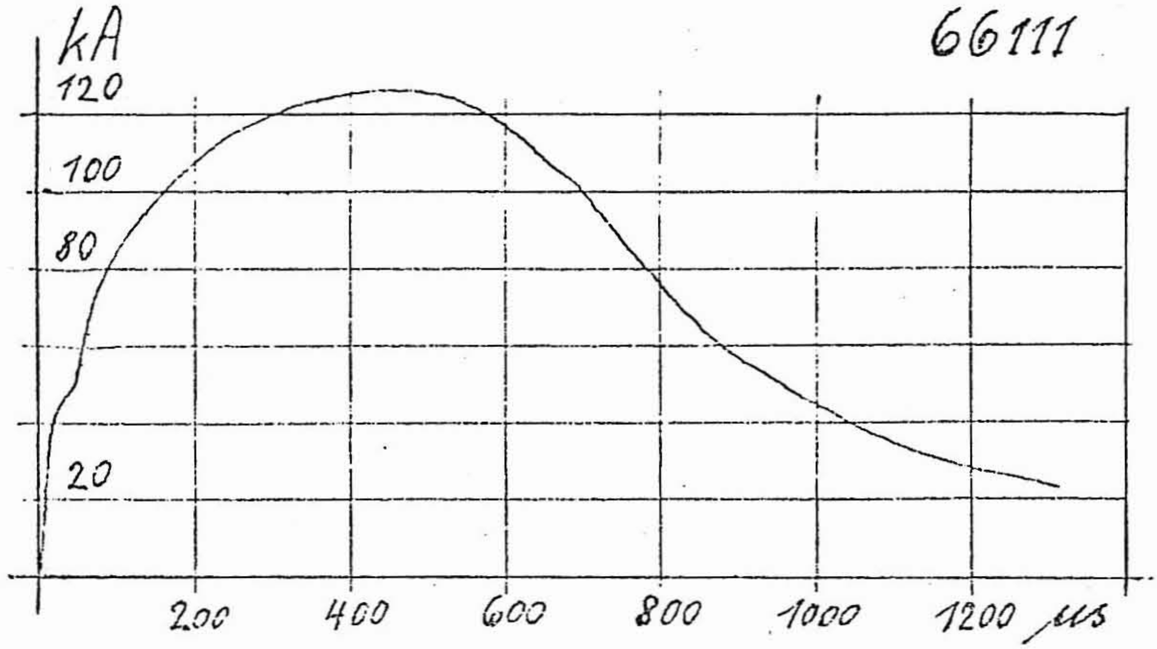
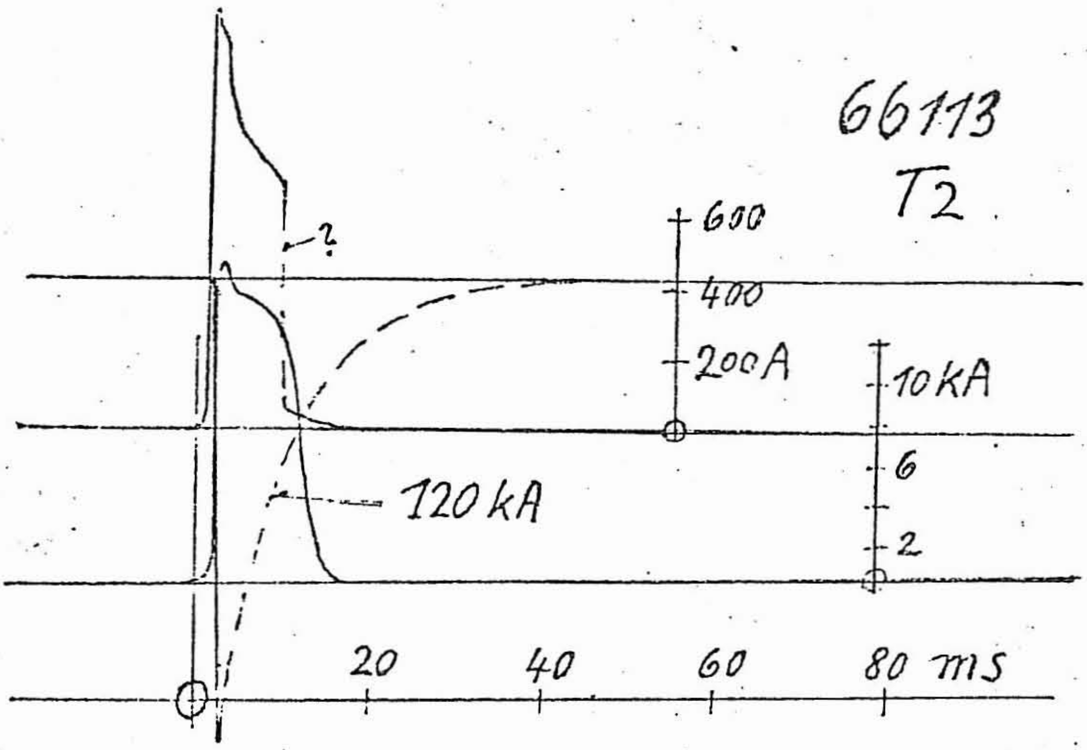


Fig. 4 Examples of oscillograms of positive flashes of type 4
to Fig. 10 above stroke current on ms-scale
middle " " on μs-scale
below (only 4...8) electric field variations during strokes
to Mount San Salvatore, details see ref. 4 and 5.


66113
T2
600
400
200 A
10 kA
6
2
120 kA
20
40
60
80 ms

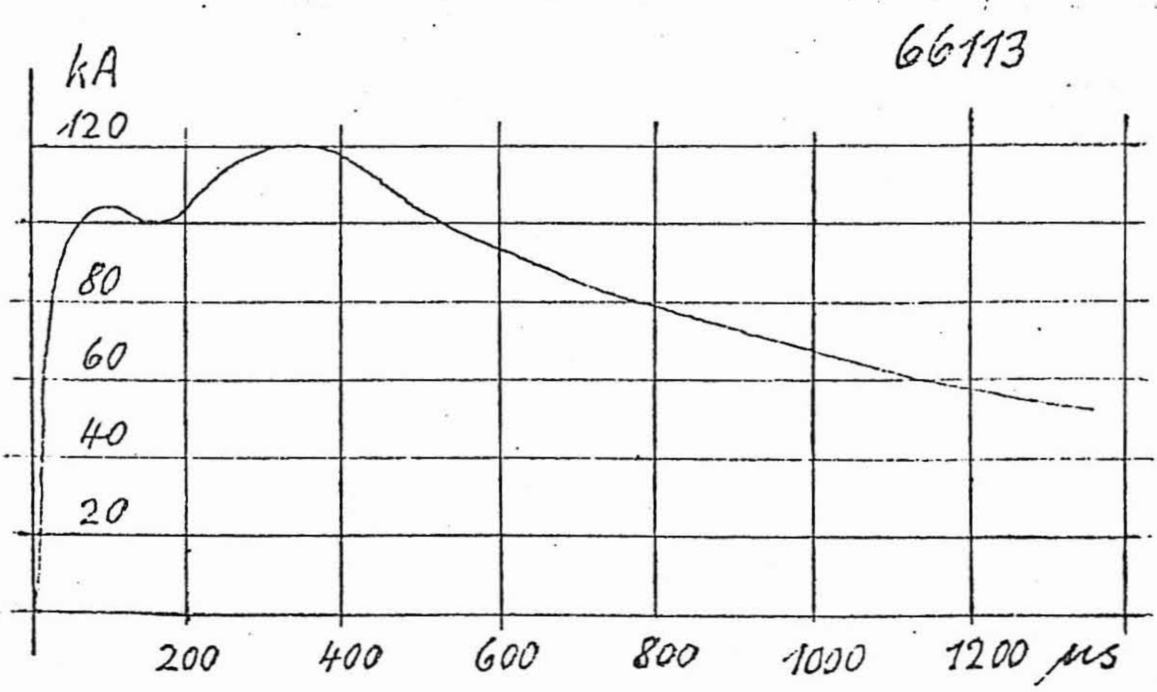

kA
66113
120
80
60
40
20
200
400
600
800
1000
1200 μs

Fig. 5

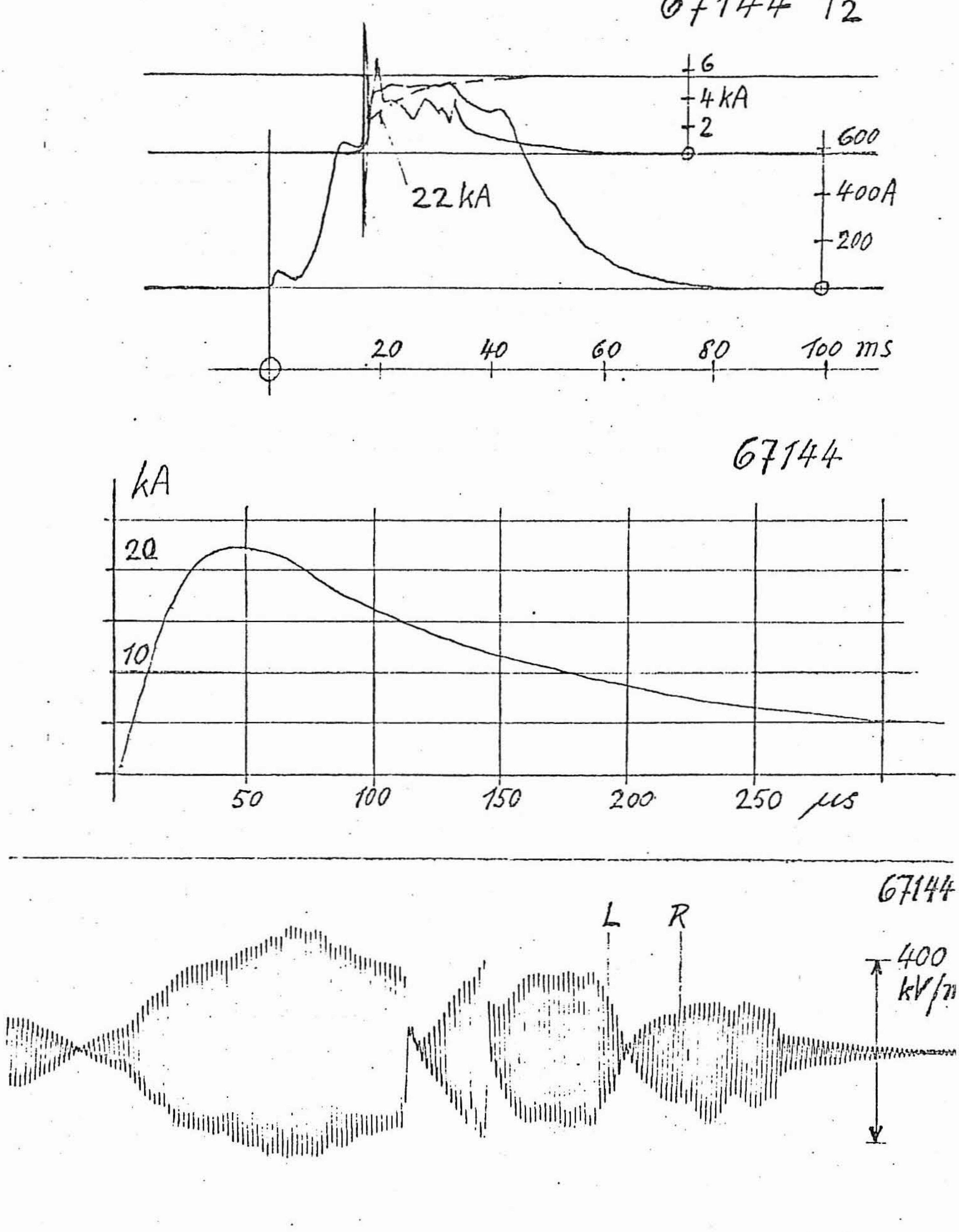

67144 T2
6
4 kA
2
600
22 kA
400 A
200
20
40
60
80
100 ms
67144
kA
20
10
50
100
150
200
250 µs
67144
L
R
400
kV/m

Fig. 6

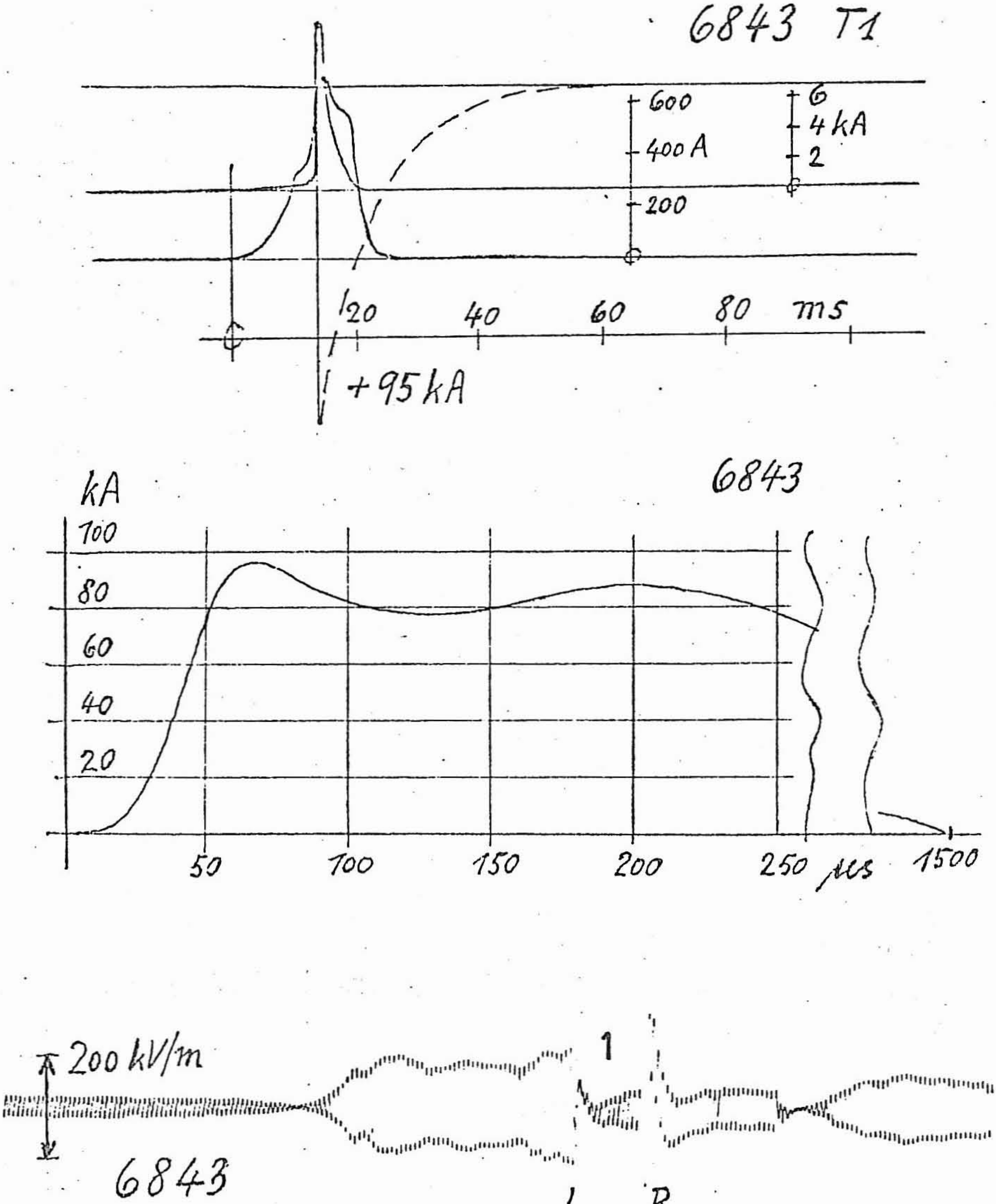

6843 T1
600
400 A
200
6
4 kA
2
20
40
60
80
ms
+95 kA
kA
6843
100
80
60
40
20
50
100
150
200
250
μs
1500
200 kV/m
1
6843
L
R

Fig. 7

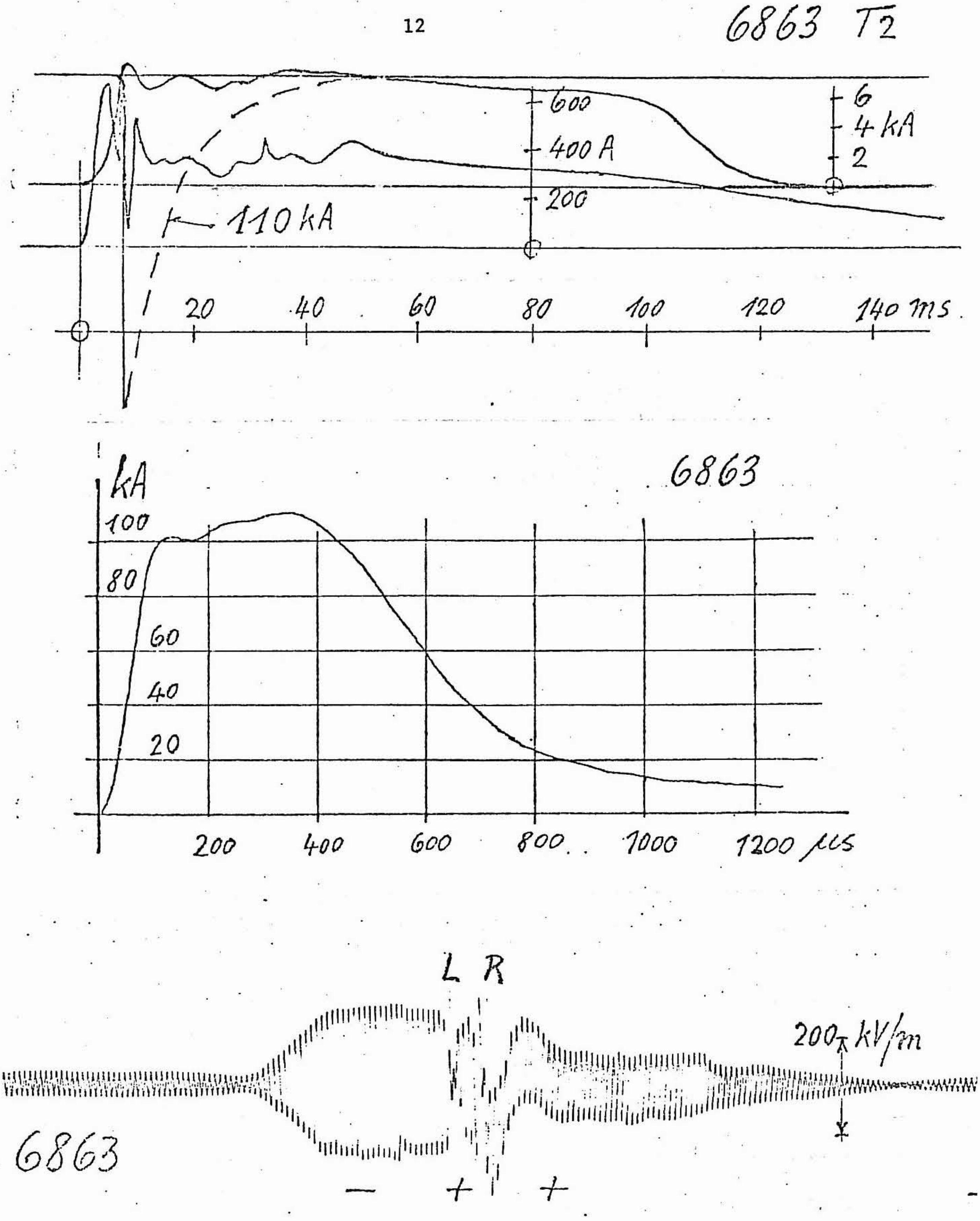

6863 T2
600
400 A
200
6
4 kA
2
110 kA
20
40
60
80
100
120
140 ms
kA
6863
100
80
60
40
20
200
400
600
800
1000
1200 μs
L R
200 kV/m
6863
–
+
+

Fig. 8

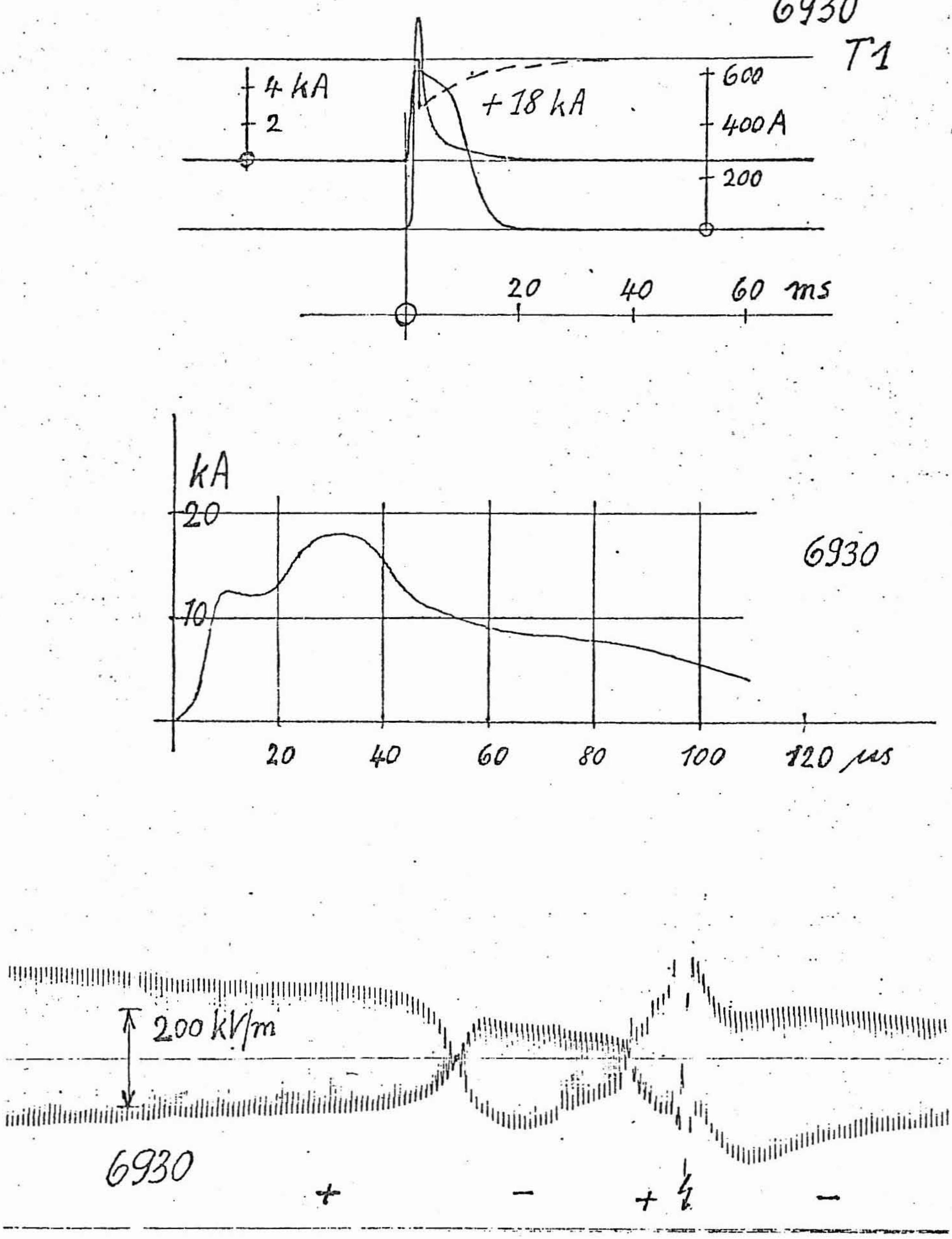

6930
T1
4 kA
2
+18 kA
600
400 A
200
20
40
60 ms
kA
20
10
6930
20
40
60
80
100
120 µs
200 kV/m
6930
+
−
+
−

Fig.9

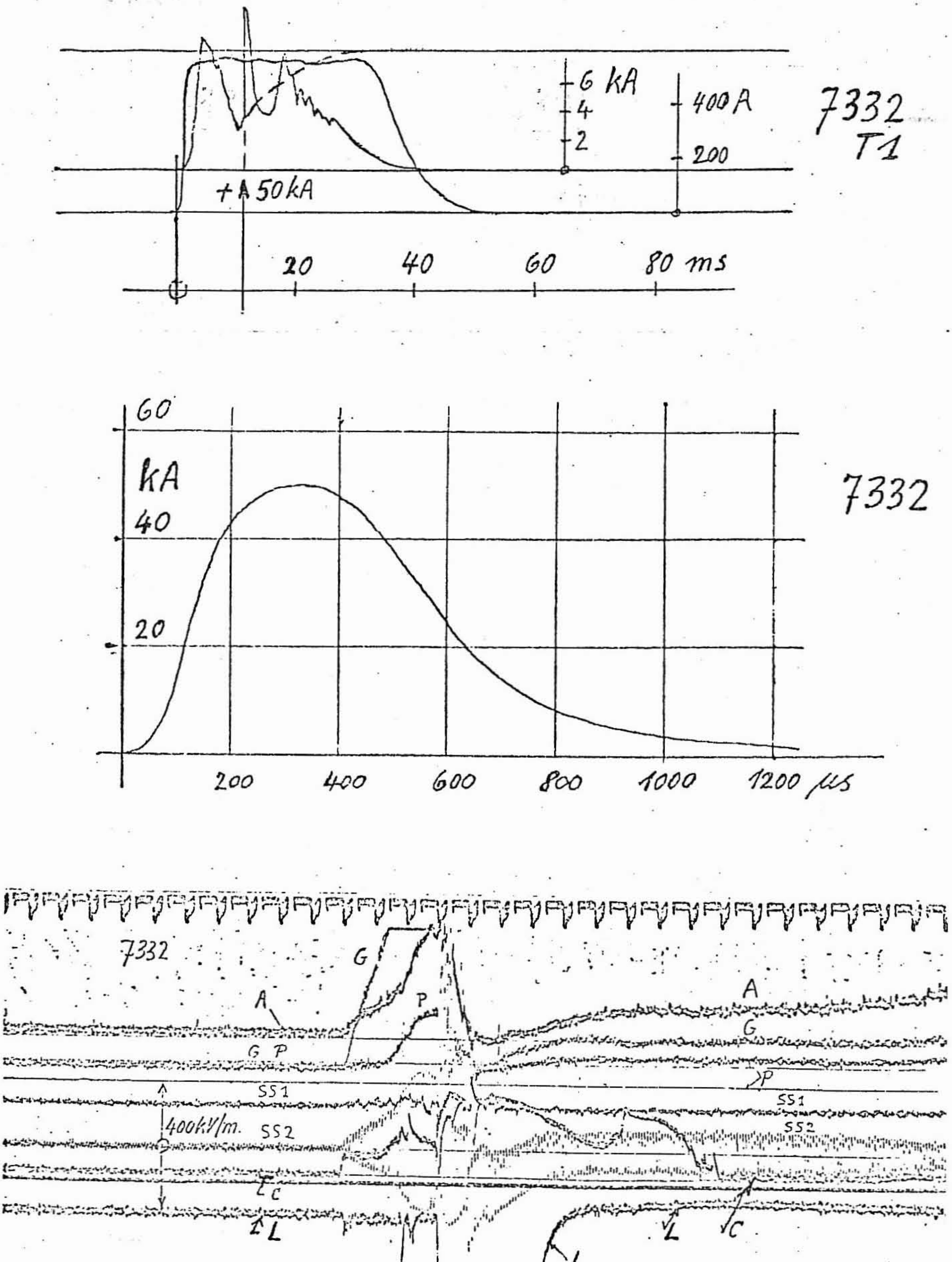

6 kA
4
2
400 A
200
7332
T1
+50 kA
20
40
60
80 ms
60
kA
40
20
7332
200
400
600
800
1000
1200 µs
7332
G
A
P
A
G
G P
P
SS1
SS1
400kV/m.
SS2
SS2
C
L
L
C
L

Fig. 10

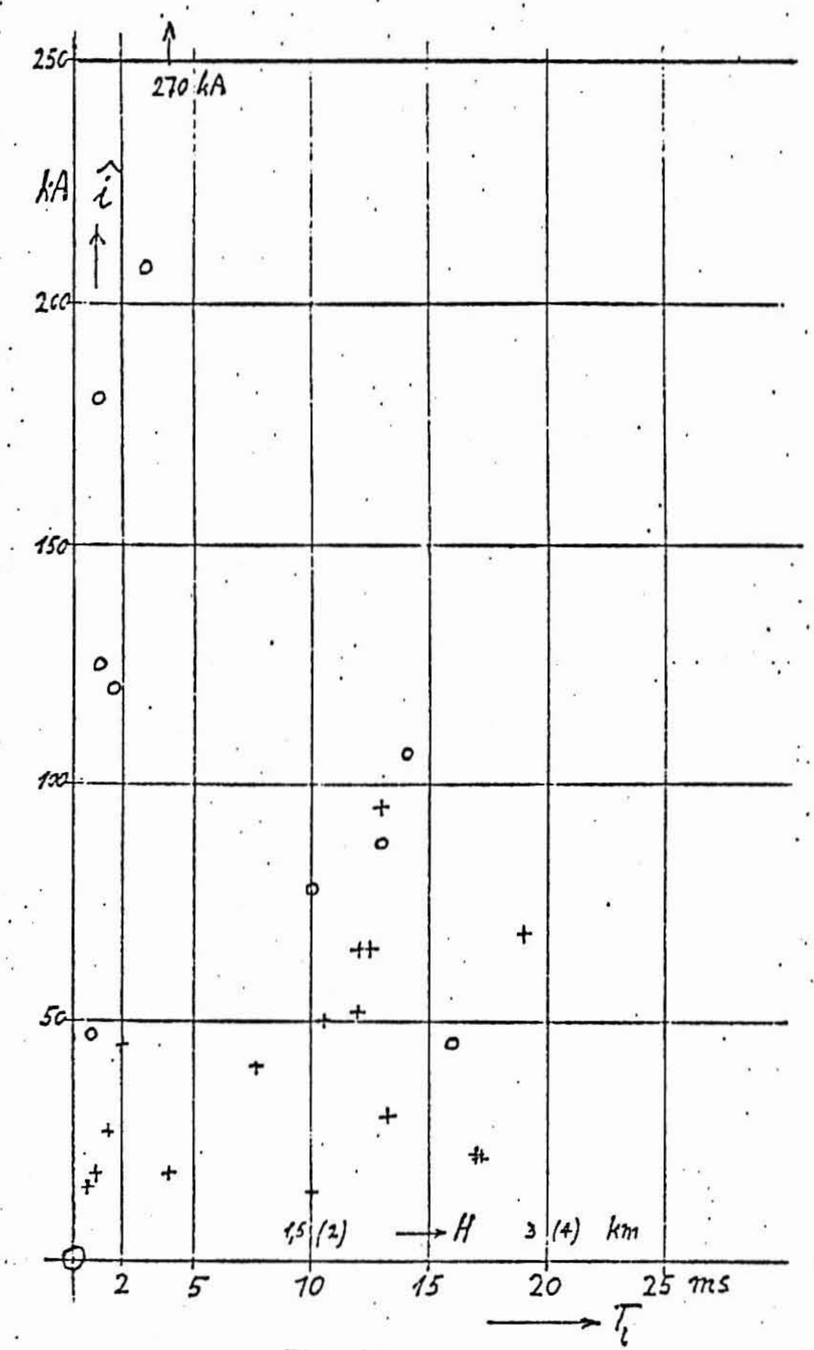


Fig. 11

Leader duration T_l and stroke current $\hat{i}$ for flashes of type 4,
Leader height H calculated with 150 and 200 m/ms leader velocity

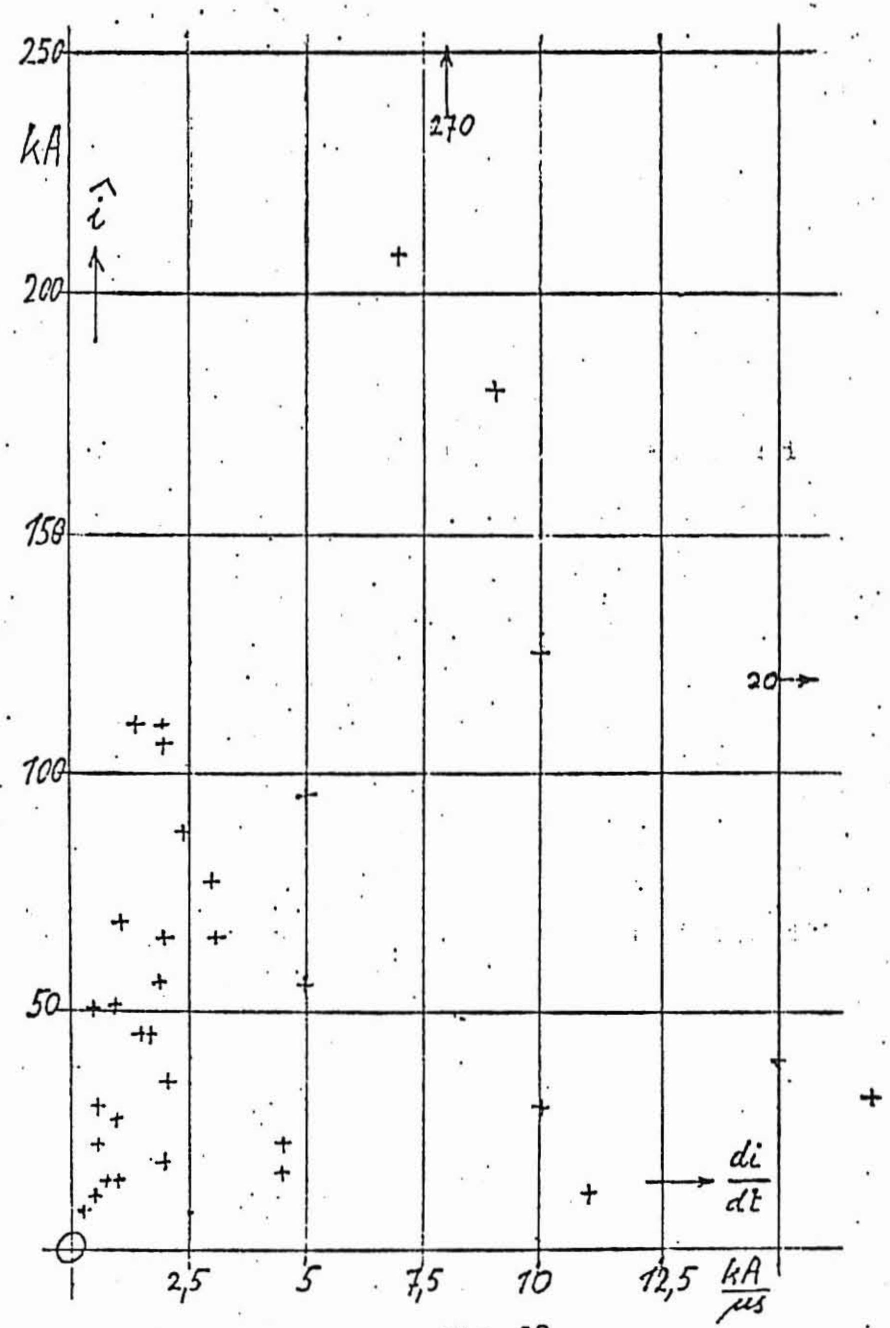


Fig. 12

Stroke current peak and current steepness for registered flashes of type 4

Blitzforschung

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B l i t z s t r o m - P a r a m e t e r

Resultate der statistischen Auswertung der Blitzstrom-Messungen auf dem Monte San Salvatore 1963...1971

Beobachtungs-No.	Parameter	Einheit	Prozentuale Ueberschreitung der Tabellenwerte 95 %	50 %	5 %
	Blitzstrom-Scheitelwert (> 2 kA)				
99	Negative erste Teilblitze	kA	14	30	80
137	" Folgeblitze	kA	4.6	12	30
28	Positive Blitze (Folgeblitze nicht vorhanden)	kA	4.6	35	250
	Ladung				
91	Negative erste Teilblitze	C	1.1	5.2	24
124	" Folgeblitze	C	0.2	1.4	11
88	" Gesamtblitze	C	1.3	7.5	40
26	Positive Blitze	C	20	80	350
	Impuls-Ladung				
88	Negative erste Teilblitze	C	1.1	4.5	20
119	" Folgeblitze	C	0.22	0.95	4.0
25	Positive Blitze (nur ein Teilblitz)	C	2.0	16	150
	Frontdauer				
87	Negative erste Teilblitze	µs	1.8	5.5	18
120	" Folgeblitze	µs	0.22	1.1	4.5
19	Positive Blitze	µs	3.5	22	200
	Grösste Steilheit di/dt				
90	Negative erste Teilblitze	kA/µs	5.5	12	32
124	" Folgeblitze	kA/µs	12	40	120
21	Positive Blitze	kA/µs	0.20	2.4	32
	Halbwertdauer				
78	Negative erste Teilblitze	µs	30	75	200
104	" Folgeblitze	µs	6.5	32	140
16	Positive Blitze	µs	25	230	2000
	Integral $i^2 dt$				
89	Negative erste Teilblitze	A^2s	6.0×10^3	5.5×10^4	5.5×10^5
64	" Folgeblitze		5.5×10^2	6.0×10^3	5.2×10^4
26	Positive Blitze		2.5×10^4	6.5×10^5	1.5×10^7
133	**Zeitintervall zwischen negativen Teilblitzen**	ms	7	33	150
	Dauer des Gesamtblitzes				
92	Negative (Einfachblitze eingeschlossen)	ms	0.15	13	1100
39	" (Einfachblitze ausgeschlossen)	ms	31	180	900
26	Positive Blitze	ms	14	85	500