HUBBELL POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1518-H-00.1
H5 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 5

This report records the results of type tests made on H5 series 20 kA Line Discharge Class 5 arresters, rated up to 612 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.0, 2004, "Surge arresters - Part 4: Metal-oxide surge arresters without gaps for a.c. systems."

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

Michael G. Comber

M. G. Comber
Manager, Engineering

Date: 2/2/2007

Separate reports provide details of each test, according to the following table:

Report No.	Description	Clause	Issue date
EU1518-H-01	Insulation Withstand Test on Arrester Housing	8.2.6, 8.2.7, 8.2.8	9/23/2004
EU1518-H-02.1	Residual Voltage	8.3.1, 8.3.2, 8.3.3	2/2/2007
EU1518-H-03	Long Duration Current Withstand	8.4.2	9/23/2004
EU1518-H-04	Accelerated Aging Procedure	8.5.2	9/23/2004
EU1518-H-05	Heat Dissipation Behaviour of Test Section	8.5.3/annex B	9/23/2004
EU1518-H-06	Switching Surge Operating Duty	8.5.5	9/23/2004
EU1518-H-07	Short Circuit	8.7/Annex N	9/23/2004
EU1518-H-08	Internal Partial Discharge	8.8	9/23/2004
EU1518-H-09	Bending Moment	8.9	9/23/2004
EU1518-H-10	Seal Leak Rate	8.11	9/23/2004
EU1518-H-11	RIV	8.12	9/23/2004
EU1518-H-12.1	Power Frequency Voltage Versus Time	Annex D	2/2/2007
EU1518-H-13	Artificial Pollution	Annex F	9/23/2004

IEC Type Test Report
Report No. EU1518-H-01
H5 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 5

Insulation Withstand Test on Arrester Housing

This report records the results of type tests made on H5 series 20 kA Line Discharge Class 5 arresters, rated up to 612 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.0, 2004, "Surge arresters - Part 4: Metal-oxide surge arresters without gaps for a.c. systems."

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

M. G. Comber
Manager, Engineering

Date: 9/23/2004

IEC TYPE TEST REPORT
Insulation Withstand Test on Arrester Housing

TESTS PERFORMED:
Insulation withstand tests were made on one arrester unit with internal components removed. Tests were conducted according to the procedures of Clauses 8.2.6, 8.2.7 and 8.2.8 of IEC 60099-4, which stipulate that the external insulation withstand of the arrester housing shall conform to the following:

- Lightning impulse withstand voltage in dry conditions shall not be less than the lightning impulse protective level of the arrester unit multiplied by 1.3.
- Switching impulse withstand voltage in wet conditions shall not be less than the switching impulse protective level of the arrester unit multiplied by 1.25.
- Power frequency withstand voltage (peak value) in wet conditions shall not be less than the switching impulse protective level of the arrester unit multiplied by 1.06 for a duration of 1 min.

RESULTS:

The H5 series of arresters uses three different housing lengths, all of the same individual weathershed geometry; they are designated as P14, P20 and P26. The P26 is the longest of the three housings and also has the highest voltage stress per unit length, as indicated in Table 1. The insulation withstand tests were performed on a sample constructed with a P26 housing.
The maximum lightning impulse protective level associated with this housing (U_c = 117.5 kVrms) is 339 kV at 20kA., and the associated maximum switching impulse protective level is 282 kV at 2kA.

Table 1. Porcelain housings used in H5 series arresters

Housing Designation	Dry arc length	Max U_c used in housing	Max voltage stress U_c / dry arc length
	mm	kVrms	V/mm
P14	813	65.5	80.6
P20	1044	90	86.2
P26	1303	117.5	90.2

Lightning impulse
The lightning impulse test was performed under dry conditions by applying 15 positive and 15 negative full-wave lightning-impulse voltages to the test sample. The impulse voltages had a virtual front time of 1.2 µs (±30%) and a virtual time to half value of 50 µs (±20%). The test sample withstood all impulses without disruptive discharge. The withstand voltages obtained were corrected to standard atmospheric conditions in accordance with IEC 60060-1.
The required minimum lightning impulse withstand voltage is 1.3 times the maximum lightning impulse protective level, or 1.3 x 339 = 441 kV.

Switching impulse
The switching impulse test was performed under wet conditions by applying 15 positive and 15 negative full-wave switching-impulse voltages to the test sample. The precipitation conditions and resistivity of the water were in accordance with the requirements of IEC 60060-1. The impulse voltages had a time to crest value of 250 µs (±20%) and a time to half value of 2500 µs (±60%). The test sample withstood all impulses without disruptive discharge. The withstand voltages obtained were corrected to standard atmospheric conditions in accordance with IEC 60060-1.
The required minimum switching impulse withstand voltage is 1.25 times the maximum switching impulse protective level, or 1.25 x 282 = 353 kV.

Power frequency
The power frequency test was performed under wet conditions by applying a 60 Hz voltage for a duration of 1 min. The precipitation conditions and resistivity of the water were in accordance with the requirements of IEC 60060-1. The test sample withstood the applied voltage without disruptive discharge.
The required minimum power frequency withstand voltage is 1.06 times the maximum switching impulse protective level, or 1.06 x 282 = 299 kVpeak.

Tests were successfully performed at levels significantly higher than the minimum levels indicated above. Results are summarized in Table 1.

Table 1. Measured and corrected withstand values

Withstand test	Uncorrected withstand voltage	Atmospheric conditions			Correction factors		Corrected withstand
		Ambient temperature	Air pressure	Absolute humidity	Air density	Humidity	
	kV pk	°C	KPa	gm^{-3}	k_1	k_2	kV peak
Lightning impulse, pos	498	23.5	98.2	18.06	.958	1.028	490
Lightning impulse, neg	503	23.5	98.2	18.06	.958	1.028	495
Switching impulse, pos	413	22.9	98.5	Wet test	.963	1.000	398
Switching impulse, neg	420	22.9	98.5	Wet test	.963	1.000	404
60 Hz	479	21.4	98.2	Wet test	.964	1.000	462

IEC Type Test Report
Report No. EU1518-H-02
H5 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 5

Residual Voltage

This report records the results of type tests made on H5 series 20 kA Line Discharge Class 5 arresters, rated up to 612 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.0, 2004, "Surge arresters - Part 4: Metal-oxide surge arresters without gaps for a.c. systems."

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

M. G. Comber
Manager, Engineering

Date: 2/2/2007

IEC TYPE TEST REPORT
Residual Voltage

TESTS PERFORMED:
Residual voltage measurements were made on three single resistor elements. Tests were conducted in accordance with clauses 8.3.1, 8.3.2 and 8.3.3 of IEC 60099-4, to determine steep current impulse residual voltages at 20 kA, lightning impulse residual voltages at 10 kA, 20 kA and 40 kA, and switching impulse residual voltages at 0.5 kA and 2 kA. Oscillograms of current and voltage were obtained for each test.

The H5 series of arresters ia comprised of multiple units in which each unit contains two matched parallel columns of non-linear resistors. Residual voltage tests were performed on individual resistors of diameter 75 mm and height 32 mm. To enable the determination of residual voltages for a complete arrester at the current levels identified above, the residual voltage tests were performed at currents that are one-half of the values identified above.

For each test sample, all measured voltages have been rationalized to the lightning impulse residual voltage of that sample at nominal discharge current (10 kA 8/20 on the individual resistor, equivalent to 20 kA in the two column arrester), and the results have been displayed in graphical form, showing per unit voltage vs. arrester impulse current.

RESULTS:
Tables 1, 2 and 3 show the residual voltages measured on test samples 1, 2 and 3, respectively. For each test sample, the measured residual voltages have been expressed in per unit of the lightning impulse residual voltage at nominal discharge current.

Table 1. Measurements made on test sample 1

Test Wave	Test current magnitude	Equivalent 2-column arrester current	Waveshape	Residual Voltage		Oscillogram
	kA	kA	_s	kV	p.u.	number
Steep current	10	20	1/2	10.88	1.080	25
Lightning impulse	5	10	8/20	9.42	0.935	1
	10	20		10.07	1.000	4
	20	40		10.90	1.082	7
Switching impulse	0.25	0.5	36/76	7.91	0.791	13
	1	2		8.35	0.829	19

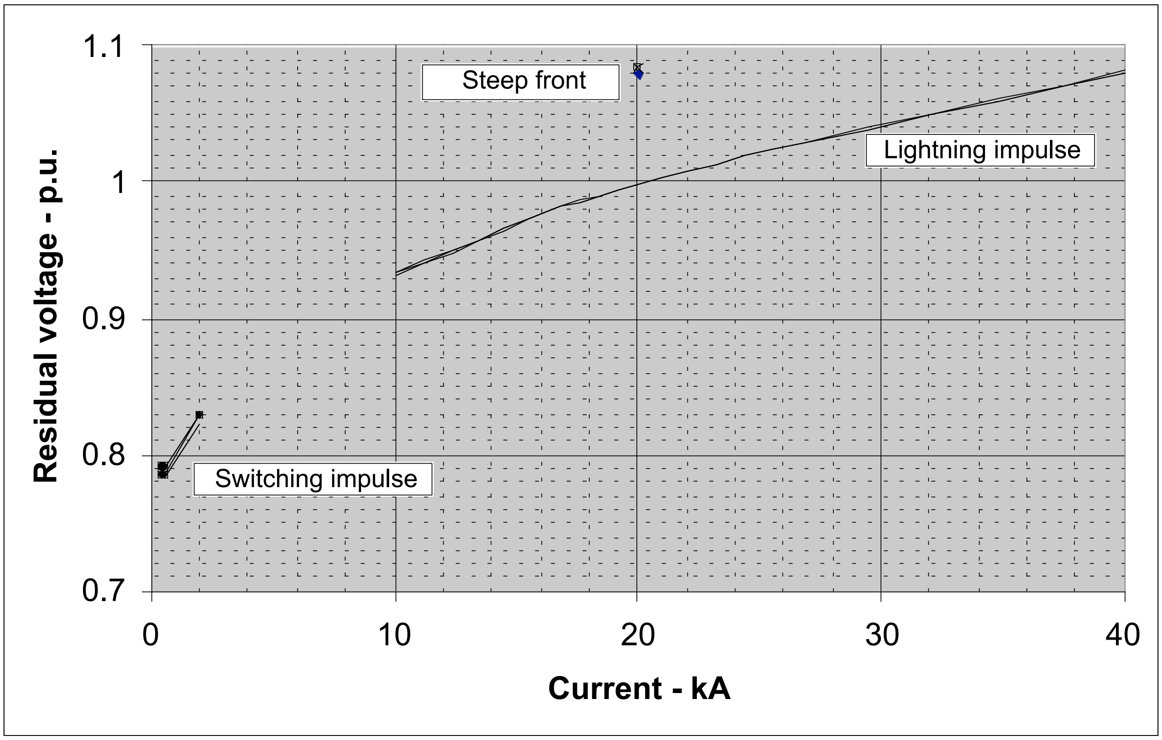
Table 2. Measurements made on test sample 2

Test wave	Current magnitude	Equivalent 2-column arrester current	Waveshape	Residual Voltage		Oscillogram
	kA	kA	_s	kV	p.u.	number
Steep current	10	20	1/2	10.88	1.084	26
Lightning impulse	5	10	8/20	9.37	0.933	2
	10	20		10.04	1.000	5
	20	40		10.86	1.082	8
Switching impulse	0.25	0.5	36/76	7.86	0.783	14
	1	2		8.30	0.823	20

Table 3. Measurements made on test sample 3

Test wave	Current magnitude	Equivalent 2-column arrester current	Waveshape	Residual Voltage		Oscillogram
	kA	kA	_s	KV	p.u.	number
Steep current	10	20	1/2	10.87	1.084	27
Lightning impulse	5	10	8/20	9.38	0.934	3
	10	20		10.04	1.000	6
	20	40		10.87	1.083	9
Switching impulse	0.25	0.5	36/76	7.88	0.785	15
	1	2		8.32	0.829	21

The results are shown graphically in the following chart. When expressed in terms of per unit of the residual voltage at nominal discharge current, the residual voltages of Type H5 arresters for steep front, lightning impulse and switching impulse do not exceed values shown in this chart.



The values shown in this chart are all normalized to the lightning impulse residual voltage at nominal discharge current (20 kA). These values (*Per-unit* $U_{res\text{-}chart}$) are used to calculate the residual voltage characteristics ($U_{res\text{-}arrester}$) of assembled H5 series arresters. For the cases of switching impulse and lightning impulse residual voltages, the arrester residual voltages are calculated as follows:

$$U_{res\text{-}arrester} = \text{Per-unit } U_{res\text{-}chart} \; x \; U_{res\text{-}nom}$$

where Ures-nom is the published maximum lightning impulse residual voltage of the arrester, as verified by routine test at time of arrester manufacture.

For the case of steep current impulse residual voltage, the arrester residual voltage is calculated as follows:

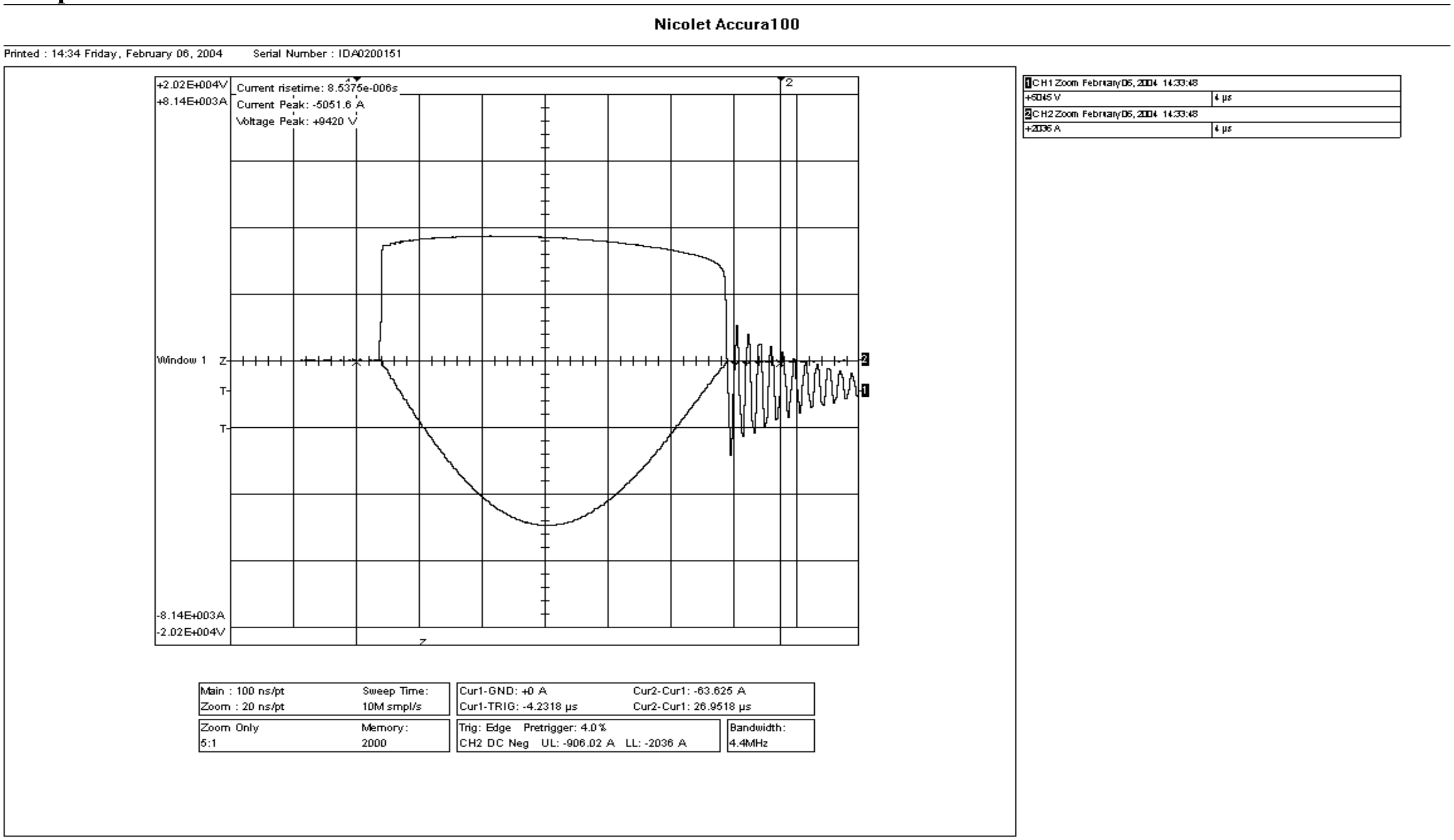
$$U_{res\text{-}arrester} = \text{Per-unit } U_{res\text{-}chart} \; x \; U_{res\text{-}nom} + L' \, h \, I_n / T_f$$

where
L' is the inductivity per unit length (= 1 µH/m)
h is the length of the arrester (excluding the resistors since resistor inductance is already included in the test measurements)
I_n is the nominal discharge current (= 20 kA)
T_f is the front time of the steep current impulse (= 1µs)

Annex

Oscillograms

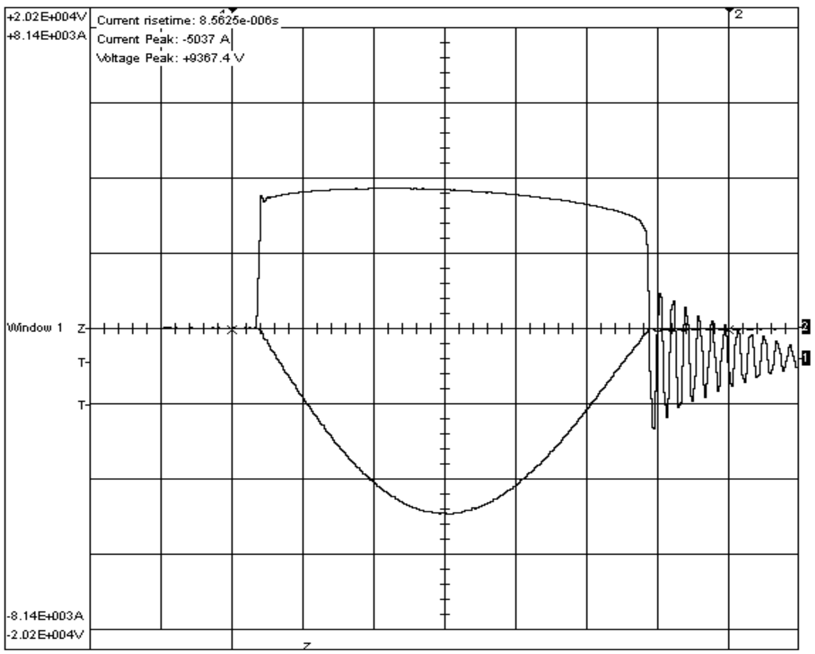
Oscillogram 1
Sample 1



Oscillogram 2
Sample 2

Nicolet Accura100

Printed : 14:36 Friday, February 06, 2004 Serial Number : IDA0200151



1 CH1 Zoom February 06, 2004 14:36:38	
+5045 V	4 µs
2 CH2 Zoom February 06, 2004 14:36:38	
+2036 A	4 µs

Main : 100 ns/pt	Sweep Time:
Zoom : 20 ns/pt	10M smpl/s
Zoom Only	Memory:
5:1	2000

Cur2-GND: -21.208 A	Cur2-Cur1: -10.604 A
Cur2-TRIG: 23.76 µs	Cur2-Cur1: 27.9918 µs

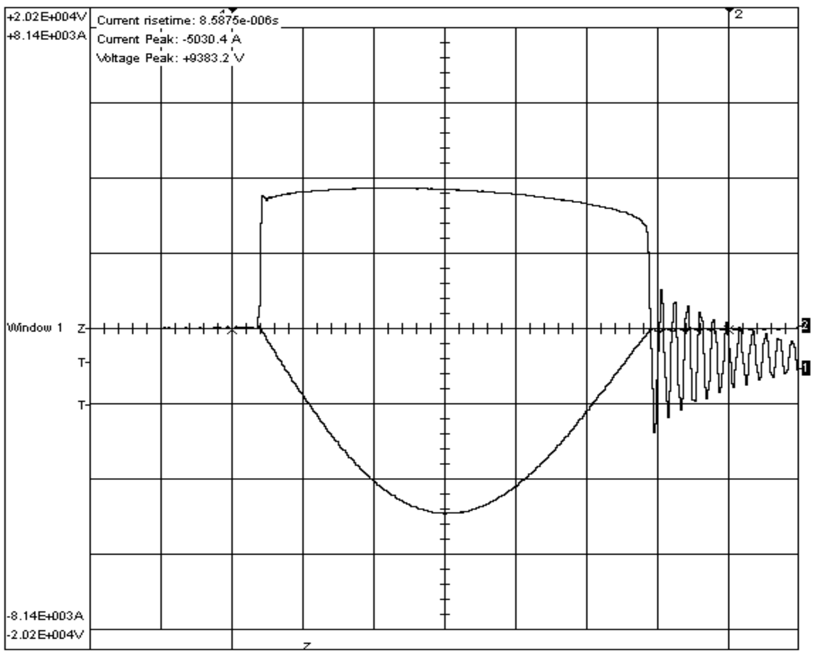
Trig: Edge Pretrigger: 4.0 %
CH2 DC Neg UL: -906.02 A LL: -2036 A

Bandwidth:
4.4MHz

Oscillogroam 3
Sample 3

Nicolet Accura100

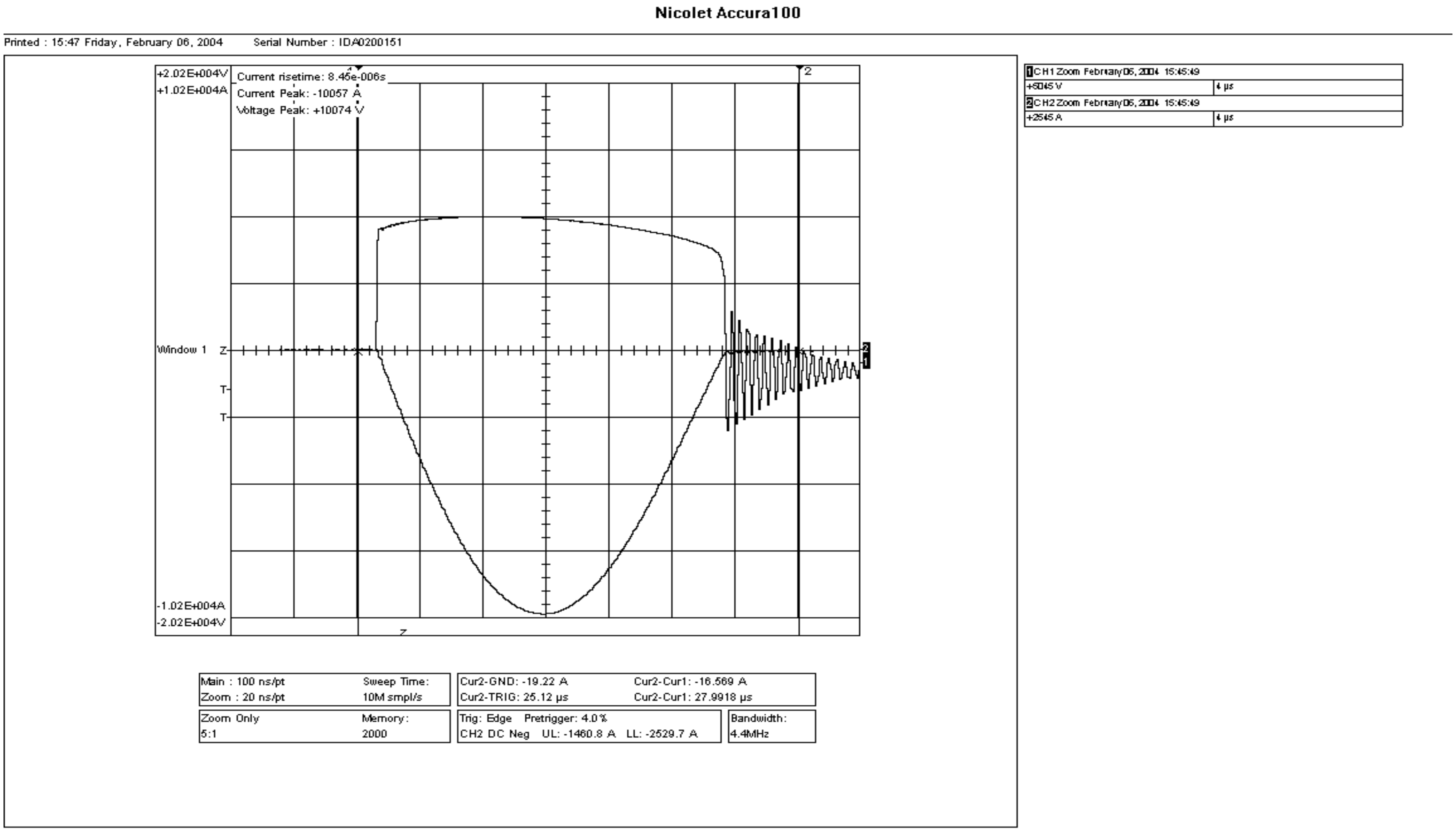
Printed : 14:38 Friday, February 06, 2004   Serial Number : IDA0200151



1 CH1 Zoom February 06, 2004 14:37:55	
+5045 V	4 μs
2 CH2 Zoom February 06, 2004 14:37:55	
+2036 A	4 μs

Main : 100 ns/pt Zoom : 20 ns/pt	Sweep Time: 10M smpl/s
Cur1-GND: -2.651 A Cur1-TRIG: -4.2318 μs	Cur2-Cur1: -29.161 A Cur2-Cur1: 27.9918 μs
Zoom Only 5:1	Memory: 2000
Trig: Edge Pretrigger: 4.0 % CH2 DC Neg UL: -906.02 A LL: -2036 A	Bandwidth: 4.4MHz

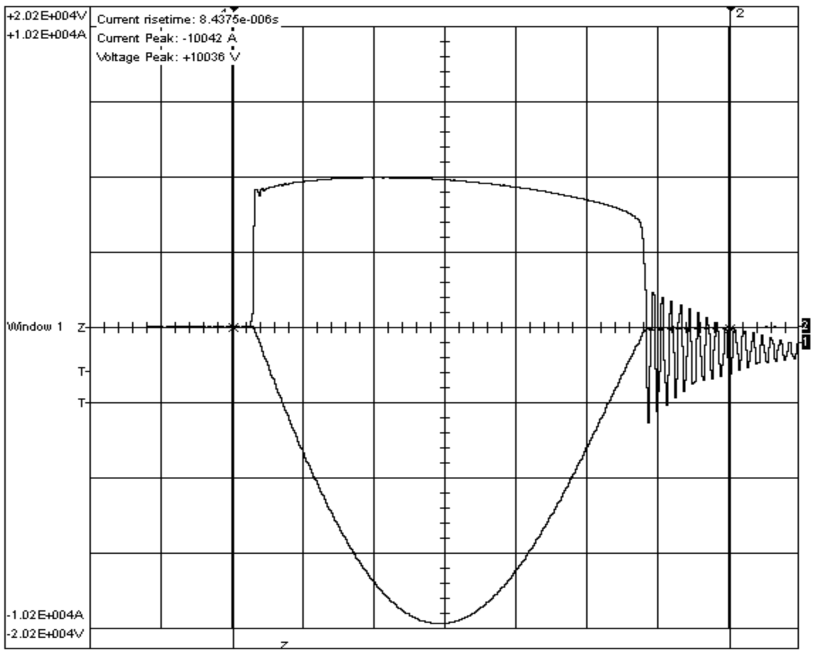
Oscillogram 4
Sample 1



Oscillogram 5
Sample 2

Nicolet Accura100

Printed : 15:48 Friday, February 06, 2004 Serial Number : IDA0200151



Main : 100 ns/pt	Sweep Time:
Zoom : 20 ns/pt	10M smpl/s

Cur2-GND: -1.3255 A	Cur2-Cur1: -7.9531 A
Cur2-TRIG: 25.12 µs	Cur2-Cur1: 27.9918 µs

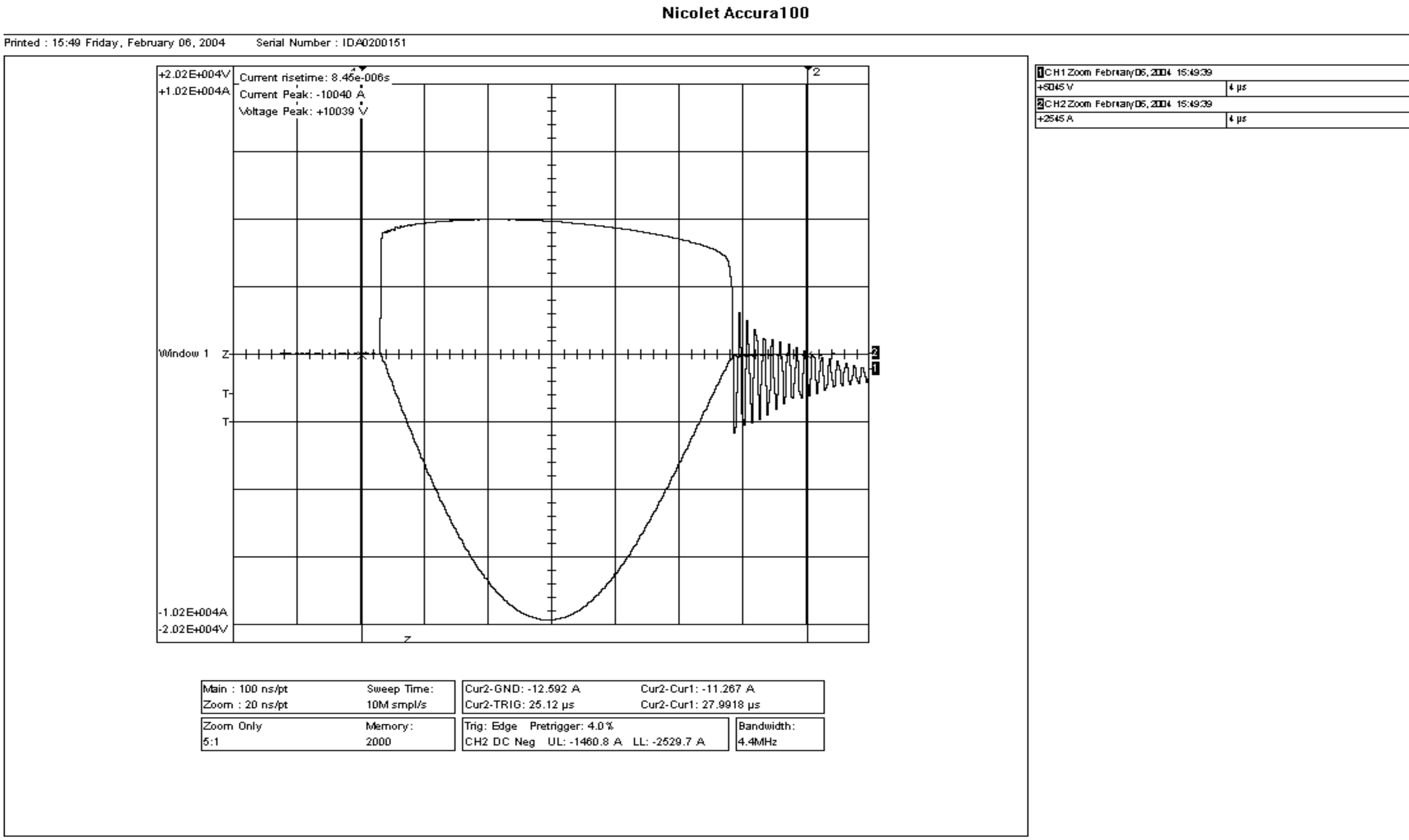
Zoom Only	Memory:
5:1	2000

Trig: Edge Pretrigger: 4.0 %
CH2 DC Neg UL: -1460.8 A LL: -2529.7 A

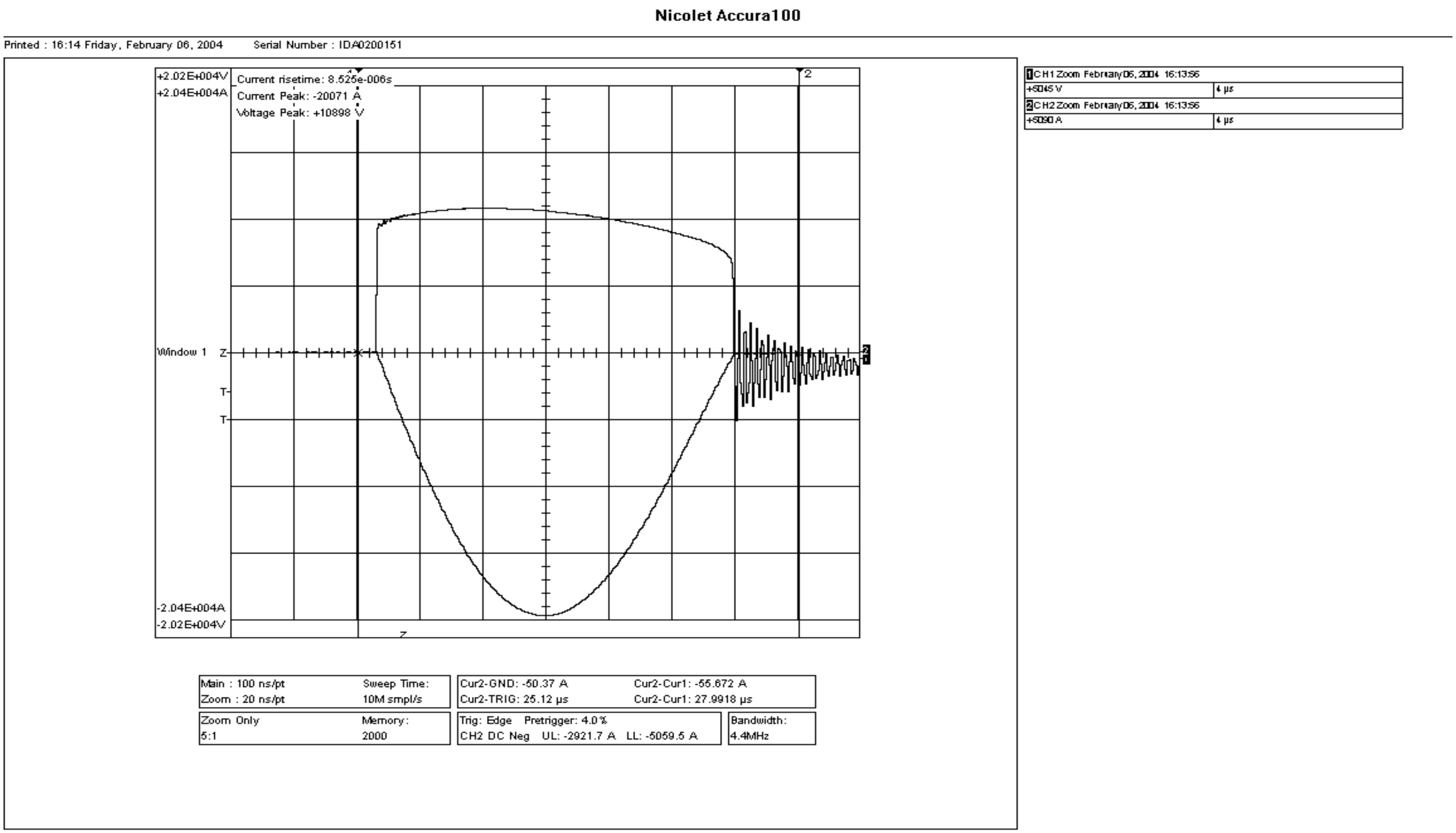
Bandwidth:
4.4MHz

1 CH1 Zoom February 06, 2004 15:48:11	
+5045 V	4 µs
2 CH2 Zoom February 06, 2004 15:48:11	
+2545 A	4 µs

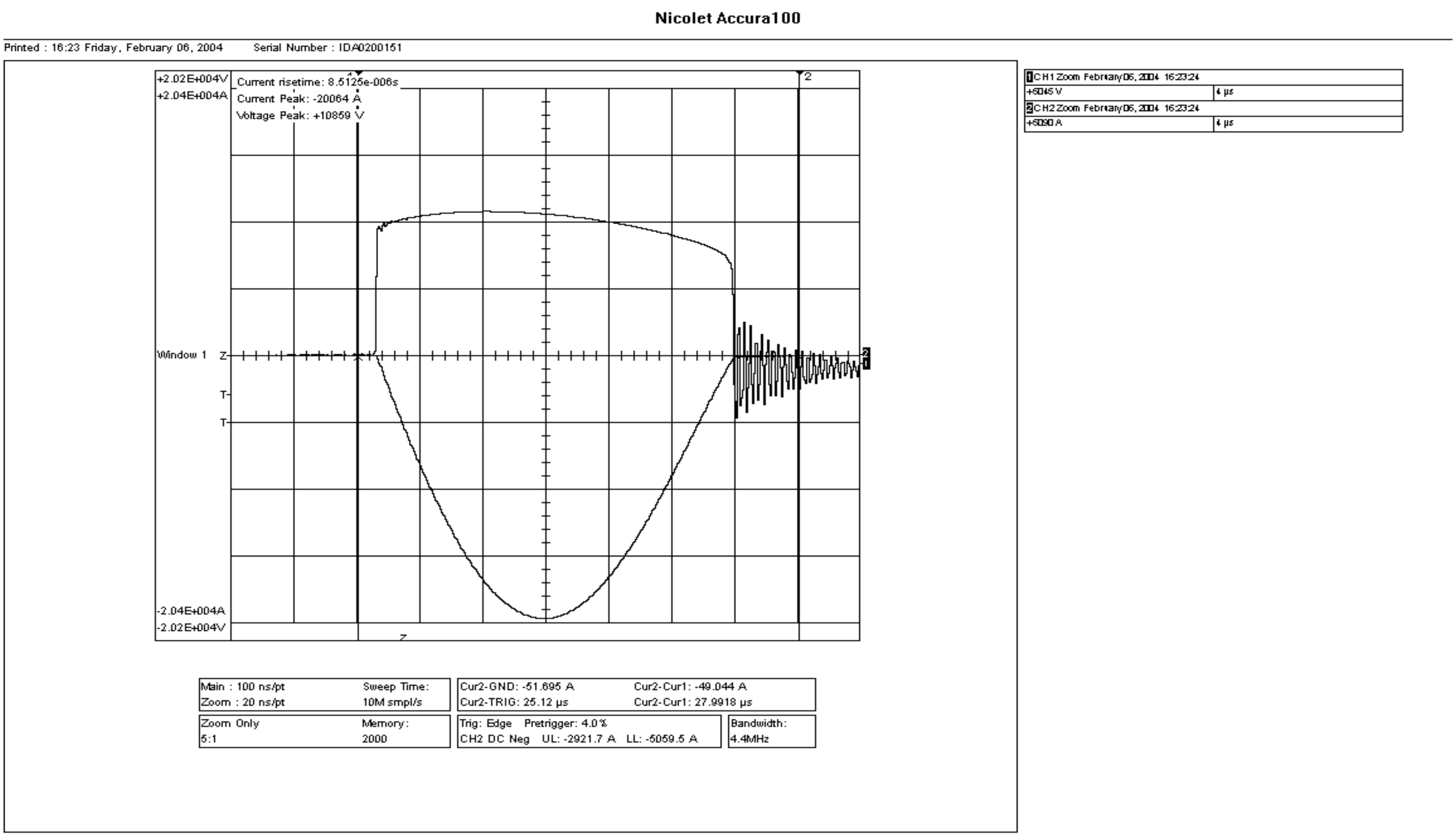
Oscillogram 6
Sample 3



Oscillogram 7
Sample 1



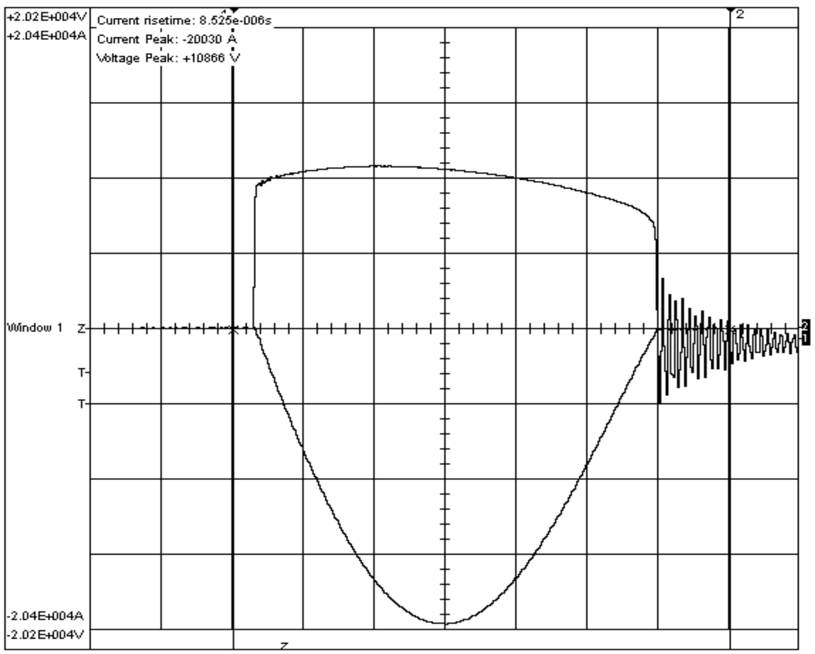
Oscillogram 8
Sample 2



Oscillogram 9
Sample 3

Nicolet Accura100

Printed : 16:17 Friday, February 06, 2004   Serial Number : IDA0200151



Main : 100 ns/pt	Sweep Time:
Zoom : 20 ns/pt	10M smpl/s
Zoom Only	Memory:
5:1	2000

Cur2-GND: -49.044 A	Cur2-Cur1: -50.37 A
Cur2-TRIG: 25.12 µs	Cur2-Cur1: 27.9918 µs

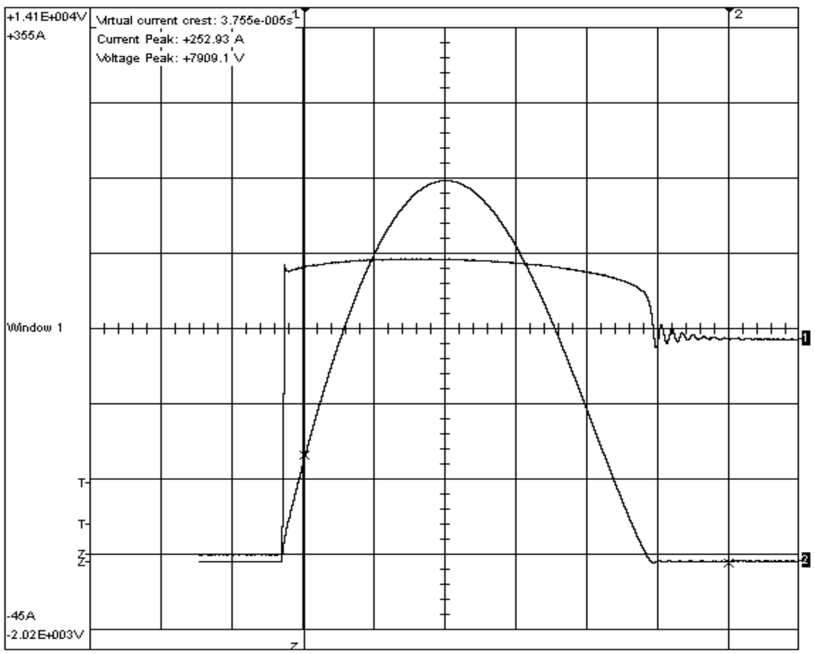
Trig: Edge Pretrigger: 4.0 %	Bandwidth:
CH2 DC Neg UL: -2921.7 A LL: -5059.5 A	4.4MHz

1 CH1 Zoom February 06, 2004 16:16:45	
+5045 V	4 µs
2 CH2 Zoom February 06, 2004 16:16:45	
+5090 A	4 µs

Oscillogram 13
Sample 1

Nicolet Accura100

Printed : 14:16 Monday, February 09, 2004   Serial Number : IDA0200151



Main : 200 ns/pt	Sweep Time:
Zoom : 100 ns/pt	5M smpl/s
Zoom Only	Memory:
2:1	2000

Cur2-GND: -0.026042 A	Cur2-Cur1: -71.536 A
Cur2-TRIG: 122.4 µs	Cur2-Cur1: 119.6 µs

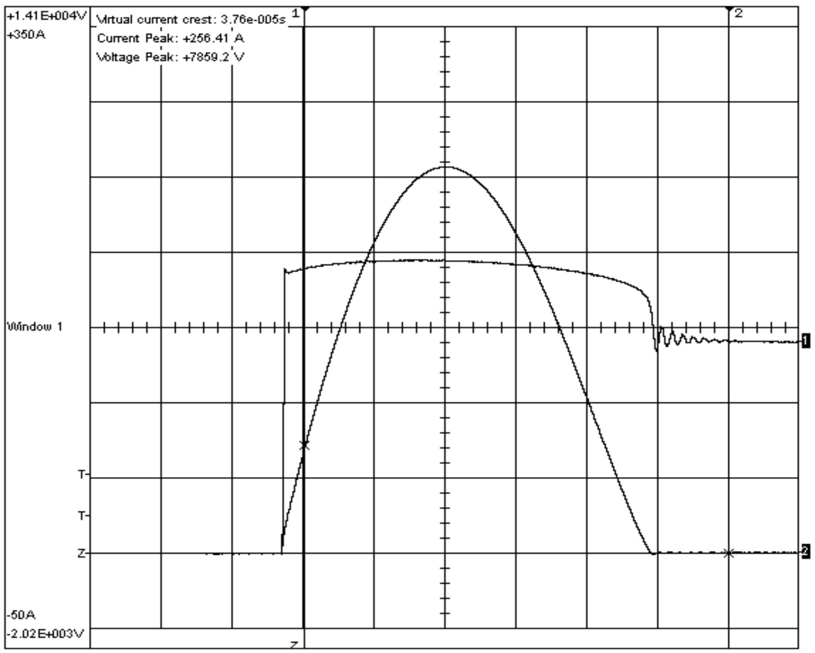
Trig: Edge Pretrigger: 6.8 %	Bandwidth:
CH2 DC Pos UL: +52.6 A LL: +25 A	2.2MHz

1 CH1 Zoom February 09, 2004 14:15:55	
+2018 V	20 µs
2 CH2 Zoom February 09, 2004 14:15:55	
+50 A	20 µs

Oscillogram 14
Sample 2

Nicolet Accura100

Printed : 14:20 Monday, February 09, 2004   Serial Number : IDA0200151



Main : 200 ns/pt	Sweep Time:
Zoom : 100 ns/pt	5M smpl/s
Zoom Only	Memory:
2:1	2000

Cur2-GND: +0 A	Cur2-Cur1: -72.24 A
Cur2-TRIG: 122.4 µs	Cur2-Cur1: 119.6 µs

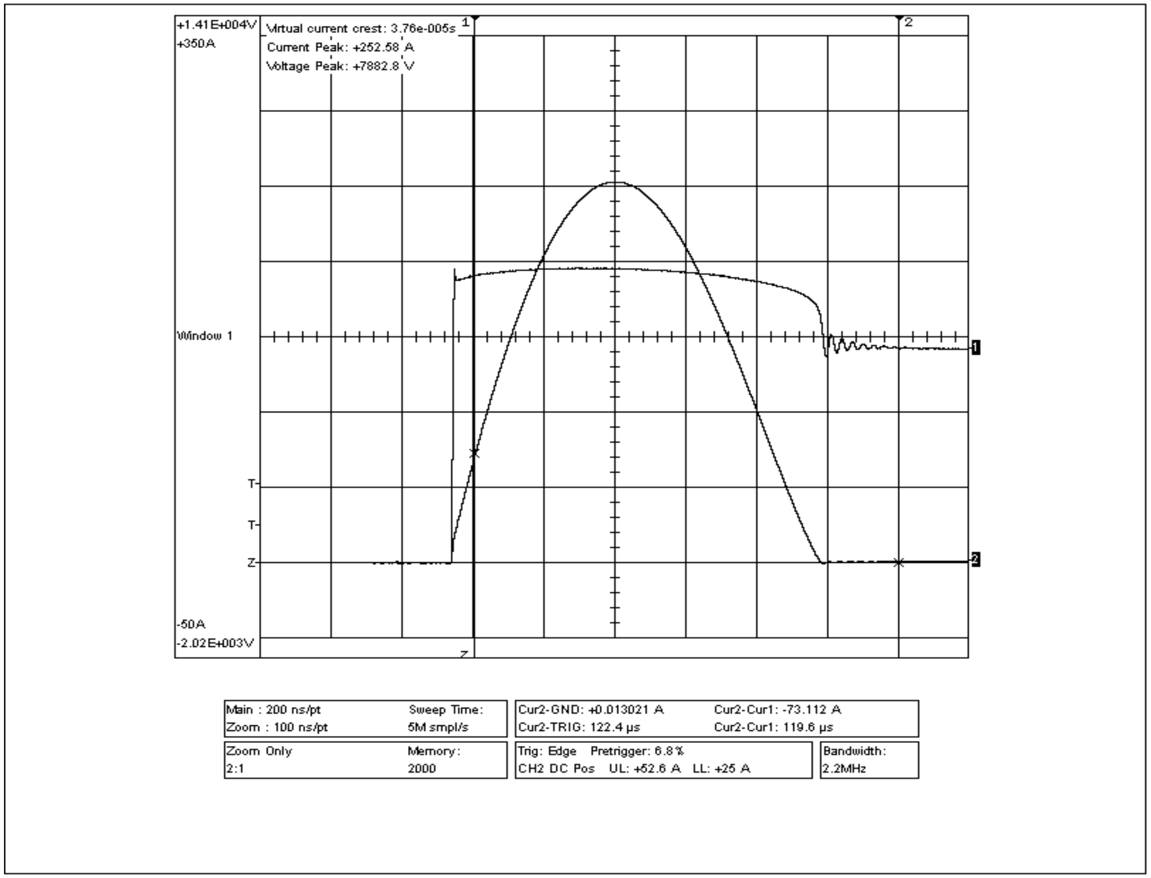
Trig: Edge Pretrigger: 6.8 %	Bandwidth:
CH2 DC Pos UL: +52.6 A LL: +25 A	2.2MHz

1 CH1 Zoom February 09, 2004 14:17:17	
+2018 V	20 µs
2 CH2 Zoom February 09, 2004 14:17:17	
+50 A	20 µs

Oscillogram 15
Sample 3

Nicolet Accura100

Printed : 14:42 Monday, February 09, 2004 Serial Number : IDA0200151

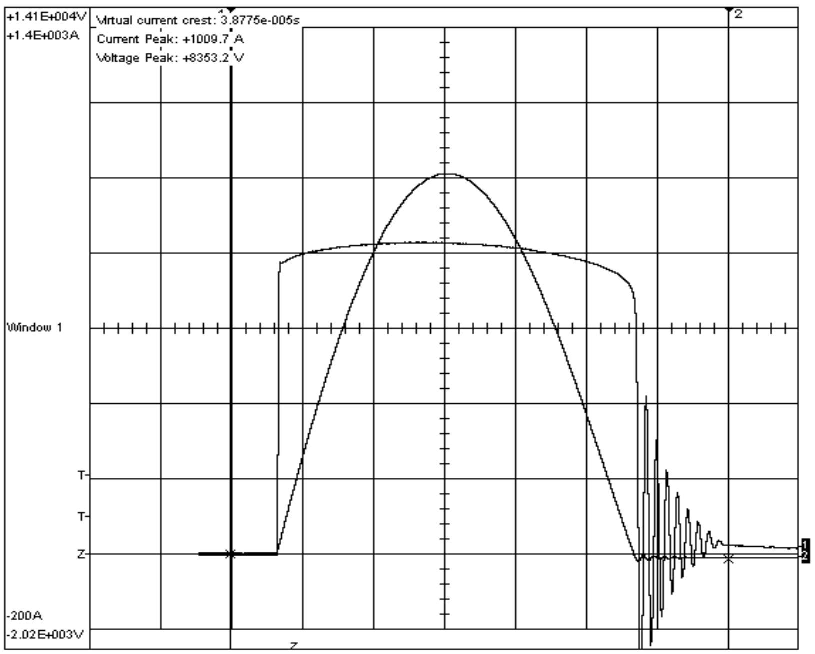


1 CH1 Zoom February 09, 2004 14:42:19	
+2018 V	20 µs
2 CH2 Zoom February 09, 2004 14:42:19	
+50 A	20 µs

Oscillogram 19
Sample 1

Nicolet Accura100

Printed : 09:45 Wednesday, February 11, 2004   Serial Number : IDA0200151



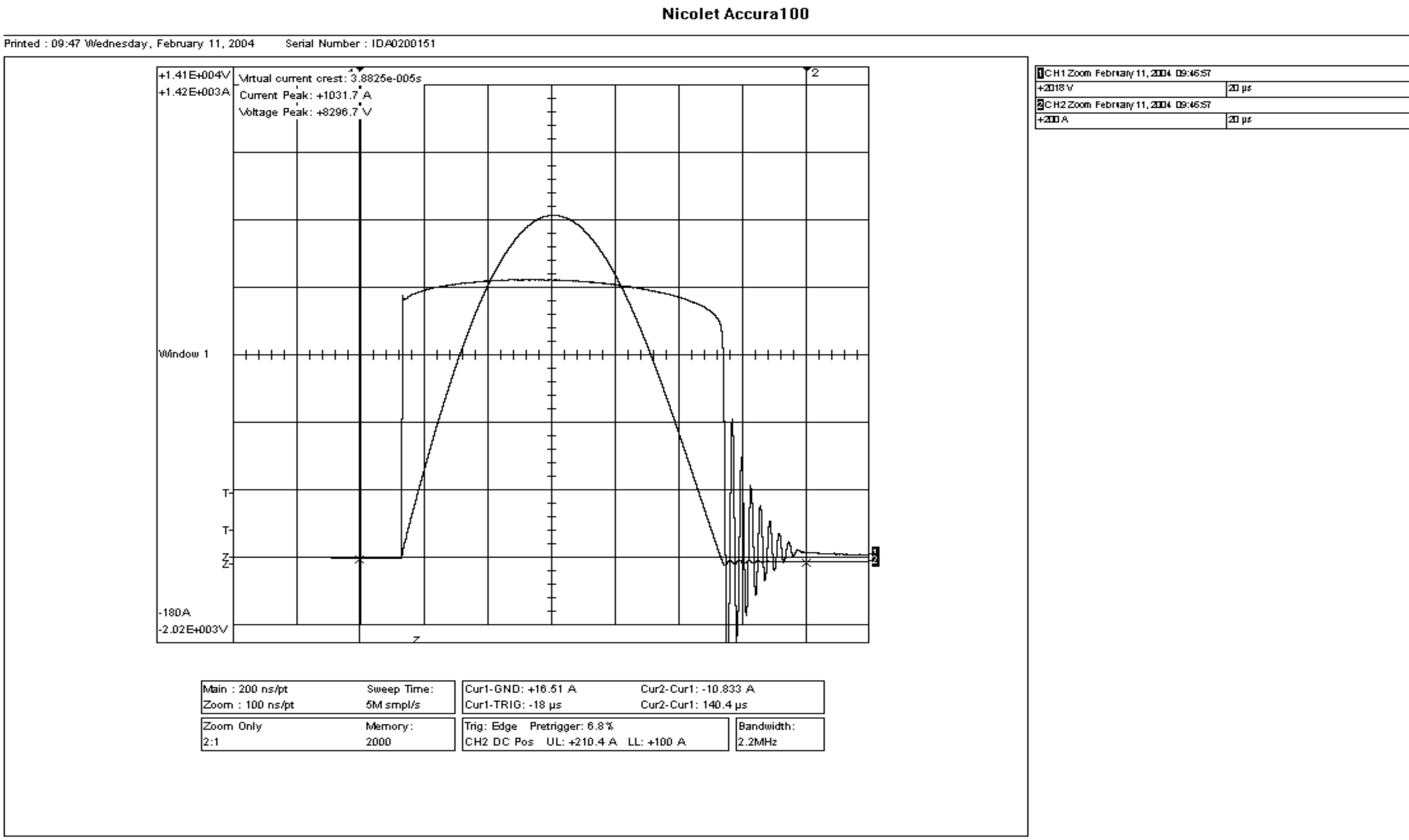
Main : 200 ns/pt	Sweep Time:
Zoom : 100 ns/pt	5M smpl/s
Zoom Only	Memory:
2:1	2000

Cur1-GND: +0.10417 A	Cur2-Cur1: -10.781 A
Cur1-TRIG: -18 μs	Cur2-Cur1: 140.4 μs

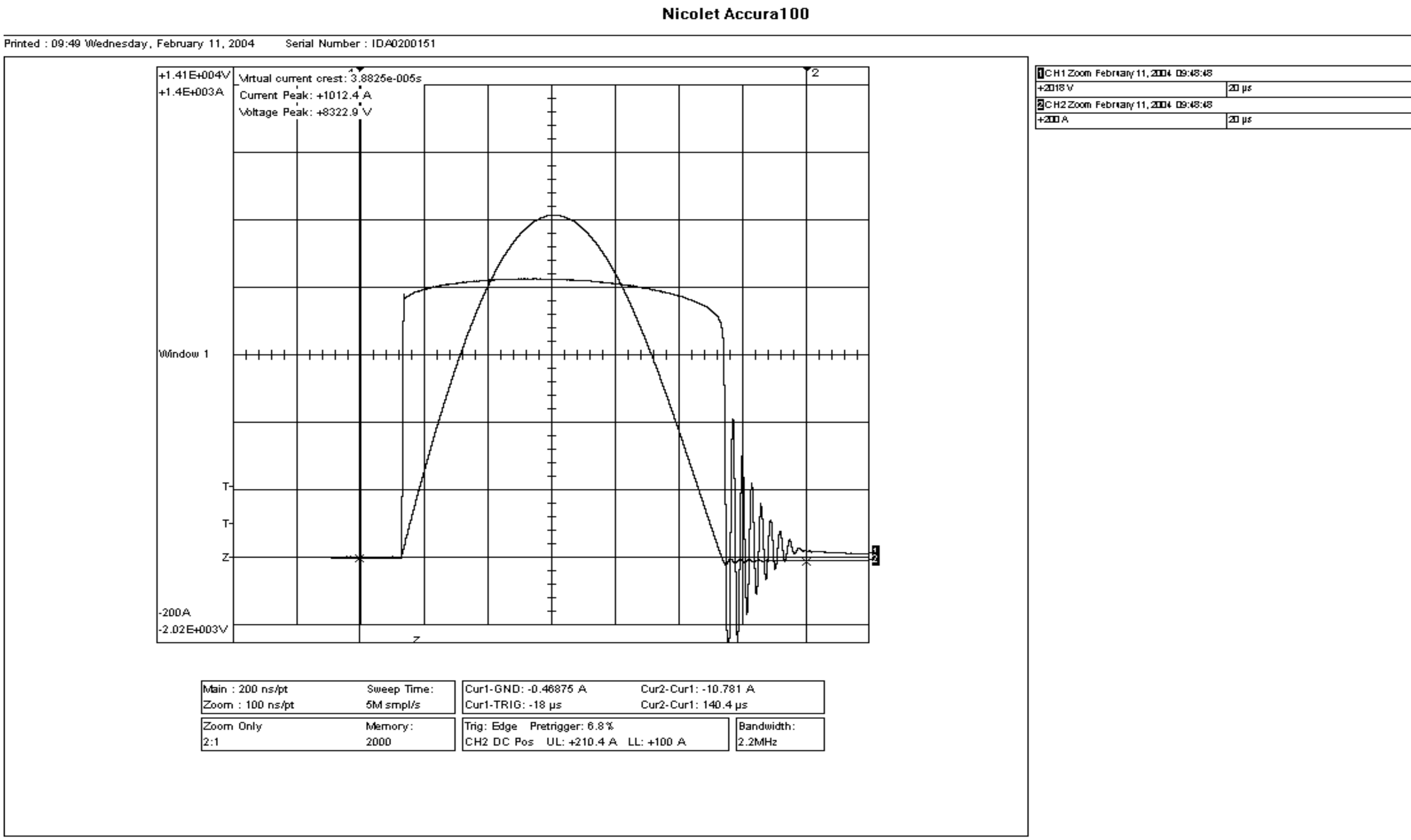
Trig: Edge Pretrigger: 6.8 %	Bandwidth:
CH2 DC Pos UL: +210.4 A LL: +100 A	2.2MHz

1 CH1 Zoom February 11, 2004 09:44:33	
+2018 V	20 μs
2 CH2 Zoom February 11, 2004 09:44:33	
+200 A	20 μs

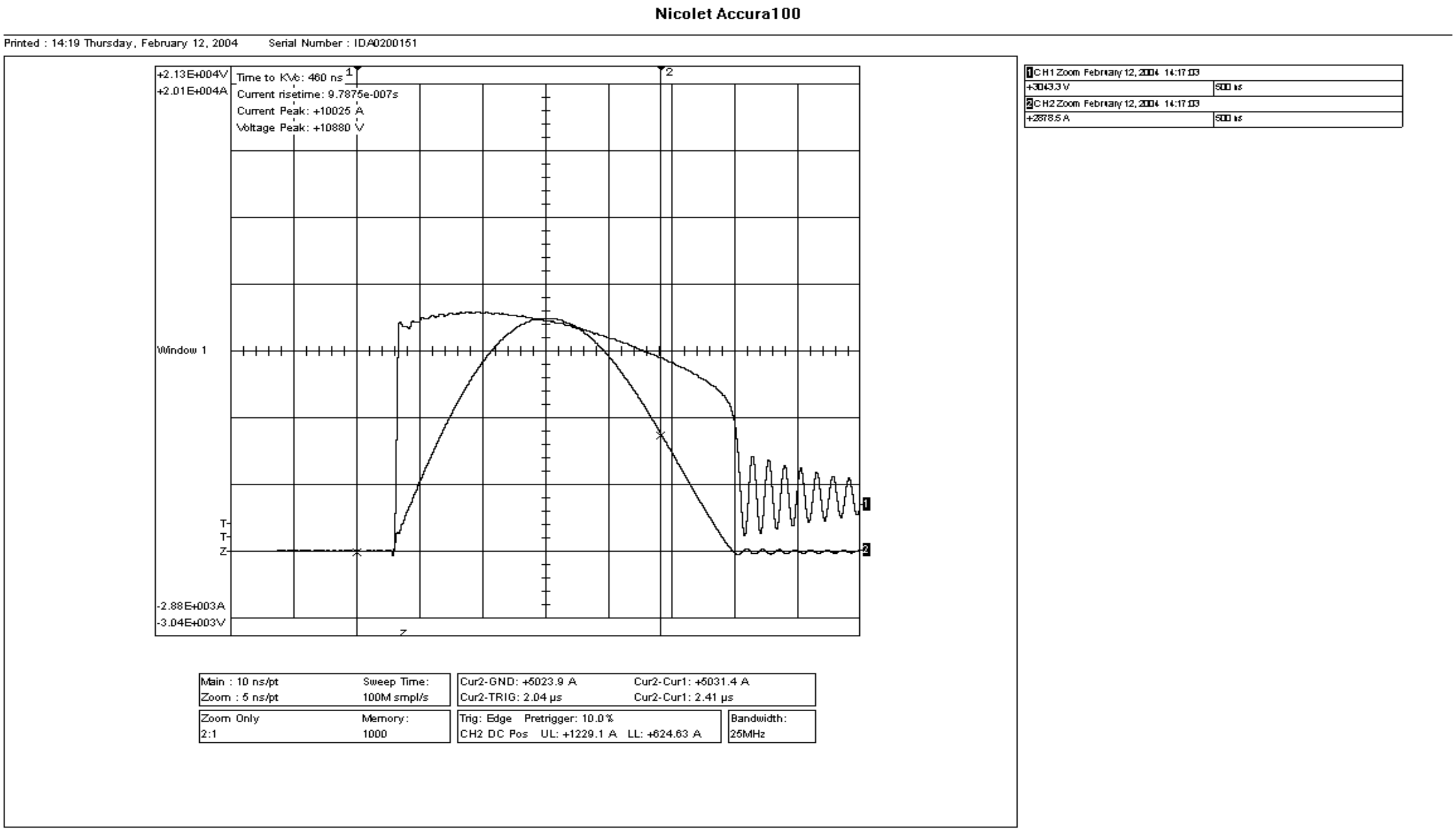
Oscillogram 20
Sample 2



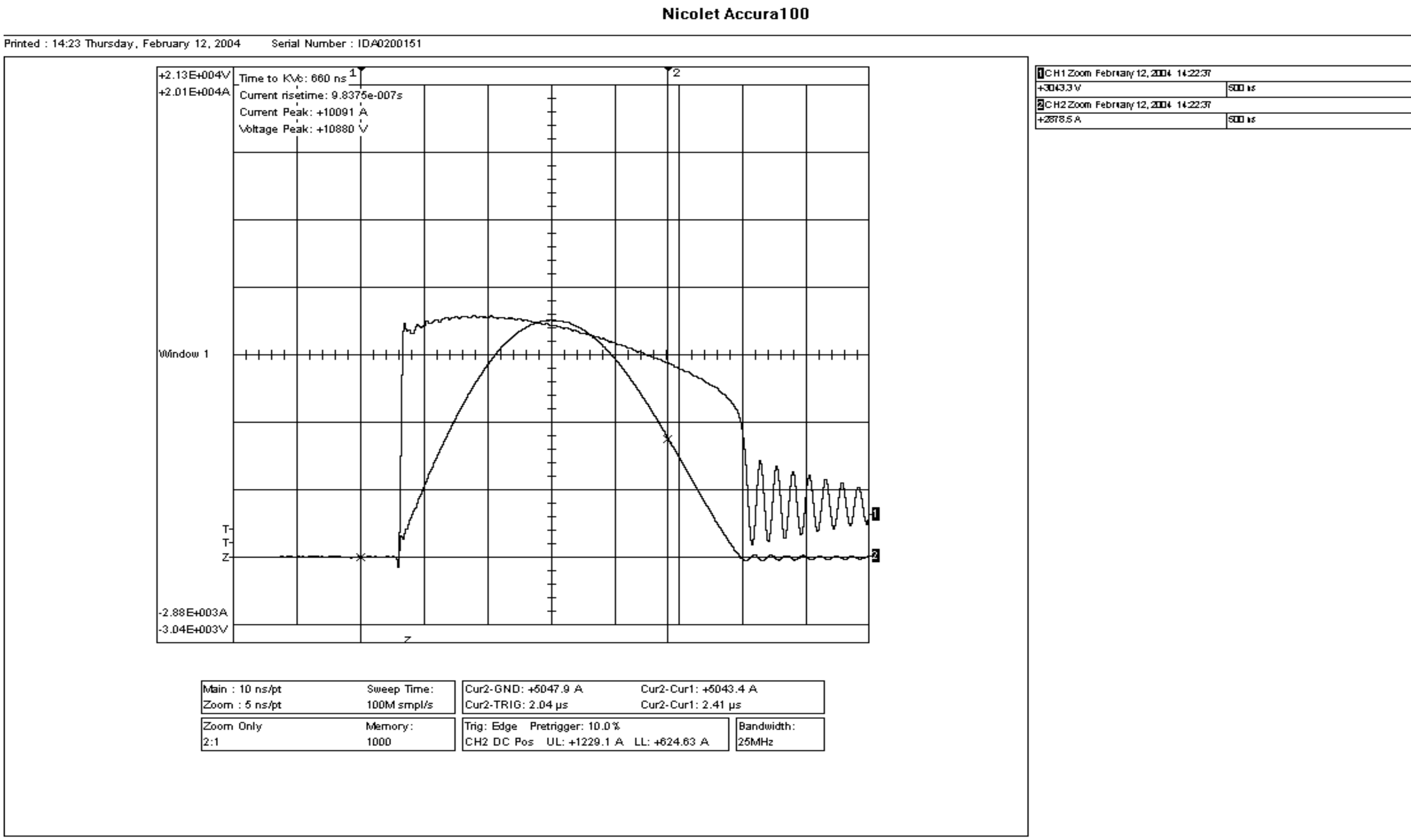
Oscillogram 21
Sample 3



Oscillogram 25
Sample 1



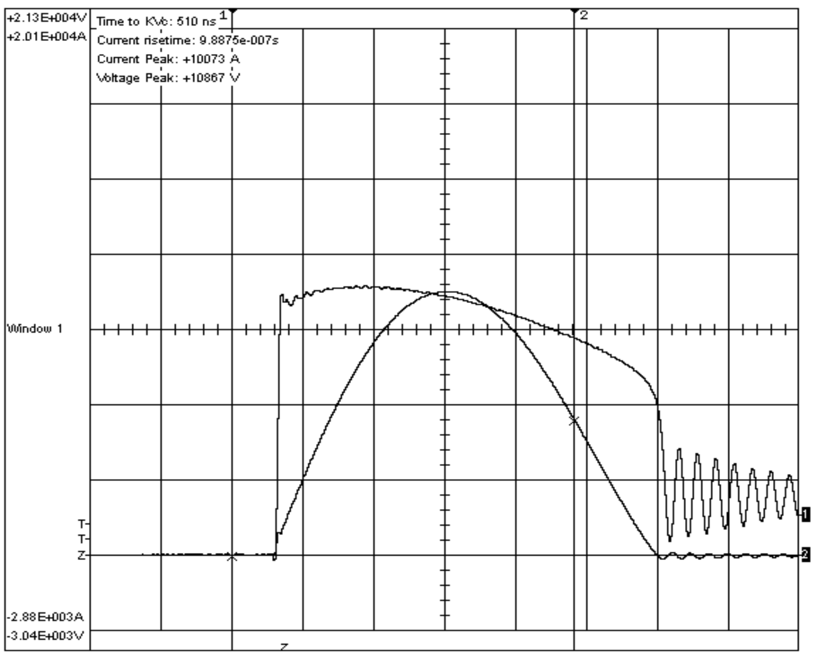
Oscillogram 26
Sample 2



Oscillogram 27
Sample 3

Nicolet Accura100

Printed : 14:25 Thursday, February 12, 2004   Serial Number : IDA0200151



Main : 10 ns/pt	Sweep Time:
Zoom : 5 ns/pt	100M smpl/s

Cur1-GND: -7.4961 A	Cur2-Cur1: +5151.3 A
Cur1-TRIG: -370 ns	Cur2-Cur1: 2.41 µs

Zoom Only	Memory:
2:1	1000

Trig: Edge   Pretrigger: 10.0 %
CH2 DC Pos   UL: +1229.1 A   LL: +624.63 A

Bandwidth:
25MHz

1 CH1 Zoom February 12, 2004 14:25:15	
+3043.3 V	500 ns
2 CH2 Zoom February 12, 2004 14:25:15	
+2878.5 A	500 ns

IEC Type Test Report
Report No. EU1518-H-03
H5 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 5

Long Duration Current Impulse Withstand Tests

This report records the results of type tests made on H5 series 20 kA Line Discharge Class 5 arresters, rated up to 612 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.0, 2004, "Surge arresters - Part 4: Metal-oxide surge arresters without gaps for a.c. systems."

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

M.G. Comber
Manager, Engineering

Date: 9/23/2004

IEC TYPE TEST REPORT
Long Duration Current Impulse Withstand Tests

TESTS PERFORMED:
Long duration current impulse withstand tests were performed on three test samples, each consisting of two parallel columns of two resistors (75 mm diameter, 44 mm long) in each column. The resistors were selected to represent the lowest acceptable reference voltage level. The tests were conducted in accordance with Clause 8.4.2 of IEC 60099-4. Prior to the administering of line discharges, measurements were made of the residual voltage and reference voltage on each test sample. The transmission line parameters conformed to the requirements for Line Discharge Class 5 in Table 5 of IEC 60099-4. Table 1 below lists the measured residual voltage and reference voltage for each sample, and lists the corresponding transmission line parameters used for the test.

Table 1. Parameters for Line Discharge Tests

Parameter	Sample 1	Sample 2	Sample 3
Initial Residual Voltage (kV) @ 20 kA, 8/20	26.89	26.95	26.94
Initial Residual Voltage (kV) @ 500 A, 39/84	21.15	21.17	21.19
Reference Current (mA) I_{ref}	10	10	10
Reference Voltage (kV peak/√2) V_{ref}	11.91	11.90	11.90
COV (kV rms) U_c	9.65	9.64	9.63
Rating (kV rms) U_r	12.06	12.05	12.04
Arrester Classification (kA)	20	20	20
Line Discharge Class	5	5	5
Virtual Duration of Peak (μs, 90-90%) - min	3200	3200	3200
Surge Impedance (Ω) Z_g - max (0.5 U_r)	6.03	6.02	6.02
Charging Voltage (kV) U_L – min (2.4 U_r)	28.95	28.92	28.90

Each sample was subjected to 18 line discharges, administered in six groups of three discharges. Within each group of three discharges, the time interval between discharges was 50 to 60 seconds. The samples were allowed to cool to ambient temperature between groups of discharges.

RESULTS:
A short circuit test was performed on the generator to confirm that generator impedance and duration of the current discharge met the requirements listed in Table 1. The oscillogram of Figure 1 shows

Z_g = 6,547 V / 1,092 A = 5.995 Ω   Virtual Duration of Peak = 3239 μs

Table 2 lists the current and voltage magnitudes and discharge energy measured on each of the 18 discharges on each of the three test samples. Figures 2, 3 and 4 show oscillograms of the third and eighteenth discharges for each of the three samples, respectively. Ambient air temperature at the time of the test was 22 °C.

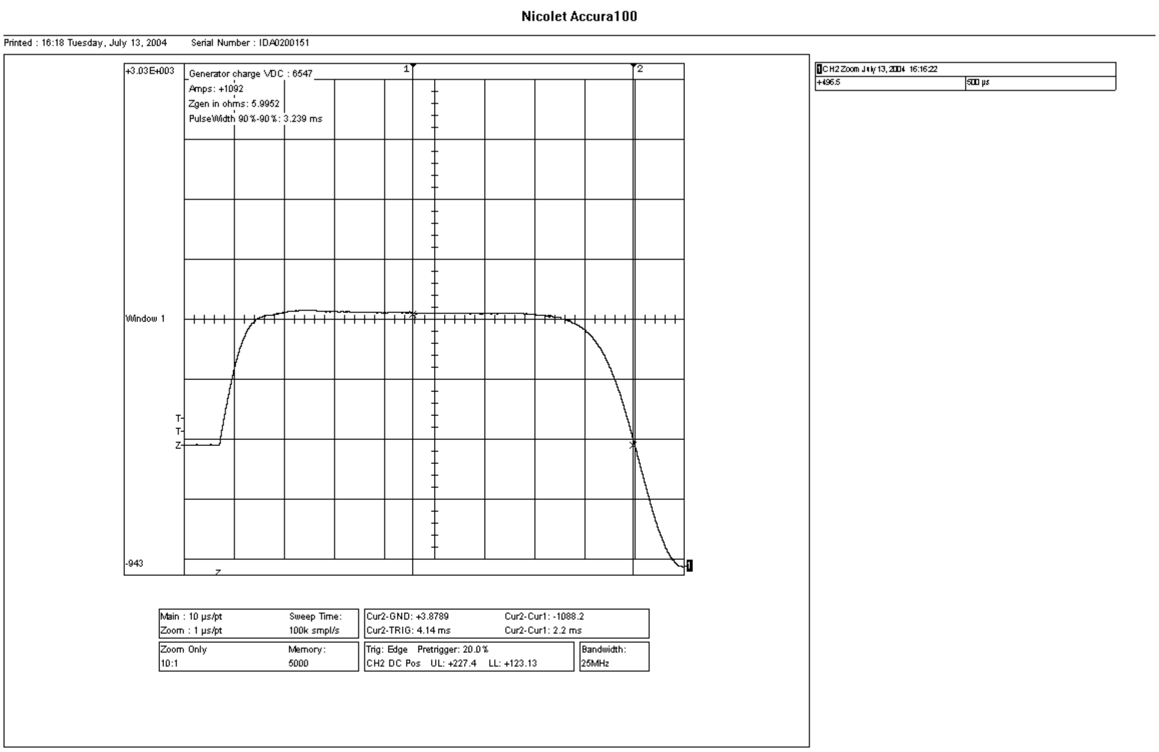
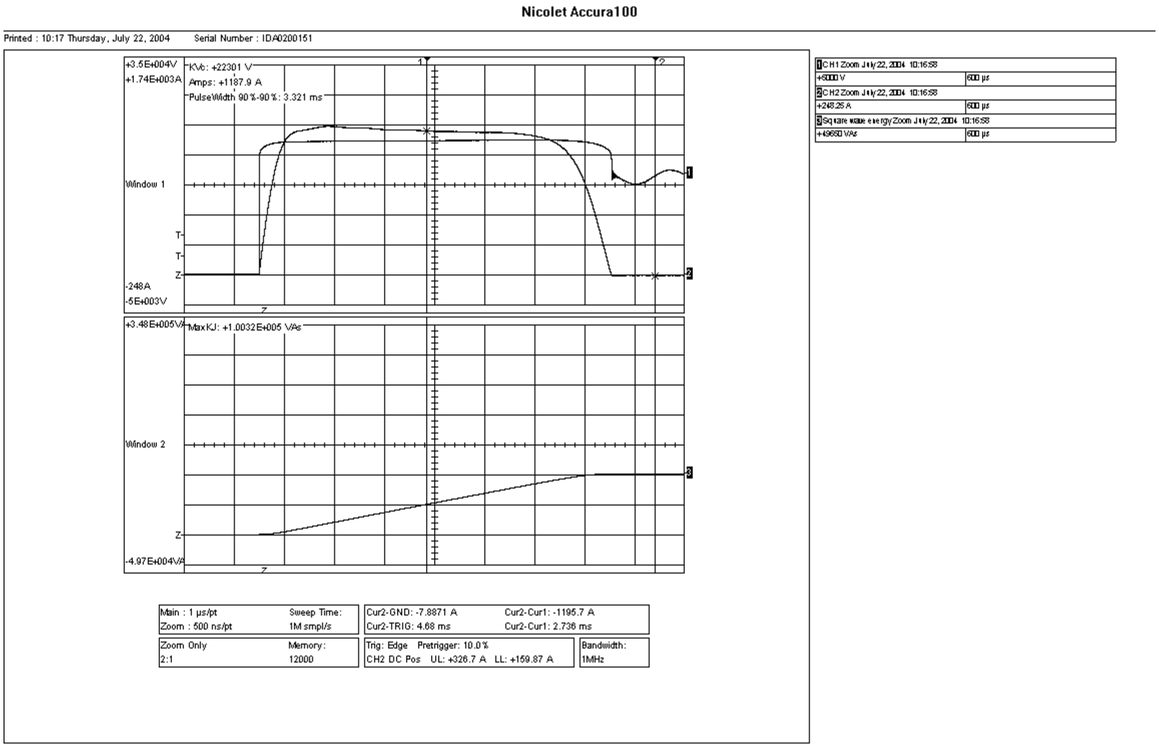


Figure 1. Oscillogram of discharge current for generator short circuit set up test

Table 2. Line Discharge Test Measurements

Impulse	Sample 1			Sample 2			Sample 3		
	I (A)	V (kV)	E (kJ)	I (A)	V (kV)	E (kJ)	I (A)	V (kV)	E (kJ)
1	1260	21.88	104.4	1258	21.91	104.4	1254	21.88	104.1
2	1220	22.07	102.2	1218	22.09	101.9	1207	22.11	101.0
3	1188	22.30	100.3	1186	22.28	100.2	1169	22.28	98.9
4	1256	21.89	104.1	1242	21.94	103.1	1242	21.94	103.1
5	1212	22.08	101.5	1203	22.11	101.1	1206	22.13	101.2
6	1182	22.32	99.8	1174	22.30	99.3	1171	22.30	99.1
7	1244	21.94	103.3	1231	21.96	102.4	1229	21.94	102.1
8	1205	22.13	101.0	1197	22.15	100.5	1195	22.15	100.2
9	1174	22.30	99.2	1169	22.32	98.9	1163	22.30	98.4
10	1242	21.93	103.3	1234	21.97	102.7	1235	21.93	102.7
11	1205	22.16	101.1	1202	22.16	100.9	1199	22.16	100.7
12	1174	22.31	99.4	1172	22.31	99.2	1169	23.33	98.9
13	1232	21.95	102.4	1226	21.97	102.1	1231	21.97	102.2
14	1200	22.12	100.6	1192	22.16	100.1	1197	22.14	100.4
15	1169	22.28	98.8	1164	22.33	98.5	1164	22.35	98.5
16	1238	21.97	102.9	1228	21.99	102.1	1227	21.95	102.0
17	1201	22.16	100.8	1197	22.18	100.5	1195	22.14	100.1
18	1171	22.32	99.0	1168	22.33	98.6	1166	22.33	98.5

Sample 1, Discharge 3



Sample 1, Discharge 18

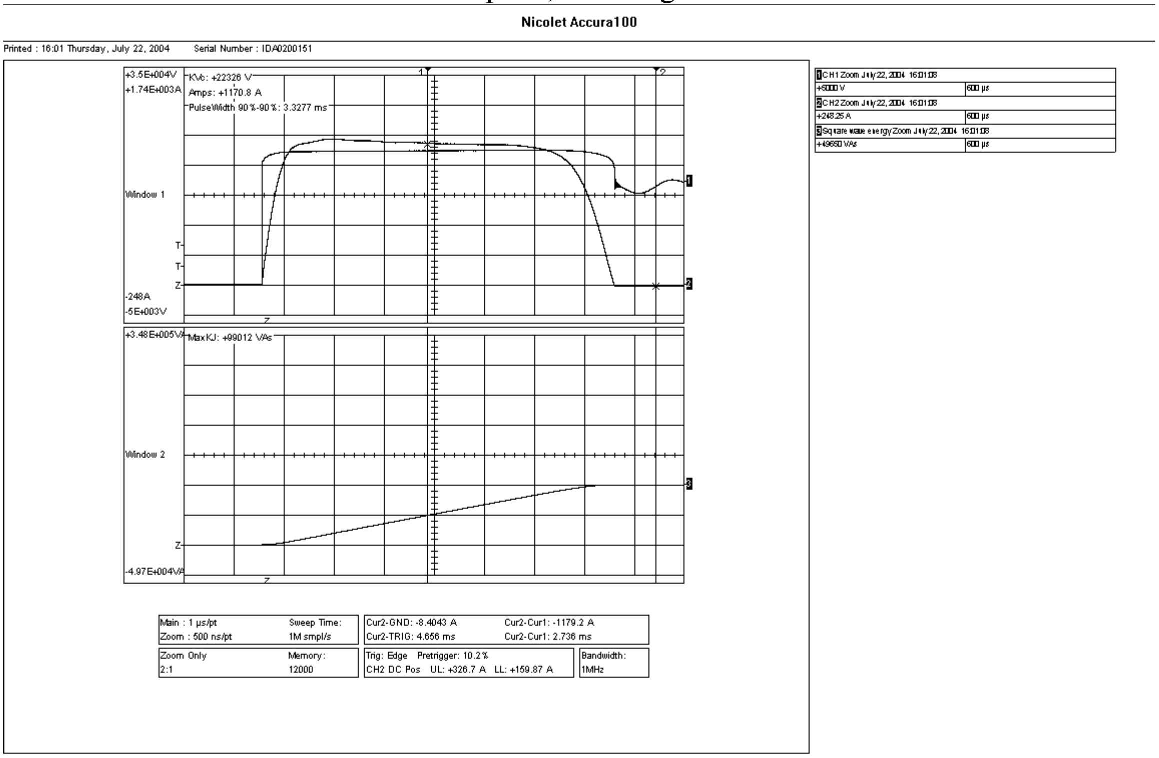
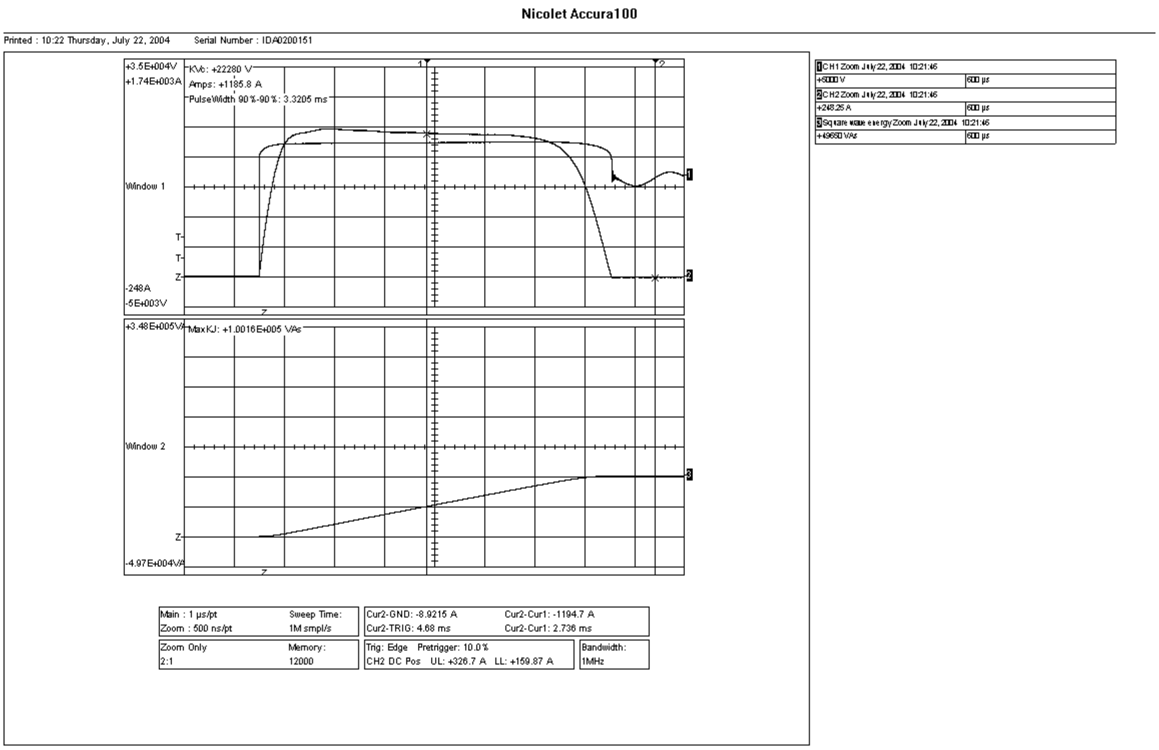


Figure 2. Oscillograms of line discharges for sample 1

Sample 2, Discharge 3



Sample 2, Discharge 18

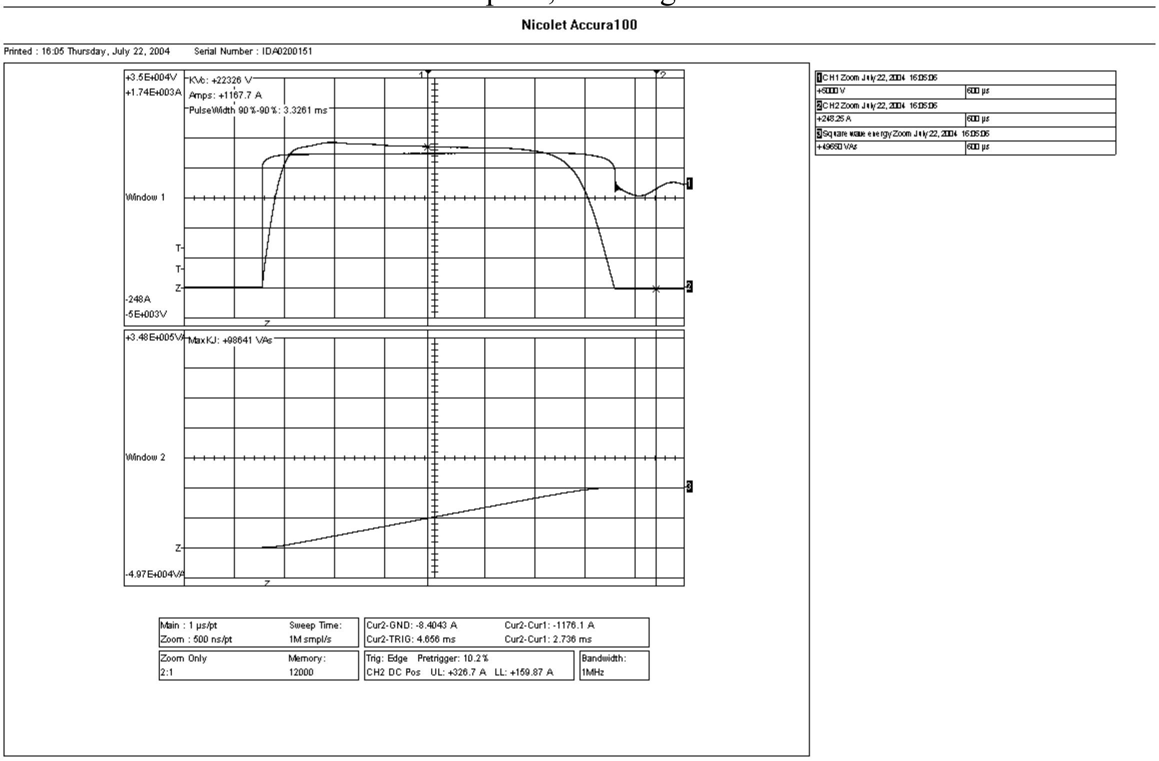
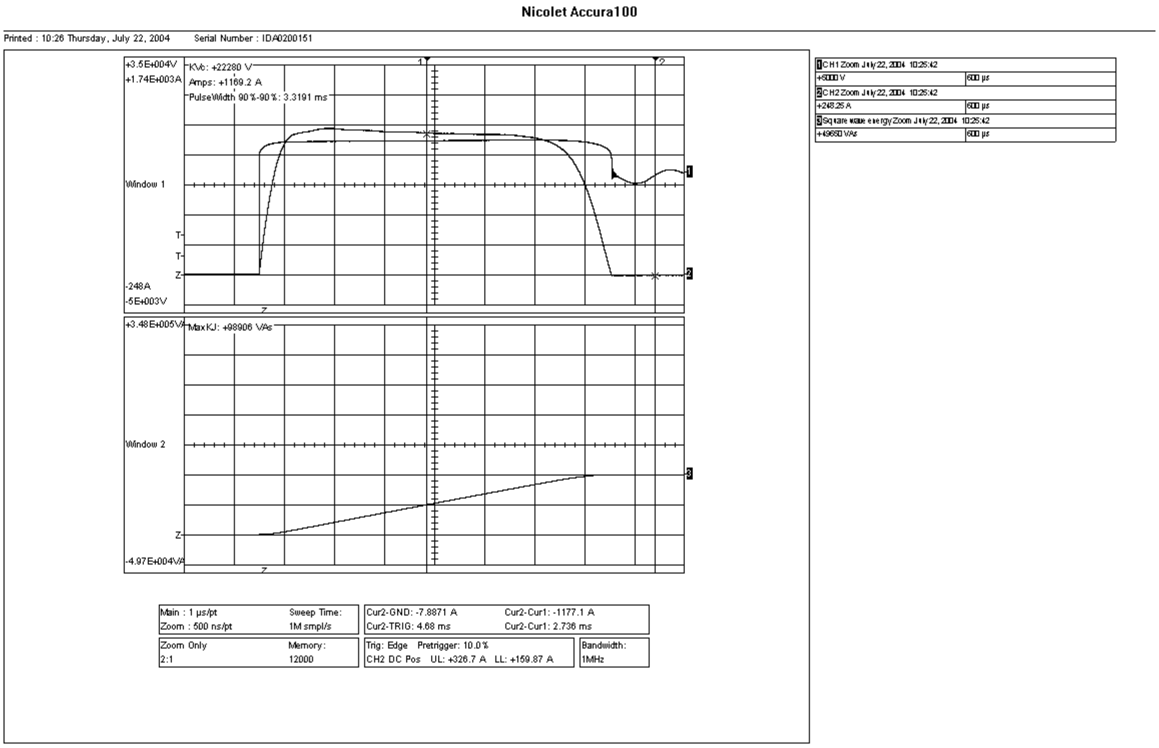


Figure 3. Oscillograms of line discharges for sample 2

Sample 3, Discharge 3



Sample 3, Discharge 18

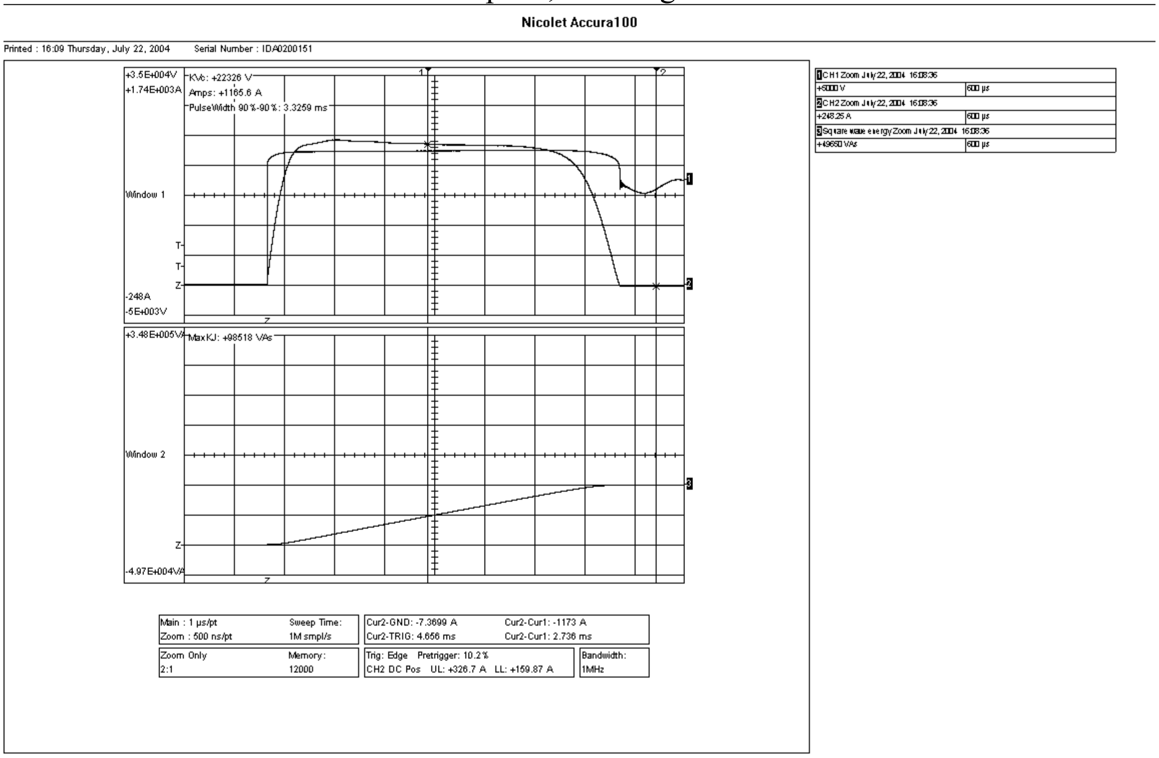


Figure 4. Oscillograms of line discharges for sample 3

Subsequent to the completion of the transmission line discharges, the residual voltage at nominal discharge current was re-measured and compared to the initial values for each test sample. Results are summarized in Table 3. The maximum change of residual voltage of the three samples is less than the permissible change of 5 % defined by IEC 60099-4.

Table 3. Initial and final residual voltage measurements.

Sample	Residual voltage (kV)		Change
	Before	After	
1	26.89	26.89	0.0 %
2	26.95	26.87	- 0.3 %
3	26.94	26.86	- 0.3 %

Disassembly of the test samples at the end of the electrical tests revealed no evidence of physical damage.

IEC Type Test Report
Report No. EU1518-H-04
H5 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 5

Accelerated Aging Procedure

This report records the results of type tests made on H5 series 20 kA Line Discharge Class 5 arresters, rated up to 612 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.0, 2004, "Surge arresters - Part 4: Metal-oxide surge arresters without gaps for a.c. systems."

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

M.G. Comber
Manager, Engineering

Date: 9/23/2004

IEC TYPE TEST REPORT
Accelerated Aging Procedure

TESTsS PERFORMED:
Accelerated aging tests were performed on two resistor elements, 75mm diameter x 44mm length. The tests were conducted in accordance with Clause 8.5.2 of IEC 60099-4. The test samples were placed in an air oven and energized at a voltage equal to the corrected maximum continuous operating voltage, U_{ct}, for 1000 hours. The temperature of the samples was maintained at 115 °C ± 2 °C for the duration of the test.

Power dissipation was measured on each sample throughout the 1000 h test period.

Clause 8.5.2 of IEC 60099-4 defines three power dissipation values:
- P_{1ct}, measured 1 h to 2 h after the initial voltage application
- P_{2ct}, measured after 1000 h
- P_{3ct}, the minimum value attained during the 1000 h test period.

If P_{2ct} is equal to or less than 1.1 times P_{3ct}, then the switching surge operating duty test of Clause 8.5.5 of IEC 6099-4 is to be performed on new resistors. Furthermore, if P_{2ct} is equal to or less than P_{1ct}, then the rated voltage and continuous operating voltage used for the operating duty test are not subject to any modification.

RESULTS:
Figure 1 graphically displays the measurements made during the 1000 h test period. Table 1 summarizes the values of P_{1ct}, P_{2ct} and P_{3ct} for each sample. The requirements that P_{2ct} is equal to or less than 1.1 times P_{3ct}, and P_{2ct} is equal to or less than P_{1ct} are met for both samples. Consequently, no modification needs to be made to the rated voltage and continuous operating voltage in the operating duty test, and the operating duty test can be performed on new resistors.

Table 1. Power dissipation values

Sample Number	Power dissipation at 2 h	Power dissipation at 1000 h	Minimum power dissipation
	P_{1ct} (W)	P_{2ct} (W)	P_{3ct} (W)
1	5.20	2.82	2.82
2	5.97	2.91	2.91

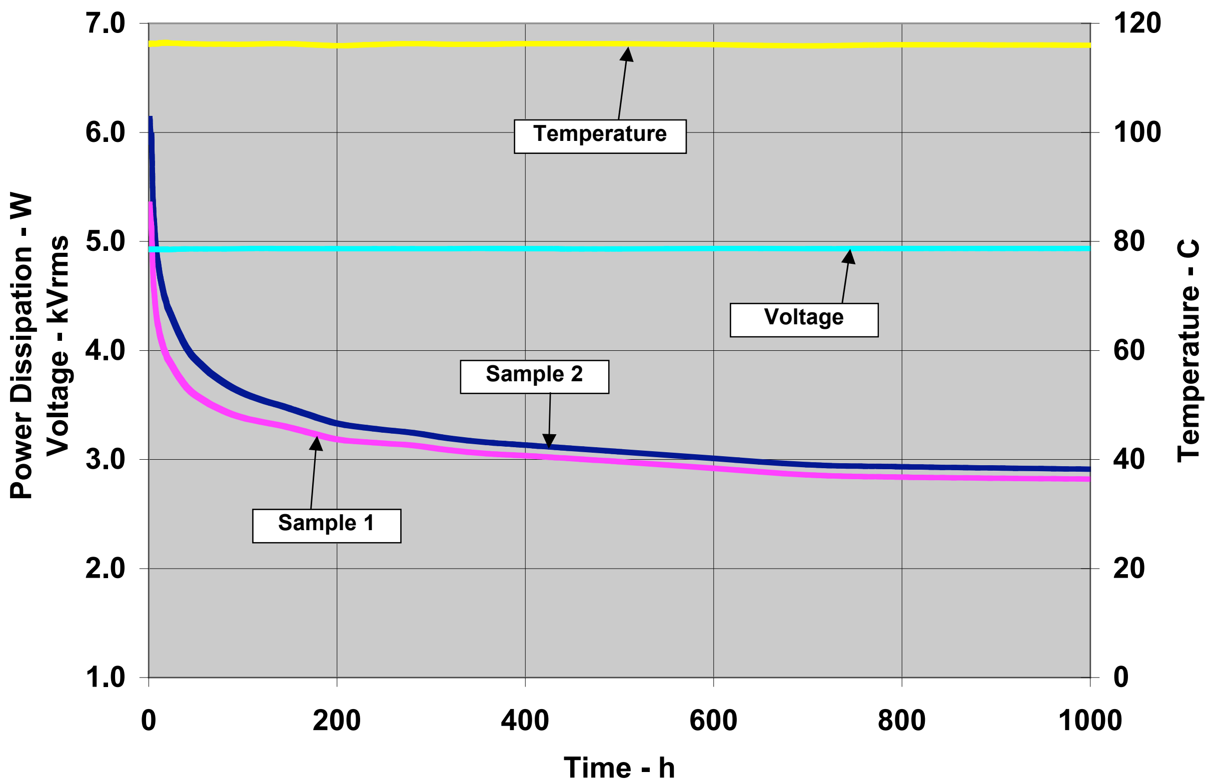


Figure 1. Power dissipation, voltage and temperature measurements during 1000 h test period

IEC Type Test Report
Report No. EU1518-H-05
H5 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 5

Heat Dissipation Behavior of Test Section

This report records the results of type tests made on H5 series 20 kA Line Discharge Class 5 arresters, rated up to 612 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.0, 2004, "Surge arresters - Part 4: Metal-oxide surge arresters without gaps for a.c. systems."

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

M.G. Comber
Manager, Engineering

Date: 9/23/2004

IEC TYPE TEST REPORT
Heat Dissipation Behavior of Test Section

TESTS PERFORMED:

Tests were performed as described in Clause 8.5.3 and Annex B of IEC 60099-4, to compare the cooling characteristics of the test section used for type tests with those of a full-size arrester unit. For this purpose, thermocouples were installed along the resistor stack of an assembled 149 kV rated unit, which represents the highest individual unit rated voltage and the most resistors per unit length of all units used in the arrester design. The unit contains two parallel columns of non-linear resistors. Three thermocouples were used in each column, located (1) between one-third and one-half of the unit length from the top, (2) at the mid-point, and (3) between one-third and one-half of the unit length from the bottom. Thermocouple wires were brought out through small holes drilled in the porcelain. The test section was comprised of two parallel columns of resistor elements (75 mm diameter, 44 mm long) assembled into a short section of porcelain housing, insulated on top and bottom ends to control the rate of cooling to meet the requirements that the test section cools at a rate not greater than that of the assembled unit. A thermocouple was located at the mid-height of the two-resistor stack

Both assembled unit and test section were heated electrically with a power frequency overvoltage to raise the average temperature of the resistors to 120^{o}C in the same amount of time. The voltage was removed and the samples allowed to cool naturally. Temperature measurements were made throughout the cooling period.

RESULTS:

Figures 1 and 2 show the fully assembled unit and the test section, respectively. The assembled unit had U_c of 117.5 kV, and the test section had U_c of 8.7 kV. The resistors in both samples were heated by applying a voltage sufficiently above Uc to raise the resistor temperature to 120^{o}C in approximately 7 min. Figure 3 graphically displays the cooling of both samples over a period of 2.85 hours.

With both samples starting from the same initial temperature of 120^{o}C, the temperature of the resistors in the test section remain at or above the temperature of the resistors in the fully assembled unit throughout the cooling period. This demonstrates the validity of the test section for use in type tests involving thermal recovery.

Figure 1.
Fully assembled unit with thermocouples between resistors at 3 locations

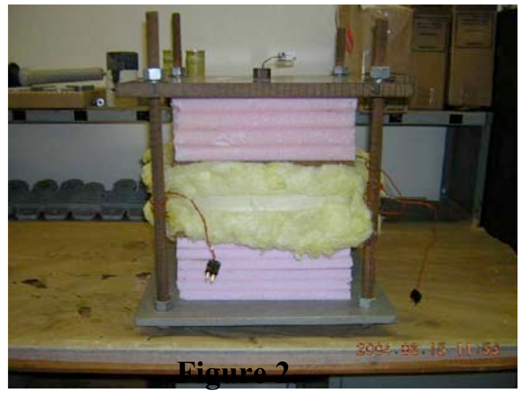


Figure 2
Two-resistor test section with thermocouple between resistors

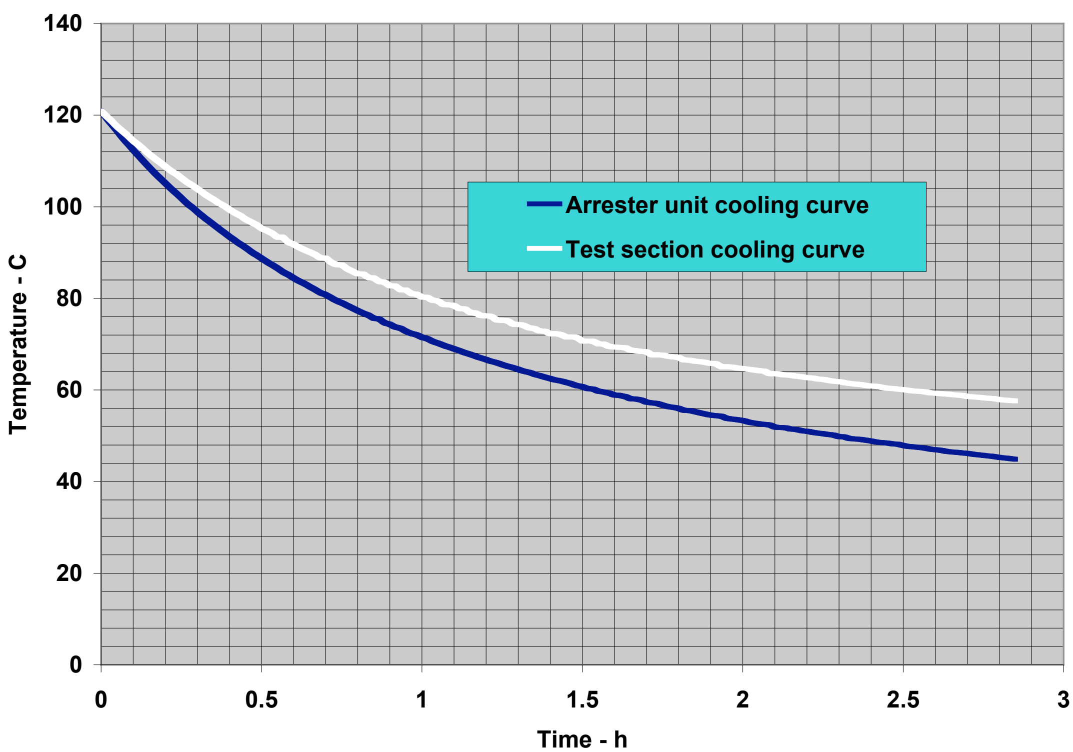


Figure 3. Cooling curves of fully assembled unit and test section

HUBBELL® POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1518-H-06
H5 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 5

Switching Surge Operating Duty Test

This report records the results of type tests made on H5 series 20 kA Line Discharge Class 5 arresters, rated up to 612 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.0, 2004, "Surge arresters - Part 4: Metal-oxide surge arresters without gaps for a.c. systems."

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

Michael G. Comber
M.G. Comber
Manager, Engineering

Date: 9/23/2004

IEC TYPE TEST REPORT
Switching Surge Operating Duty Test

TESTS PERFORMED:
Switching surge operating duty tests were performed on three prorated test sections prepared based on the results of the tests to verify heat dissipation behavior of test sample. Each section consisted of two parallel columns of two resistors (75 mm diameter, 44 mm long) in each column. The resistors were selected to represent the lowest acceptable reference voltage level. The tests were conducted in accordance with Clause 8.5.5 of IEC 60099-4. Prior to the conditioning portion of the test, measurements were made of the lightning impulse residual voltage of each section, and also of reference voltage of each section. Additional measurements were made of power dissipation at U_c, and an adjusted value U_c' was determined such that the power dissipation of each sample represented the maximum power dissipation of resistors that could be used in arrester assembly. The adjusted value Uc' was used in the thermal recovery portion of the test.

The conditioning portion of the test consisted of two parts. In the first part, a series of twenty 8/20 lightning current impulses were applied to each section, with peak value of the impulses being equal to the nominal discharge current. The series of impulses was divided into four groups of five, with the interval between impulses within each group being between 50 and 60 seconds and the interval between groups being between 25 and 30 minutes. Test sections were energized at 60 Hz voltage of $1.2 \times U_c$ during the application of the impulses within each group. The impulses were timed to occur 60° before the crest of the 60 Hz voltage with the same polarity of the impulse. In the second part, a series of two 100kA 4/10 impulses were applied to each section, with the section allowed to cool to ambient temperature between impulses.

Following the conditioning portion of the test, each section was placed in an oven and heated overnight to 60 ± 3 °C. After removal from the oven, each section was subjected to two long duration current impulses, with time between impulses being between 50 and 60 seconds. The parameters of the transmission line used to generate these impulses conformed to the requirements for Line Discharge Class 5 in Table 5 of Clause 8.4.2 of IEC 60099-4. Within 100 milliseconds of the second long duration current impulse, rated voltage (U_r) was applied to each section for 10 seconds, immediately followed by the adjusted U_c' for 30 minutes, during which period the power dissipation was monitored to verify thermal stability.

At the end of the above test sequence, each section was allowed to cool to ambient temperature, at which point the lightning impulse residual voltage at nominal discharge current was re-measured.

Table 1 lists the initial measurements of residual voltage and reference voltage for each section, and lists the corresponding transmission line parameters used for the test.

Table 1. Initial Measurements and Parameters for Line Discharge Tests

Parameter	Sample 1	Sample 2	Sample 3
Initial Residual Voltage (kV) @ 20 kA, 8/20	26.94	26.90	26.89
Reference Current (mA) I_{ref}	10	10	10
Reference Voltage (kVpeak/√2) V_{ref}	11.89	11.88	11.87
COV (kV rms) U_c	9.63	9.62	9.62
Adjusted COV 9kVrms) Uc'	10.04	10.02	10.01
Rating (kV rms) U_r	12.03	12.02	12.02
Arrester Classification (kA)	20	20	20
Line Discharge Class	5	5	5
Virtual Duration of Peak (μs, 90-90%) - min	3200	3200	3200
Surge Impedance (W) Z_g - max (0.5 U_r)	6.03	6.01	6.01
Charging Voltage (kV) U_L – min (2.4 U_r)	28.88	28.85	28.85

RESULTS:

Figures 1, 2 and 3 show recordings made during application of the 5th and 20th lightning impulse conditioning discharges on each section. Figures 4, 5 and 6 show recordings made during application of the 1st and 2nd high current conditioning impulse on each section.

A short circuit test was performed on the generator to confirm that generator impedance and duration of the current discharge met the requirements listed in Table 1. The oscillogram of Figure 1 shows

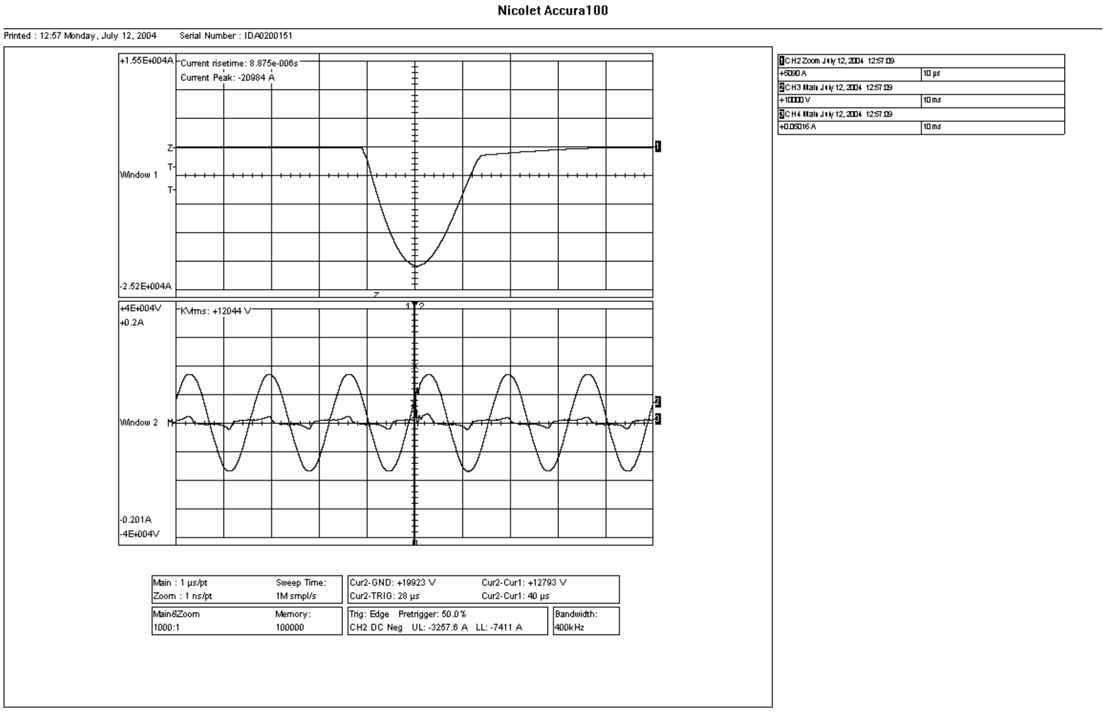
$$Z_g = 6{,}547 \text{ V} / 1{,}092 \text{ A} = 5.995\ \Omega \qquad \text{Virtual Duration of Peak} = 3239\ \mu\text{s}$$

Table 2 lists the current and voltage magnitudes and discharge energy measured on each of the two line discharges for each of the three test samples.

Table 2. Line Discharge Test Measurements

Impulse	Section 1			Section 2			Section 3		
	I (A)	V (kV)	E (kJ)	I (A)	V (kV)	E (kJ)	I (A)	V (kV)	E (kJ)
1	1224	22.27	95.0	1234	22.20	95.1	1224	22.09	94.9
2	1183	22.48	95.6	1194	22.40	96.6	1178	22.33	98.6

Section 1: 5th conditioning impulse



Section 1: 20th conditioning impulse

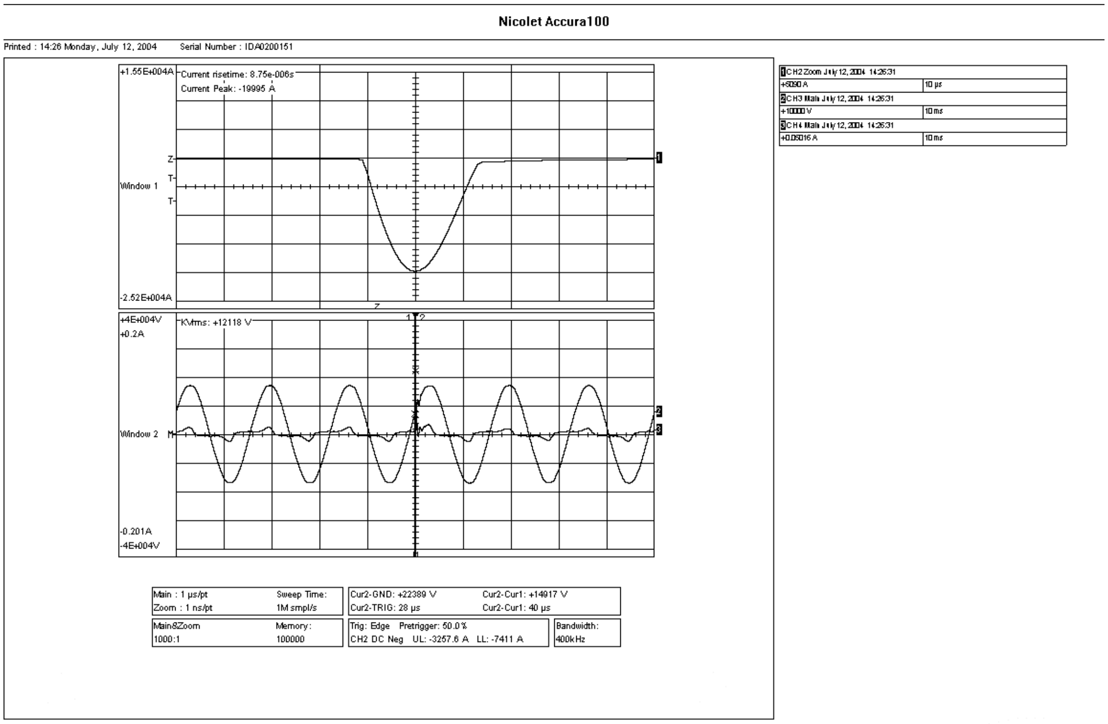
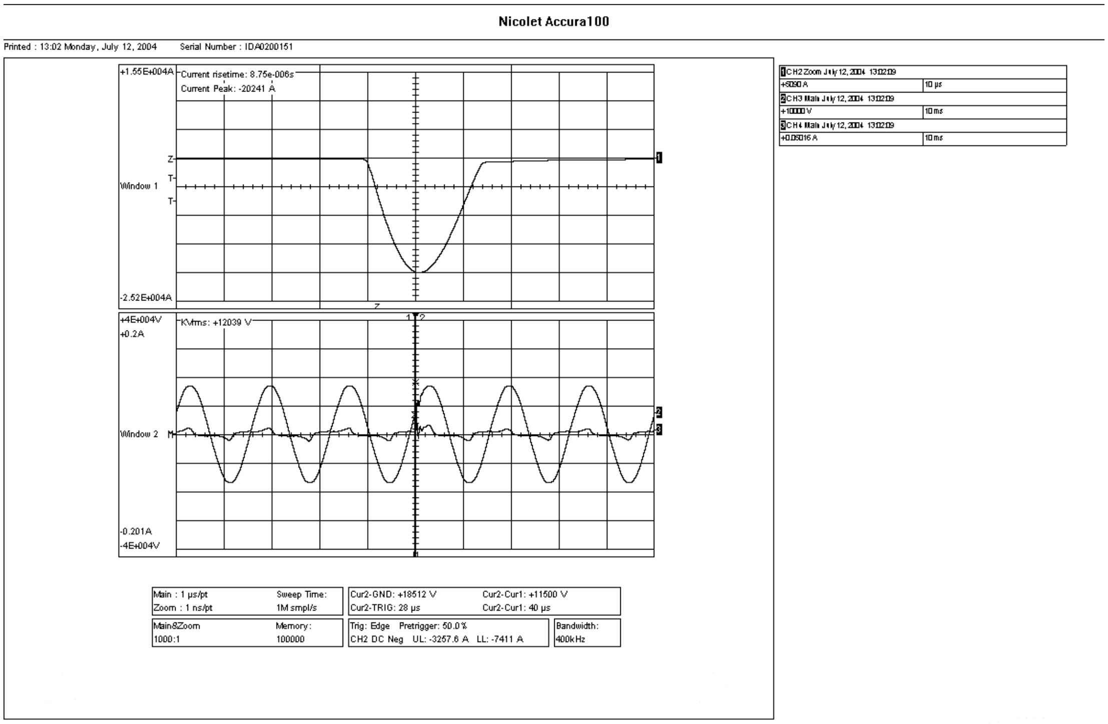


Figure 1. Oscillograms of 10kA 8/20 conditioning impulses for section 1

Section 2: 5th conditioning impulse



Section 2: 20th conditioning impulse

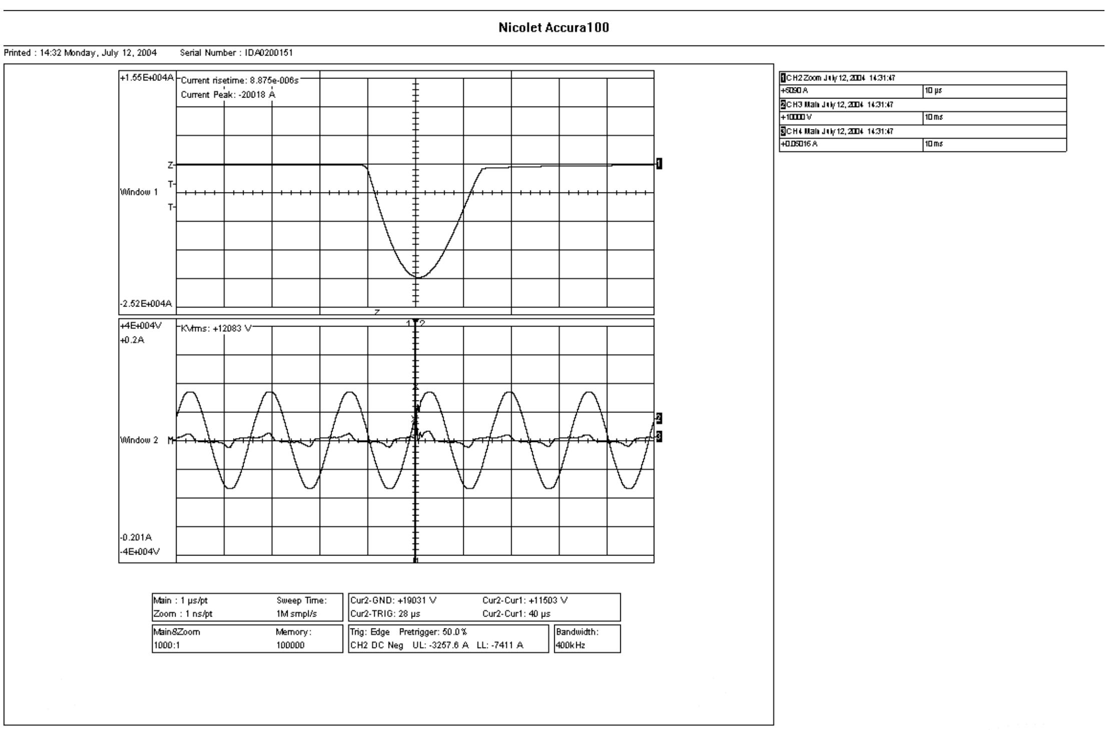
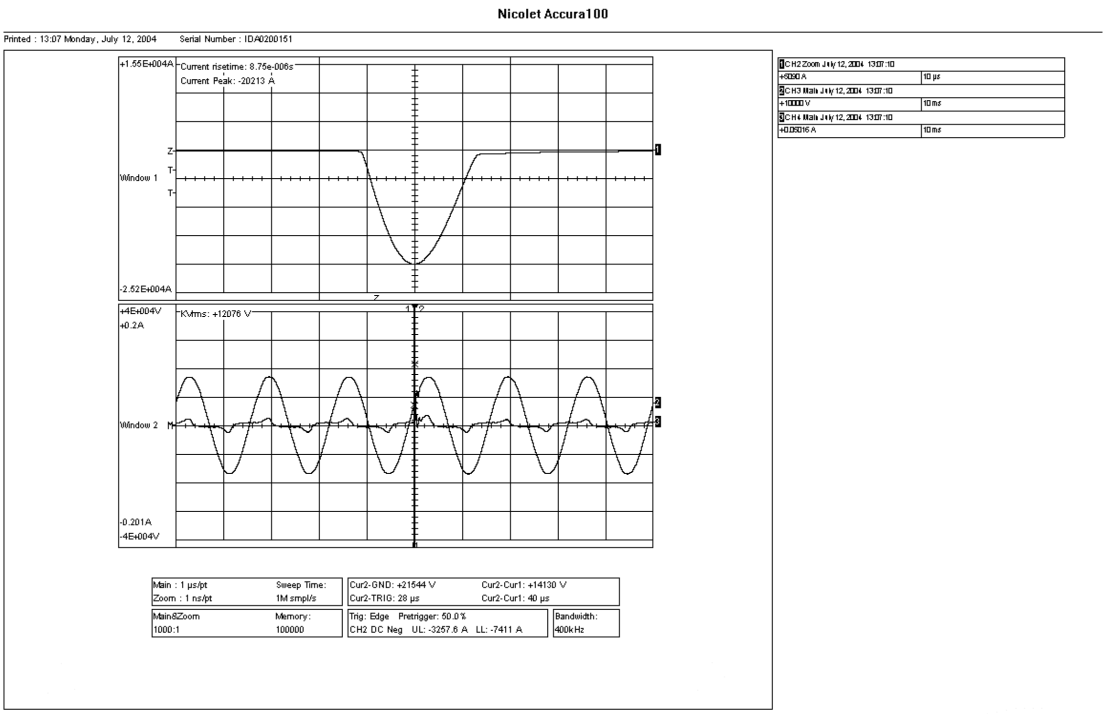


Figure 2. Oscillograms of 10kA 8/20 conditioning impulses for section 2

Section 3: 5th conditioning impulse



Section 3: 20th conditioning impulse

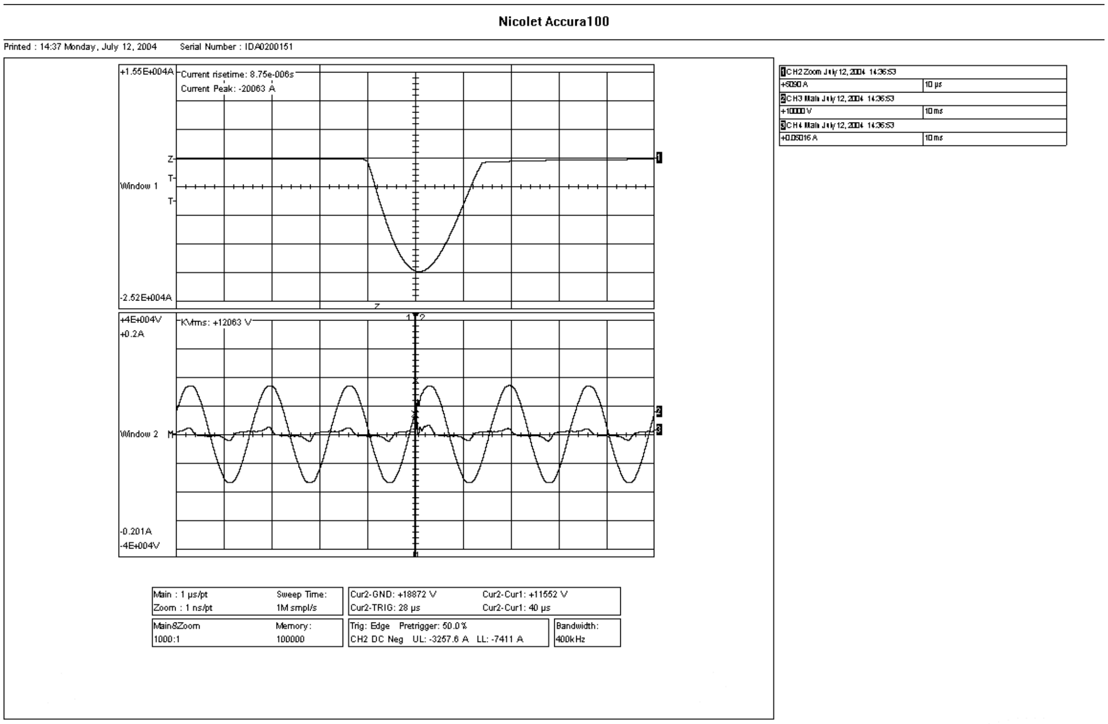
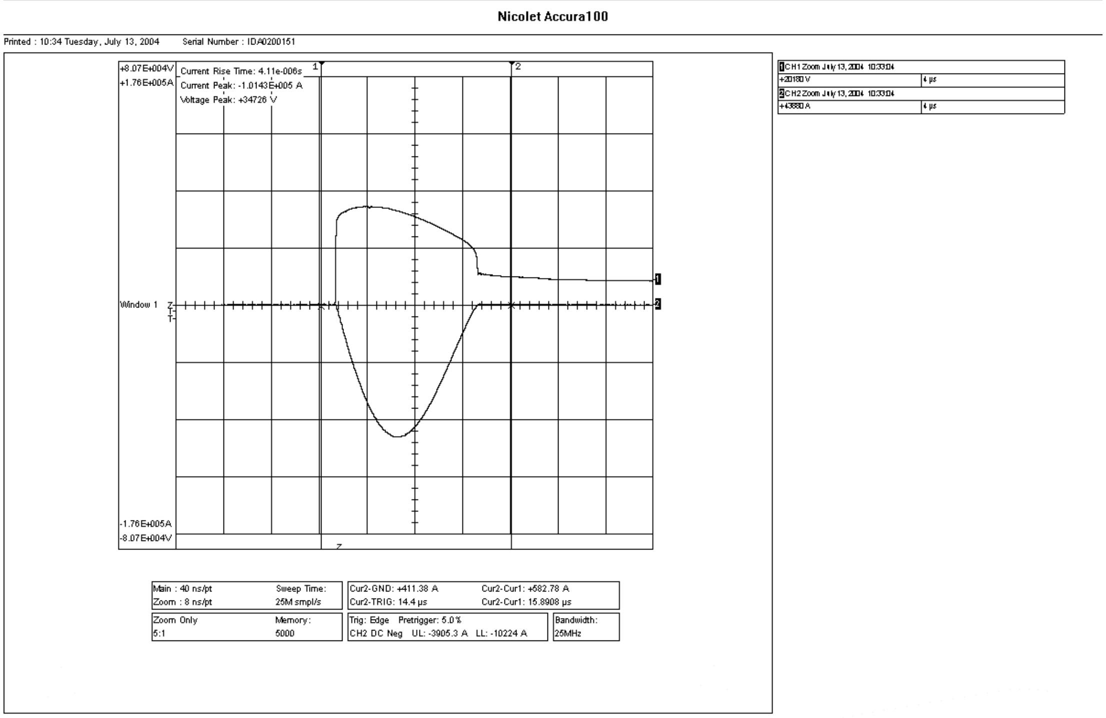


Figure 3. Oscillograms of 10kA 8/20 conditioning impulses for section 3

Section 1: 1st conditioning impulse



Section 1: 2nd conditioning impulse

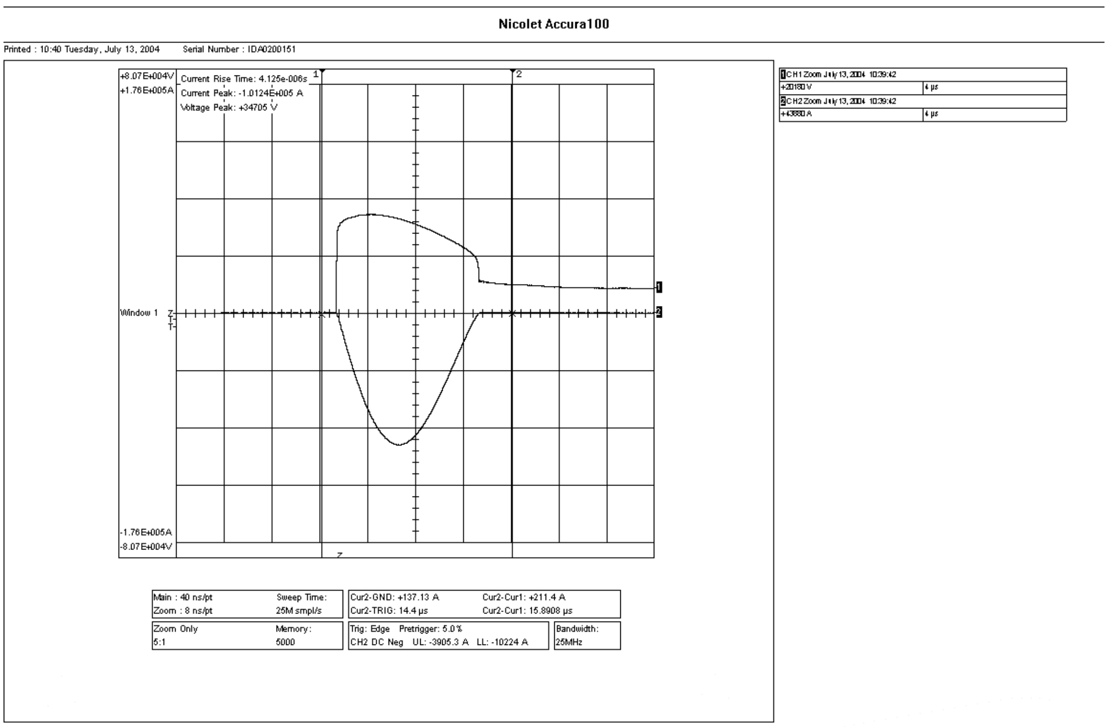
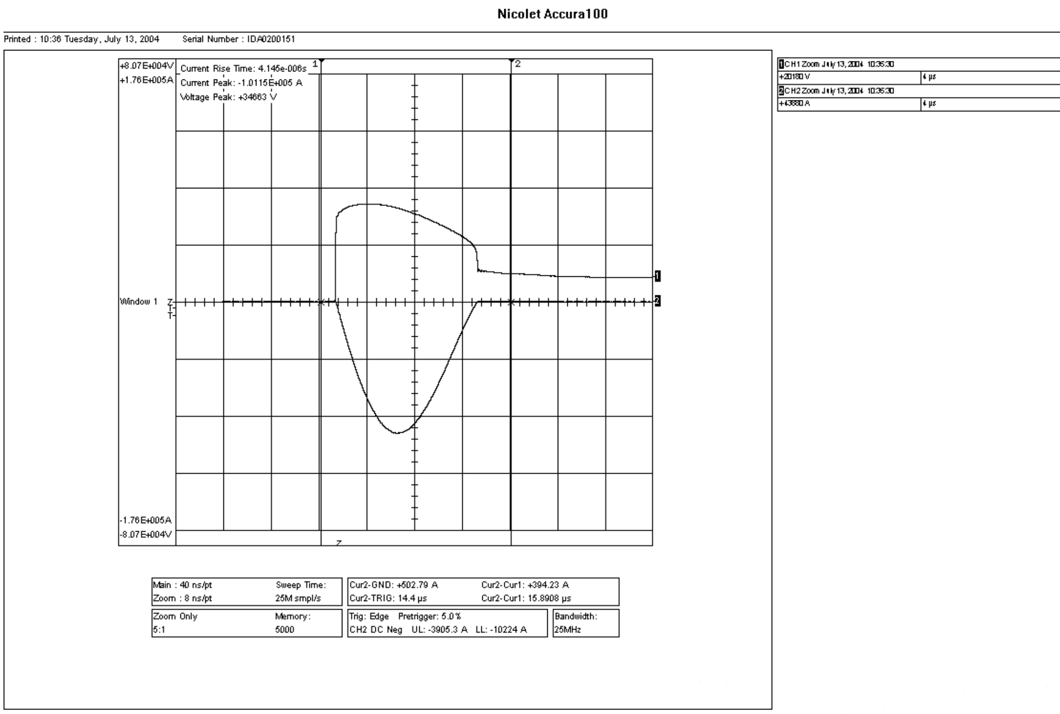


Figure 4. Oscillograms of 100kA conditioning impulses for section 1

Section 2: 1st conditioning impulse



Section 2: 2nd conditioning impulse

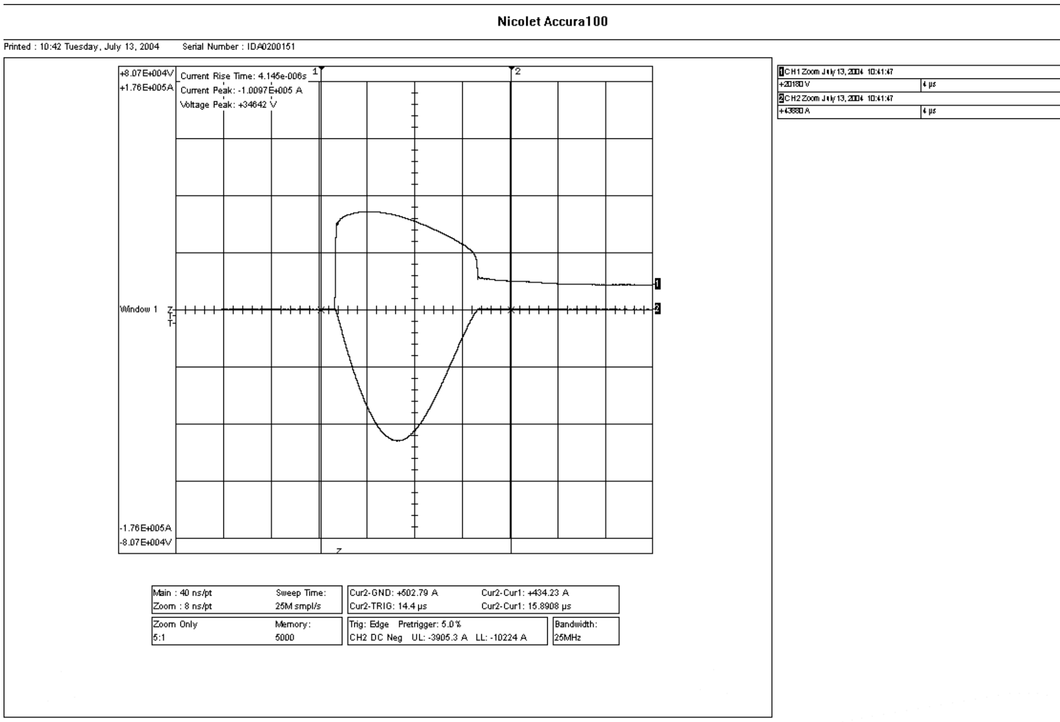
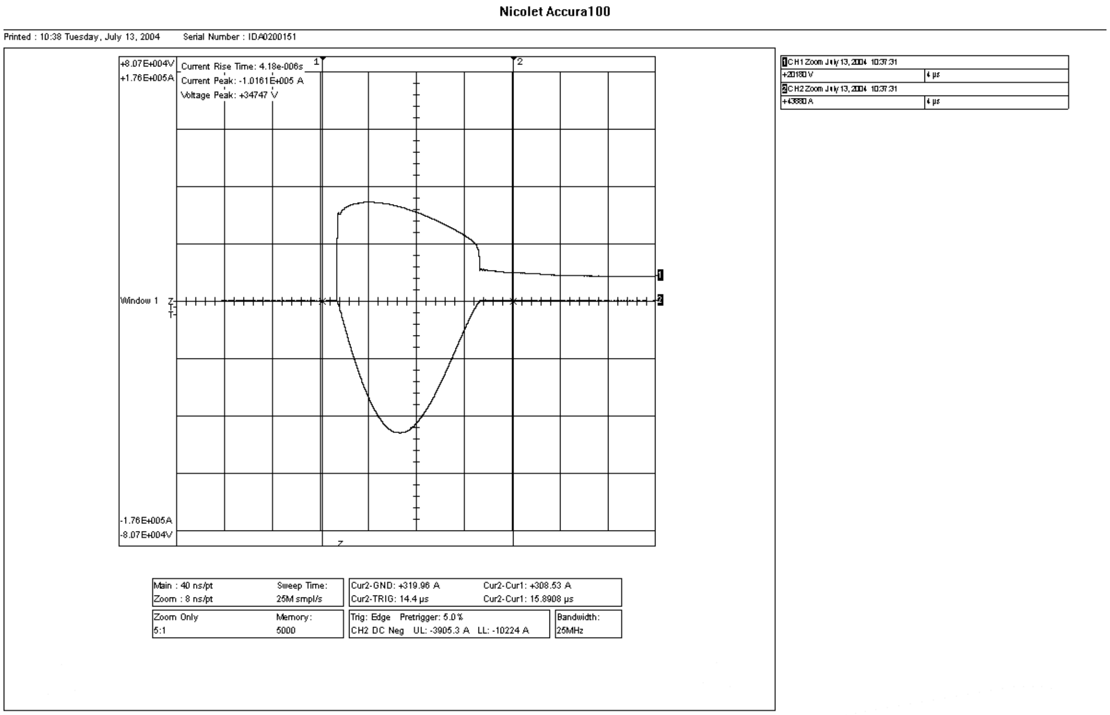


Figure 5. Oscillograms of 100kA conditioning impulses for section 2

Section 3: 1st conditioning impulse



Section 3: 2nd conditioning impulse

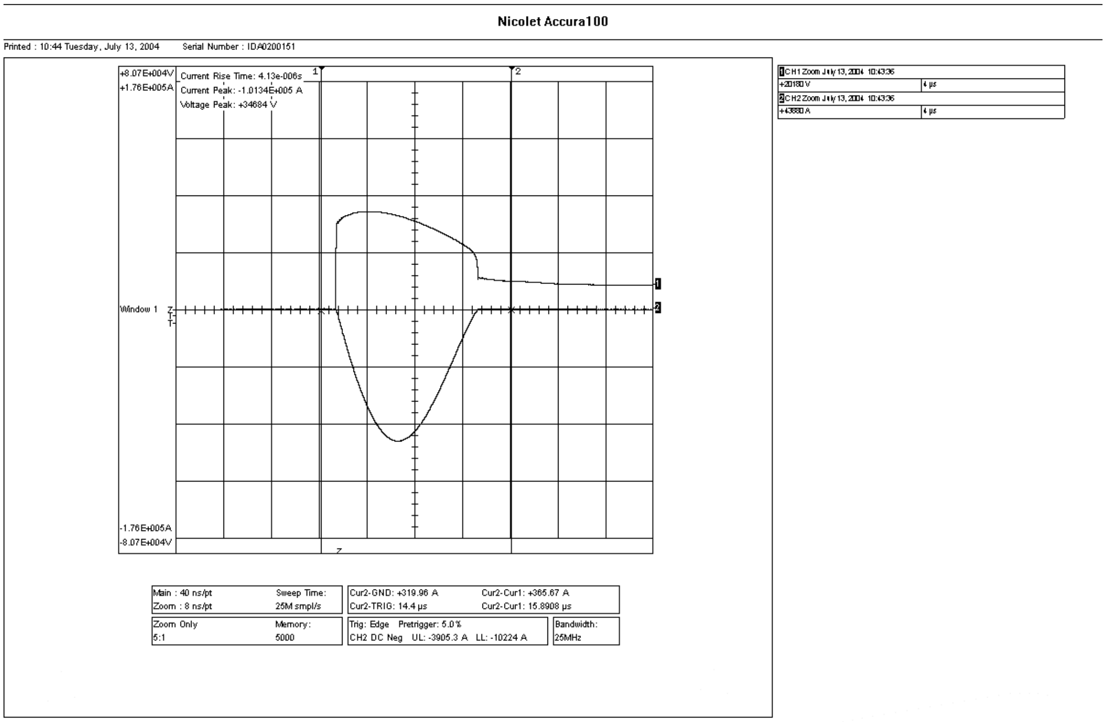


Figure 6. Oscillograms of 100kA conditioning impulses for section 3

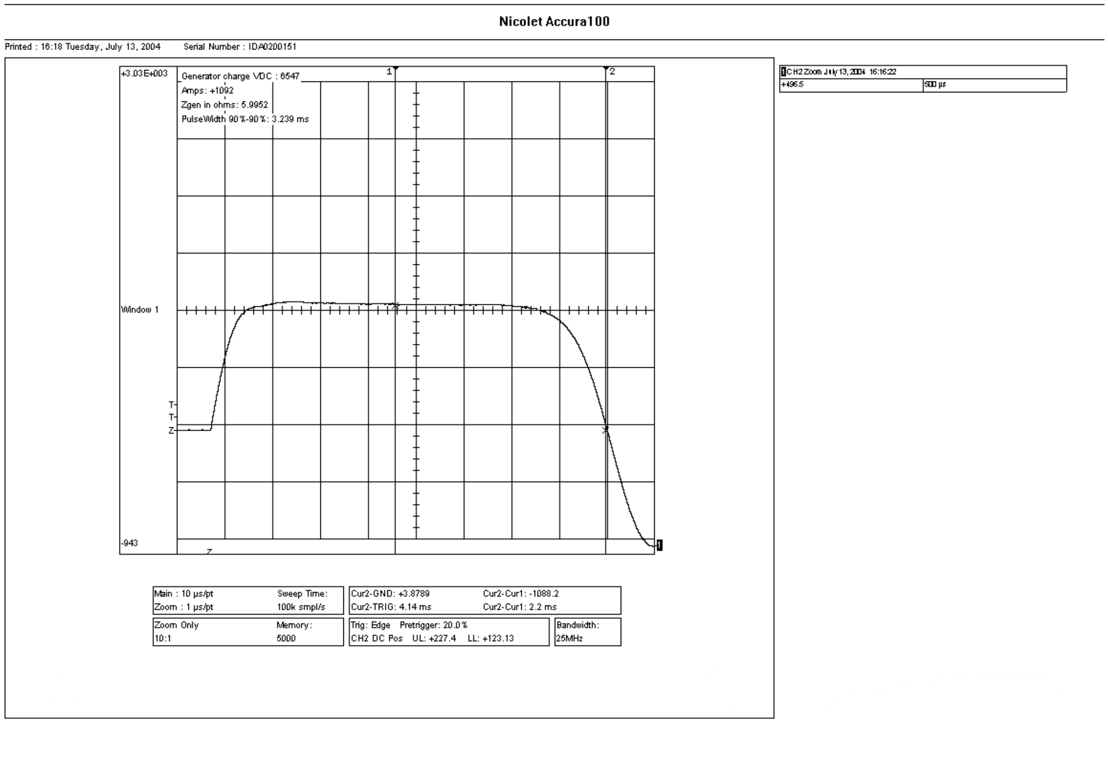


Figure 7. Oscillogram of discharge current for generator short circuit set up test

Figures 8, 9 and 10 show oscillograms of the second line discharge and the 10 s application of U_r on each section. Ambient air temperature at the time of the test was 22 °C. Table 3 lists measurements made during this period.

Table 3. Measurements made during 10 s application of U_r.

Section 1			Section 2			Section 3		
Time (s)	**Voltage (kVc)**	**Current (mAc)**	**Time (s)**	**Voltage (kVc)**	**Current (mAc)**	**Time (s)**	**Voltage (kVc)**	**Current (mAc)**
0.06	**17.02**	**128.2**	**0.06**	**17.02**	**161.9**	**0.074**	**16.98**	**148.4**
1	**17.17**	**135.4**	**1**	**17.25**	**172.1**	**1**	**17.22**	**163.1**
2	**17.16**	**131.2**	**2**	**17.27**	**170.8**	**2**	**17.26**	**158.6**
4	**17.19**	**135.8**	**4**	**17.26**	**167.0**	**4**	**17.27**	**160.3**
6	**17.19**	**133.7**	**6**	**17.26**	**164.1**	**6**	**17.27**	**157.3**
8	**17.19**	**130.3**	**8**	**17.27**	**165.3**	**8**	**17.26**	**154.4**
10	**17.19**	**132.0**	**10**	**17.27**	**169.5**	**10**	**17.27**	**156.5**

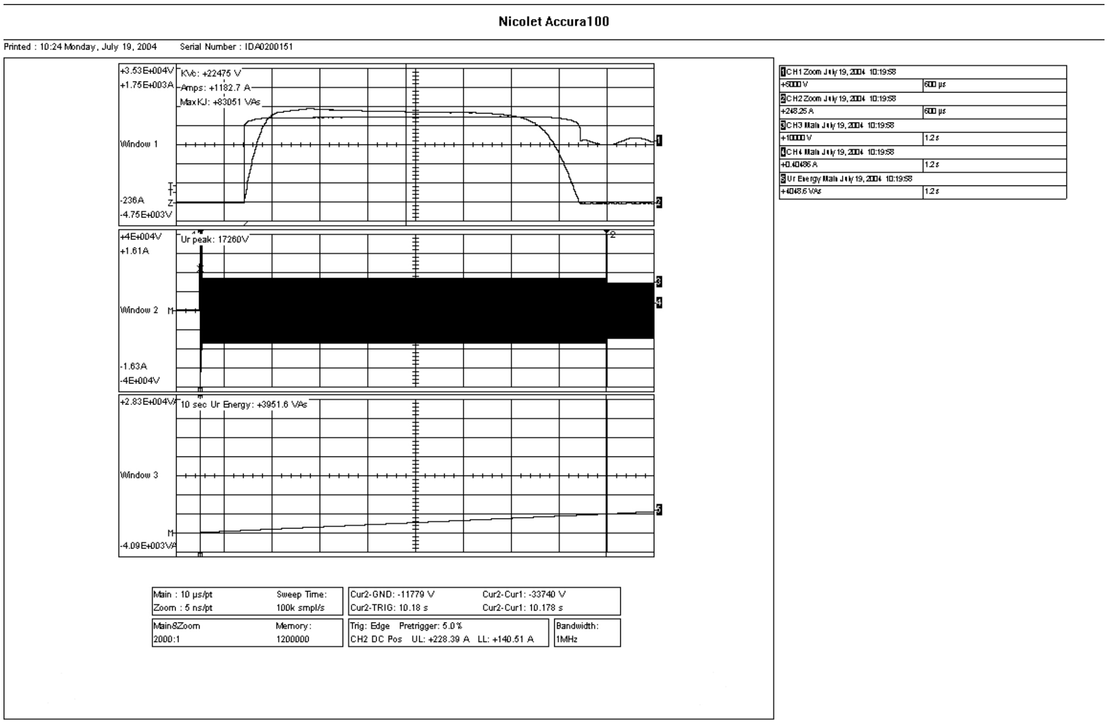


Figure 8. Oscillogram of second line discharge for section 1

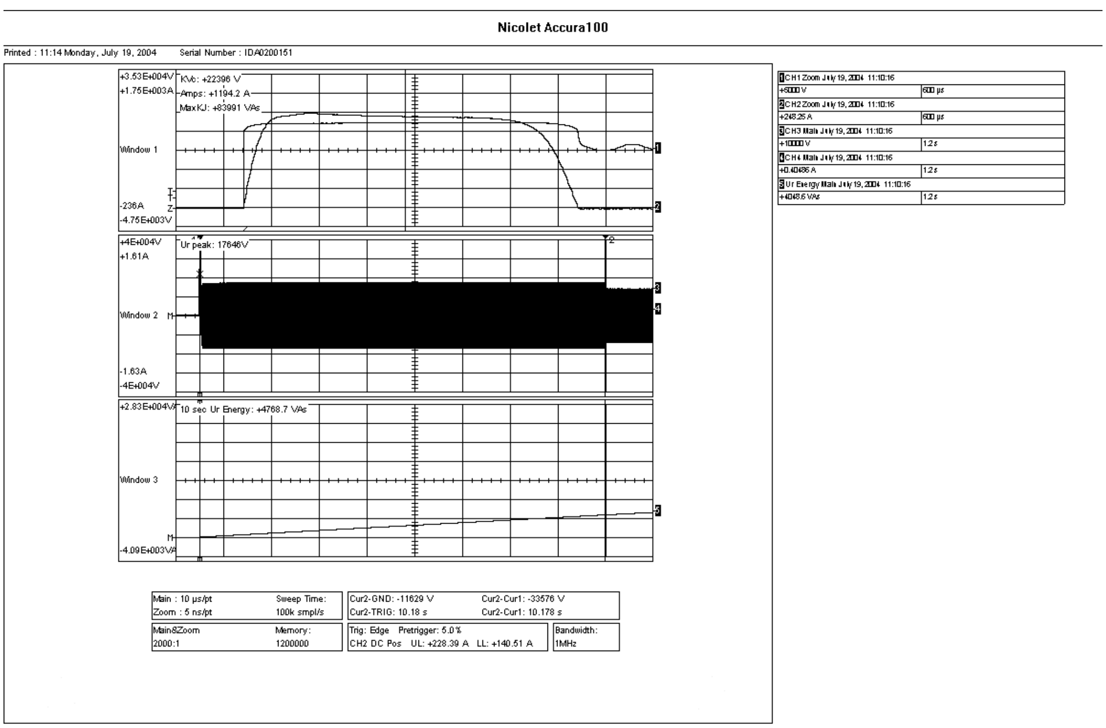


Figure 9. Oscillogram of second line discharge for section 2

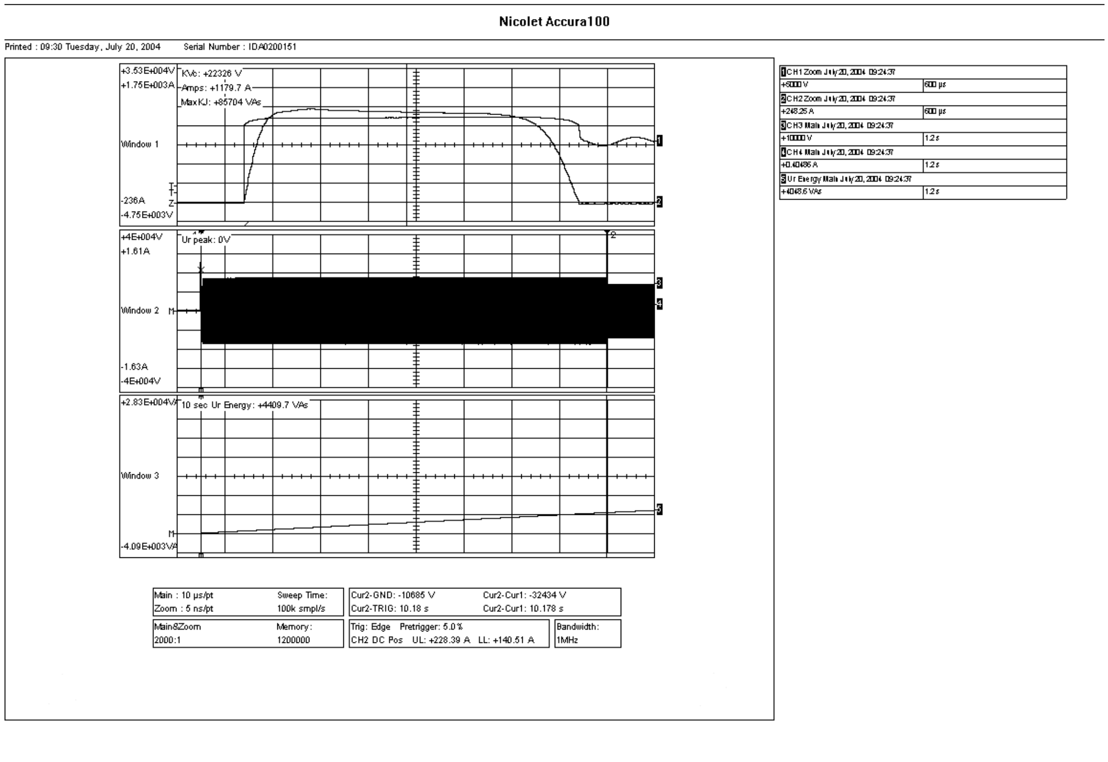
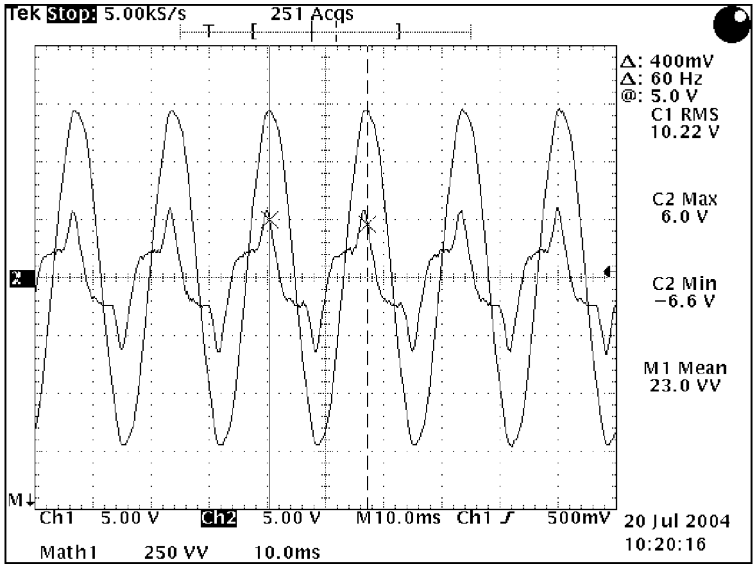


Figure 10. Oscillogram of second line discharge for section 3

Figures 11, 12 and 13 show oscillograms of voltage and current at the beginning and end of the 30 min application of U_c' on each section. Table 4 lists measurements of power dissipation made during this period.

Table 4. Measurements of power dissipation made during 30 min at U_c'

Time (min)	Power Dissipation (W)		
	Section 1	Section 2	Section 3
0	51.4	50.2	43.5
0.5	49.1	46.9	44.7
1	41.3	44.7	42.4
2	40.2	42.4	
5	35.7	38.0	35.7
10	32.4	34.6	32.4
20	29.0	31.3	30.1
30	26.8	29.0	27.9



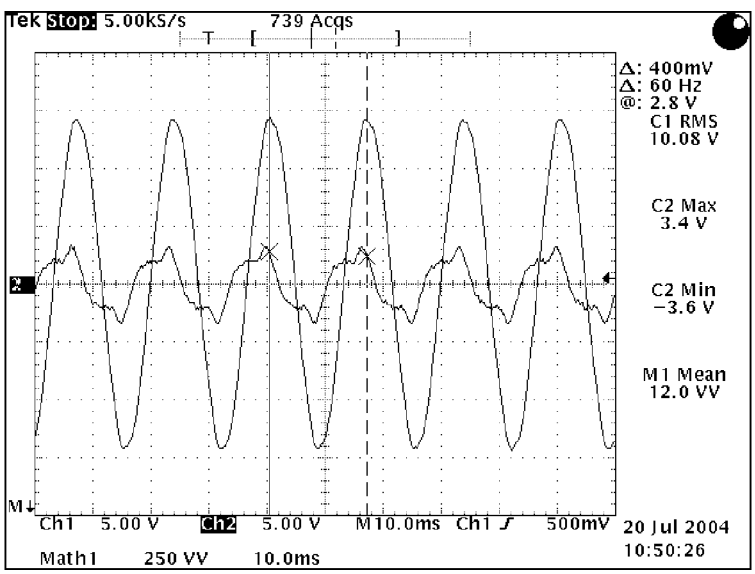
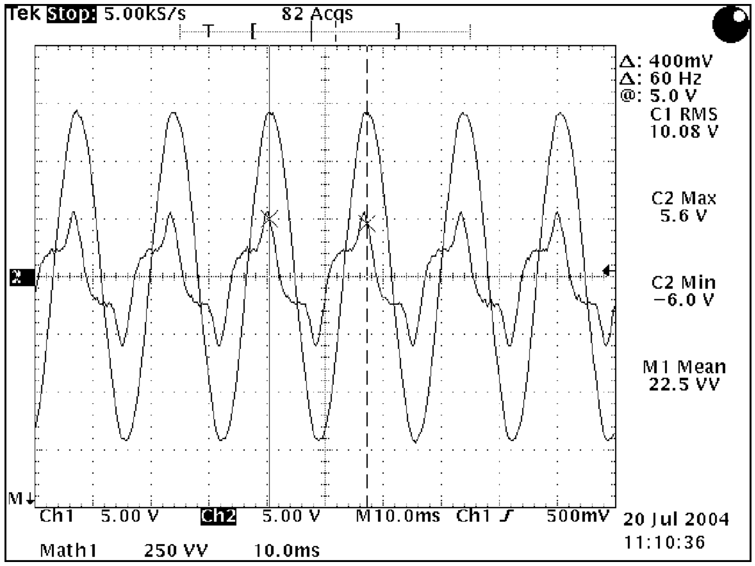


Figure 11. Oscillograms of voltage and current at the beginning and end of the 30 min application of U_c' for section 1



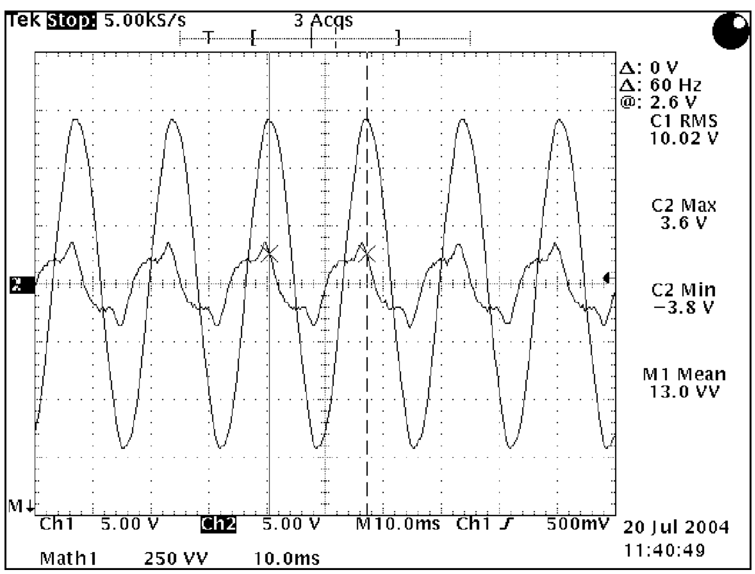
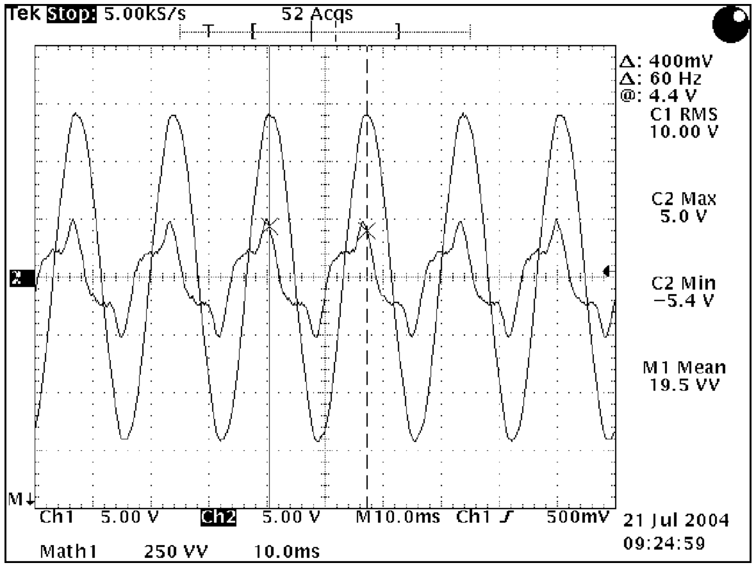


Figure 12. Oscillograms of voltage and current at the beginning and end of the 30 min application of U_c' for section 2



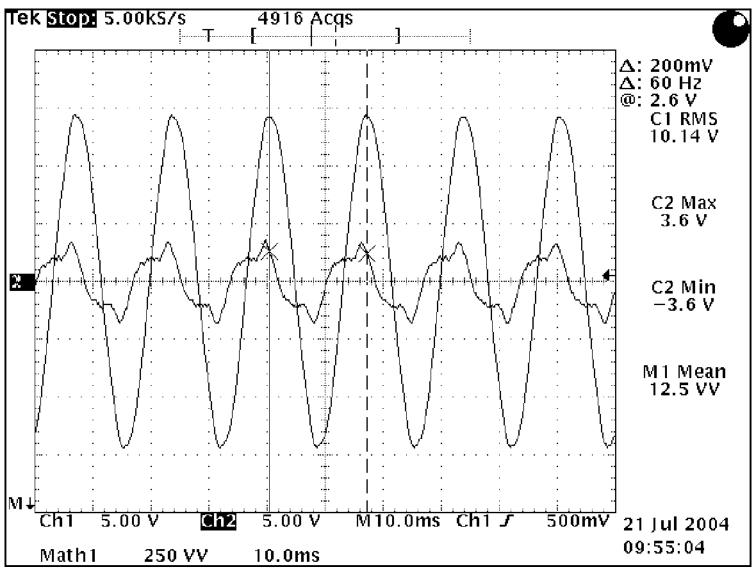


Figure 13. Oscillograms of voltage and current at the beginning and end of the 30 min application of U_c' for section 3

Subsequent to the completion of the thermal recovery, and after the sections had cooled to ambient temperature, the residual voltage at nominal discharge current was re-measured and compared to the initial values for each test sample. Results are summarized in Table 5. The maximum change of residual voltage of the three samples is less than the permissible change of 5 % defined by IEC 60099-4.

Table 5. Initial and final residual voltage measurements.

Section	Residual voltage (kV)		Change
	Initial	Final	
1	26.94	26.94	0.0%
2	26.90	26.94	+ 0.1%
3	26.89	26.86	- 0.1%

Disassembly of the test samples at the end of the electrical tests revealed no evidence of physical damage.

IEC Type Test Report
Report No. EU1518-H-07
H5 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 5

Short Circuit

This report records the results of type tests made on H5 series 20 kA Line Discharge Class 5 arresters, rated up to 612 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.0, 2004, "Surge arresters - Part 4: Metal-oxide surge arresters without gaps for a.c. systems."

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

M.G. Comber
Manager, Engineering

Date: 9/23/2004

IEC TYPE TEST REPORT
Short Circuit

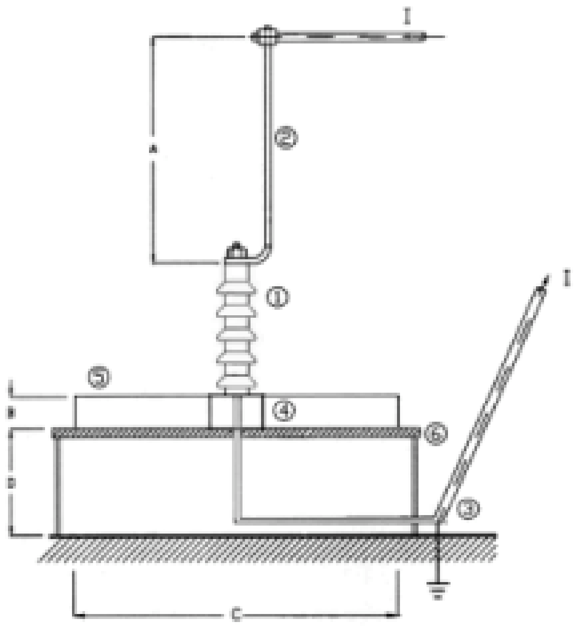
TESTS PERFORMED:
Short circuit tests were performed at the CESI high power laboratory in Milan, Italy according to the procedures described in Clause 8.7 and Annex N of IEC 60099-4. The H5 series of arresters has a rated short circuit capability of 63000 A symmetrical. Verification of capability requires three high current tests and one low current test. The high current tests are performed with rated short circuit current (63000 A) and two reduced short circuit currents (25000 A and 12000 A); the low current test is performed with short circuit current of 600±200 A. Four fully assembled test units were prepared, each containing as many resistor elements as possible within the available stacking length. The internal elements of each test unit were shorted by a fuse wire running along the outside of the stack of elements. The units tested represented the longest mechanical unit with the highest rated voltage used in the H5 series of arresters.

RESULTS:
Complete results of the testing are contained in a CESI test report that is available on request. Results are summarized in the following extracts from the CESI report.

The test samples were rated 147 kV and had an overall unit length of 1570 mm. Figure 1 shows the general arrangement of the test set up. Figure 2 shows one of the units in the test chamber.

All four samples successfully withstood their respective short circuit current tests with no release of components and no fracturing of the porcelain housing. Tests were conducted in the sequence: 12000 A, 25000 A, low current, 63000 A. Actual prospective rms values of test currents were 12600 A, 25500 A, 651 A and 67000 A. For the rated current test, the peak of the first half cycle of test current was 176000 A, meeting the requiremnt that this be at least 2.5 times the rms value of the rated short circuit current. Data sheets for the tests are shown in Figures 3– 6, and associated oscillograms are shown in Figures 7 - 10.

D8045 - Test arrangement



1 : Surge arrester
2 : Flexible conductor
3 : Rigid conductor
4 : Support
5 : Surrounding fence
6 : Insulating wood platform

A : 1,00 m
B : 0,40 m
C : 3,50 m
D : 1,00 m

The arrester to be tested was fixed on a support at 1.40 m to ground in the middle of a circular enclosure of 3,50 m in diameter. The circular enclosure was positioned on an insulating wood platform. The pressure relief device was directed toward the power supply conductors (inside the current loop).
The live side of the supply was connected to the upper end of the arrester while the return circuit, earthed, was connected to the lower end.

D8045IG

Figure 1. Test circuit arrangement

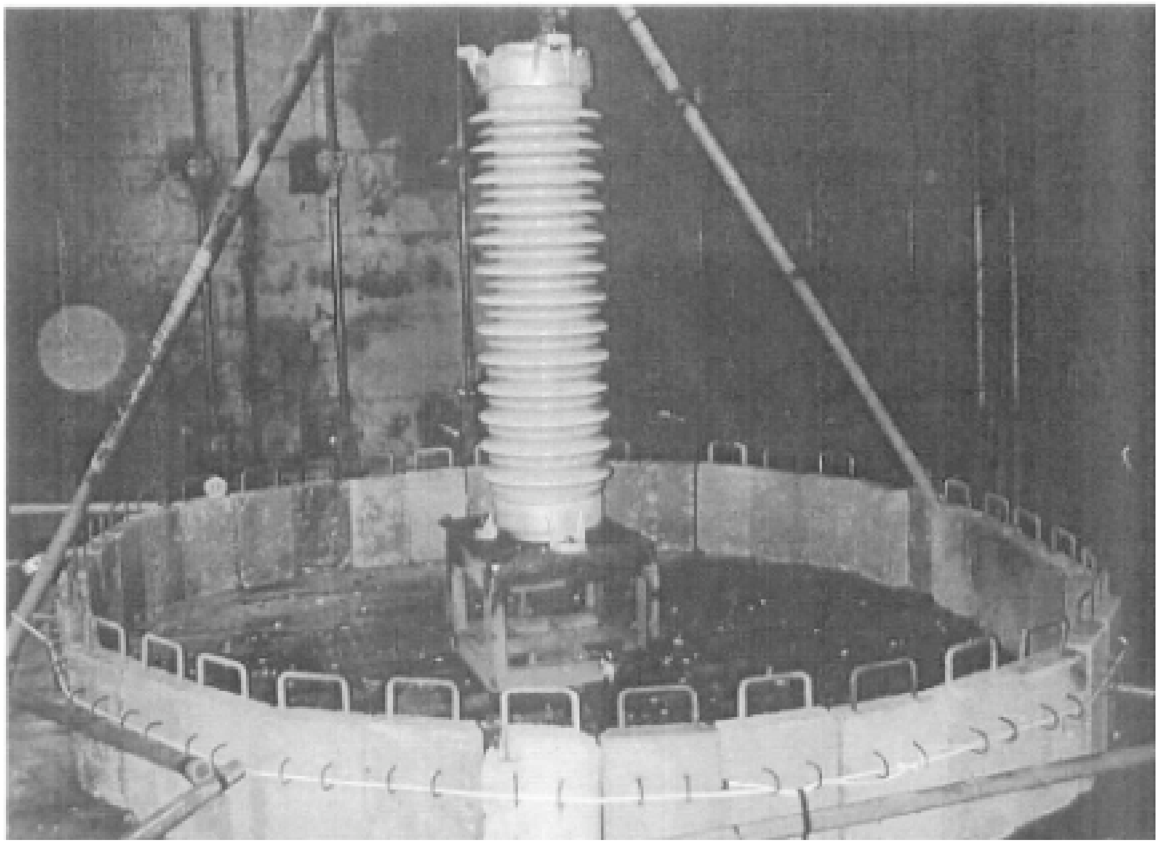


Figure 2. Test sample mounted in test chamber

igh-current short-circuit test with ,6 for 0,

circuit : See D0046 factor Frequency Hz

est arrangement and photo No.
internal discharge Client epl CESI with surge arrester ing non-linear resistors bypassed by fuse wire.
photo resistor was used → detector the opening explosion

Prospective test current			
Oscillogram		rms value	Peak value
No.	Sheets	kA	kA
2	1	12,6	35,0

Condition the apparatus the tests: new see photo

Date: June 23, 2004

Test	Oscillogram		Arrester under test	Duration	Test voltage	Test current		Opening time of the explosion vent		Notes
						Peak value	rms value			
No.	No.	Sheets	No.	s	kV	kA	kA	ms	-	No.
		2	1	0,21	29,0	31,7	12,6	9,80	-	-

Condition the apparatus after the tests: see photos

The arrester structure remained almost intact with light damages porcelain housing.
The arrester remained connected to the supply and return circuits.
No pieces were projected inside or outside the circular enclosure.

Figure 3. Data sheet for 12000 A test

High-current short-circuit ith 25,5 kA for

Test circuit : See D0046 Power factor Frequency 50

est arrangement : See D0045
To achieve discharge, the suppl CESI with surge arrester having the bypassed by
photo resistor was used as detector opening the explosion

Prospective test current			
Oscillogram		rms value	Peak value
No.	Sheets	kA	kA
7	1	25,5	70,7

Condition apparatus before photo

Date: June 23, 2004

Test	Oscillogram		Arrester under test	Duration	Test voltage	Test current		Opening time of the explosion vent		Notes
						Peak value	rms value			
No.	No.	Sheets	No.	s	kV	kA	kA	ms	-	No.
				0,21	23,0	60,6	25,5	8,00	-	-

Condition the apparatus photos

The arrester structure remained almost intact with light damages the porcelain housing.
The arrester remained connected to the supply and return circuits.
No pieces were projected inside outside the circular enclosure.

Figure 4. Data sheet for 25000 A test

Lo short- wi 65 for 00

est circuit : See D0046 Frequency

rrangement : See u804
scharge, the supplied surge arrester hav bypassed by
photo ued opening the plosion

Prospective test current			
Oscillogram		rms value	Peak value
No.	Sheets	A	A
12	1	651	

Conditi apparat before the tests: new see photo

Date: June 21, 2004

Test	Oscillogram		Arrester under test	Duration	Test voltage	Test current		Opening time of the explosion vent		Notes
						Peak value	rms value			
No.	No.	Sheets	No.	s	kV	kA	A	Ms	-	No.
3	14	1	3	1,01	29,0		651	492	-	-

Condition the apparatus after the ph

The arrester remained intact.
The arrester remained connected the supply and return circuits.
No pieces were projected inside outside the circular enclosure.

Figure 5. Data sheet for low current test

igh-current hort-circuit test wit 67 kA for ,2

Test circuit : See D0046 Frequency 50

Test arrangement
achieve internal discharge, supplied CESI with the surge arrester having bypassed by
photo detector the opening explosion

Prospective test current			
Oscillogram		rms value	Peak value
No.	Sheets	kA	kA
16	1	67,0	199

Cond the apparatus before photo No.10.

Date: June 25, 2004

Test	Oscillogram		Arrester under test	Duration	Test voltage	Test current		Opening time of the explosion vent		Notes
						Peak value	rms value			
No.	No.	Sheets	No.	s	kV	kA	kA	ms	-	No.
4	17	2	4	0,21	15,0	176	63,5	5,70	-	-

ondition the fter the photos

The arrester structure remained almost intact with light damages porcelain housing.
The arrester remained connected to the supply and return circuits.
No pieces were projected inside or outside the circular enclosure.

Figure 6. Data sheet for 63000 A current test

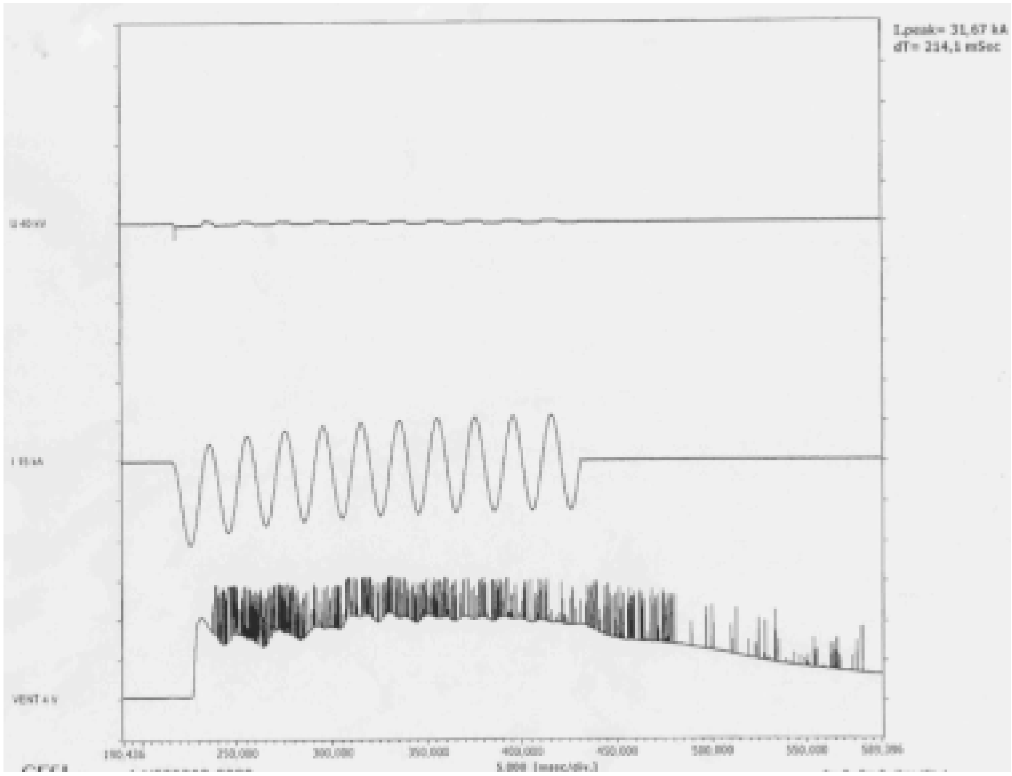


Figure 7. Oscillograms for 12500A test

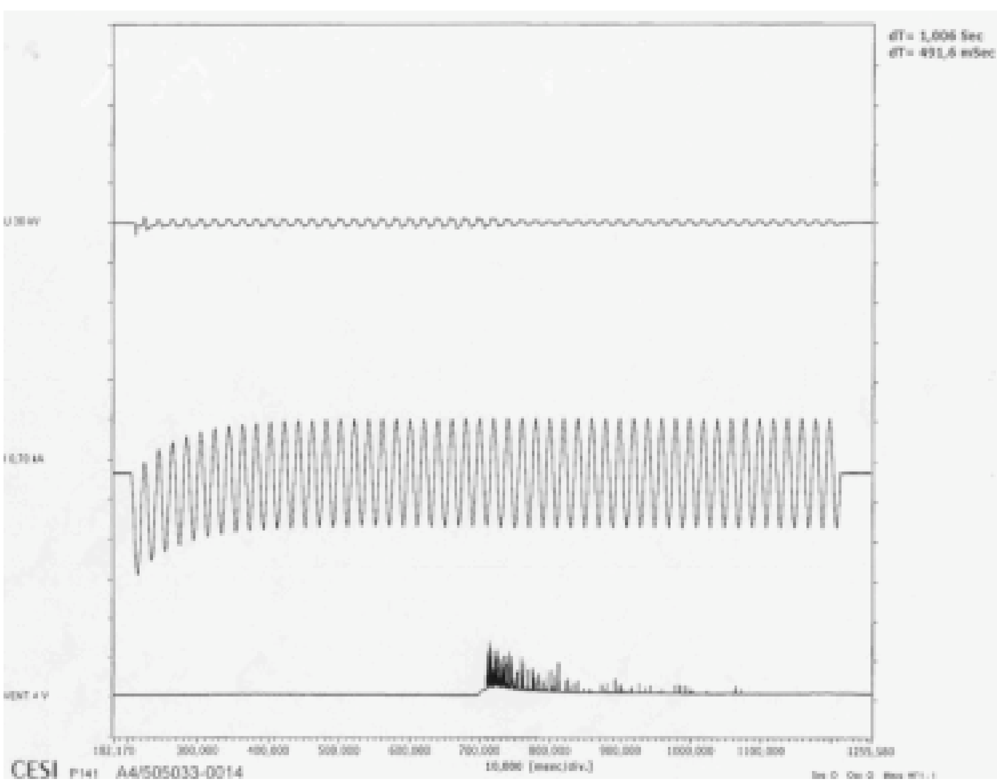


Figure 8. Oscillograms for 25000A test

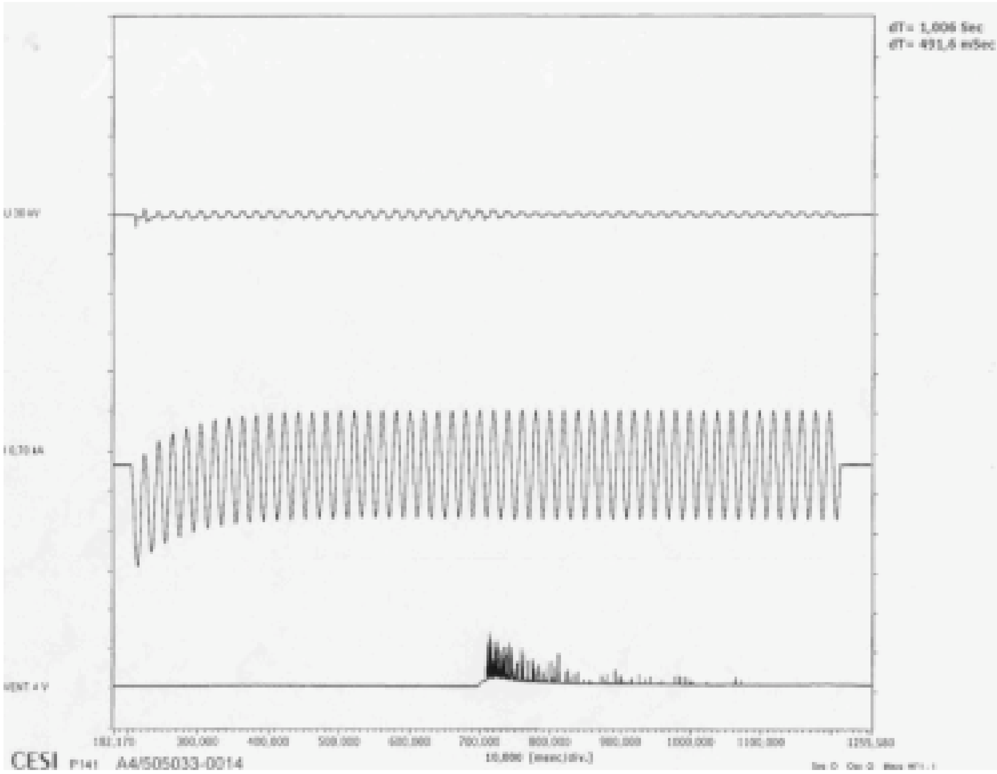


Figure 9. Oscillograms for 650A test

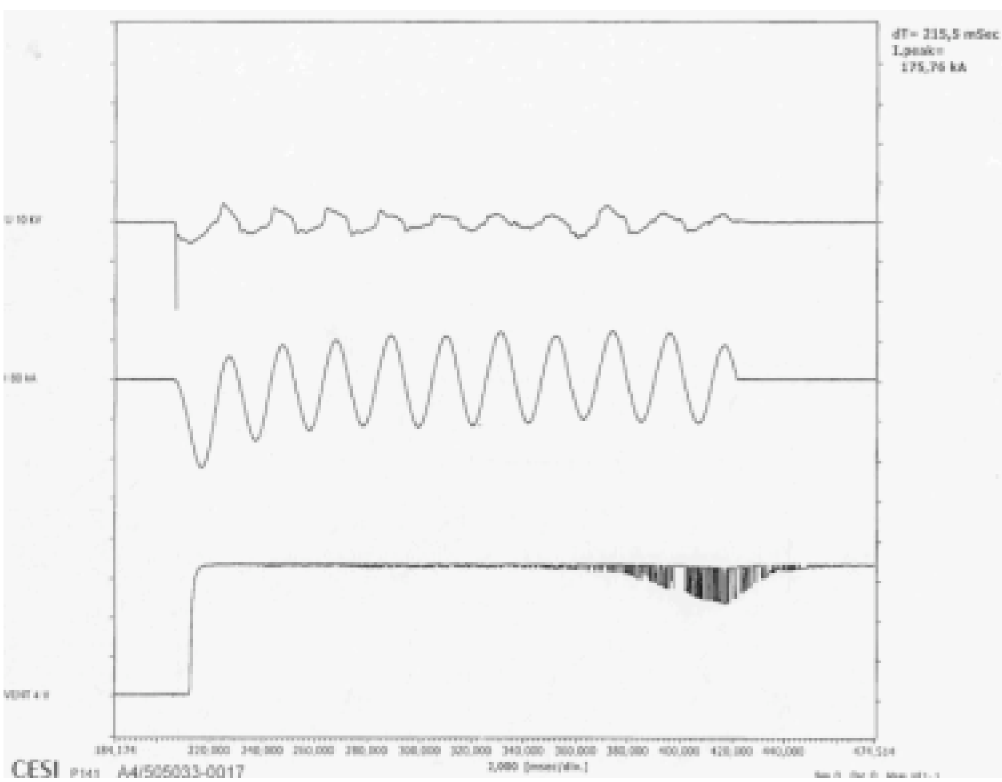


Figure 10. Oscillograms for 63000A test

HUBBELL POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1518-H-08
H5 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 5

Internal Partial Discharge

This report records the results of type tests made on H5 series 20 kA Line Discharge Class 5 arresters, rated up to 612 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.0, 2004, "Surge arresters - Part 4: Metal-oxide surge arresters without gaps for a.c. systems."

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

Michael G. Comber

M.G. Comber
Manager, Engineering

Date: 9/23/2004

IEC TYPE TEST REPORT
Internal Partial Discharge

Clause 8.8 of IEC 60099-4 requires that the longest electrical unit of the arrester design be subjected to an internal partial discharge type test. Under the prescribed testing procedure, the partial discharge level at 1.05 times the continuous operating voltage of the unit shall not exceed 10 pC.

Clause 9.1 c) of this same standard requires that all manufactured units be subjected to an internal partial discharge test that is identical to that of Clause 8.8, and that the partial discharge level of all units produced shall not exceed 10 pC. Routine test reports are provided on request verifying that this requirement has been met.

By performing the routine testing of units according to Clause 9.1 c), the type test requirements of Clause 8.8 are automatically met.

POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1518-H-09
H5 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 5

Bending Moment

This report records the results of type tests made on H5 series 20 kA Line Discharge Class 5 arresters, rated up to 612 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.0, 2004, "Surge arresters - Part 4: Metal-oxide surge arresters without gaps for a.c. systems."

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

Michael G. Comber
M.G. Comber
Manager, Engineering

Date: 9/23/2004

IEC TYPE TEST REPORT
Bending Moment

TESTS PERFORMED:
Bending moment tests were performed as described in Clause 8.9 of IEC 60099-4 on a fully assembled arrester unit. The test unit was securely mounted to the horizontal base of the test equipment and lateral (horizontal) loading was applied at a rate necessary to reach the bending moment corresponding to the maximum permissible dynamic service load (MPDSL) in approximately 90 s. The load was then maintained at not less than this level for at least 60 s. After release of load, the test sample was inspected to verify that no mechanical damage had occurred, and then the test sample was subjected to standard seal leak and partial discharge tests to verify that no damage to the sealing mechanism or to the internal structure had occurred.

RESULTS:
According to the requirements of IEC 60099-4, if the arrester design consists of multiple units or where the arrester has different specified bending moments at each end, it is necessary to verify the integrity of each different design bending moments. The H5 series of arresters uses one, two, three, four or five units depending on voltage rating and overall creepage distance requirements. The design uses two general porcelain housing types. Within each type, physical characteristics are identical except for the lengths. Both types have the same diameter and weathershed profile, but have different intrinsic mechanical strengths. These are designated as types 1 and 2, with type 1 having the higher intrinsic mechanical strength. The design also uses two different end fitting designs. These are designated as types F1 and F2.

The MPDSL assigned to H5 arresters is that load that results in a bending moment of 28000 Nm at the base of the arrester. Table 1 indicates the “worst case” combinations for – i.e. those that give rise to the highest moments at each end fitting location when MPDSL is applied to the top of the arrester – for one, two three, four and five-unit designs. The maximum bending moment at locations of end fitting type F1 is 28000 Nm, while the maximum bending load at locations of end fitting type F2 is 23096 Nm.

To verify the design capability, two bending moment tests were performed; one on a type 1 housing with type F1 end fitting, the other on type 2 housing with type F2 end fitting. In the first test, sufficient load was applied at the top of the unit to subject the bottom end of the unit to a minimum of 28000 Nm for a minimum of 60 s. In the second test, sufficient load was applied at the top of the unit to subject the bottom end of the unit to a minimum of 23096 Nm for a minimum of 60 s. Loading curves for these two tests are shown in Figures 1 and 2. These indicate that the loads were actually maintained at higher levels and for longer time than required. The gradual reduction of load during the “hold” period resulted from slow loss of pressure in the hydraulic system, and does not reflect any change in the mechanical property of the tested unit.

Subsequent to the loading tests, both units were examined and found to have suffered no visual mechanical damage. The units were then returned to the factory for seal leak rate check and partial discharge tests. Seal leak rate was found to be less than $1x10^{-7}$ Pa.m^{3}s$^-$1, and partial discharge at 1.05 U_c was found to be less than 10pC, both levels being below the limits allowed by IEC 60099-4.

Unit	L	M
F2.1		0
1	1567	
F1.1		**28000**

Unit	L	M
F2.2		0
2	1567	
F2.2		15140
F2.1		15140
1	1331	
F1.1		**28000**

Unit	L	M
F2.2		0
2	1567	
F2		9827
F2.2		9827
2	1567	
F2.2		19653
F2.1		19653
1	1331	
F1.1		**28000**

Unit	L	M
F2.2		0
2	1567	
F2.2		7274
F2.2		7274
2	1567	
F2.2		14548
F2.2		14548
2	1567	
F2.2		21822
F2.1		21822
1	1331	
F1.1		**28000**

Unit	L	M
F2.2		0
2	1567	
F2.2		5774
F2.2		5774
2	1567	
F2.2		11548
F2.2		11548
2	1567	
F2.2		17322
F2.1		17322
2	1567	
F2.2		**23096**
F2.1		**23096**
1	1331	
F1.1		**28000**

Max moment for F1.1 (dark shading) — Max moment for F2.1 and F2.2 (light shading)

Table 1. Worst-case bending moments for 1, 2, 3 and 4-unit arresters

Unit numbers 1 and 2 indicate porcelain housing type

F1.1, F2.1 and F2.2 indicate the different end fitting/porcelain housing type combinations (e.g. F2.1 indicates fitting type 2 attached to housing type 1)

L is length in mm, M is moment in Nm

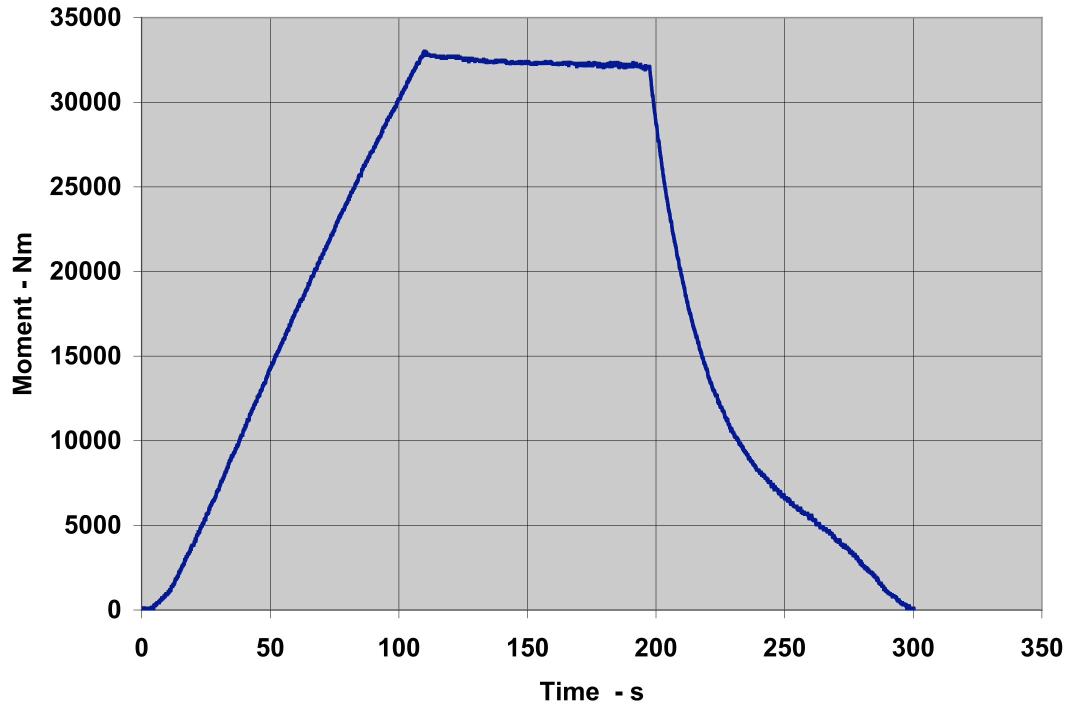


Figure 2. Bending moment at bottom end of housing type 1 with end fitting type F1
Max design moment at MPDSL: 28000 Nm

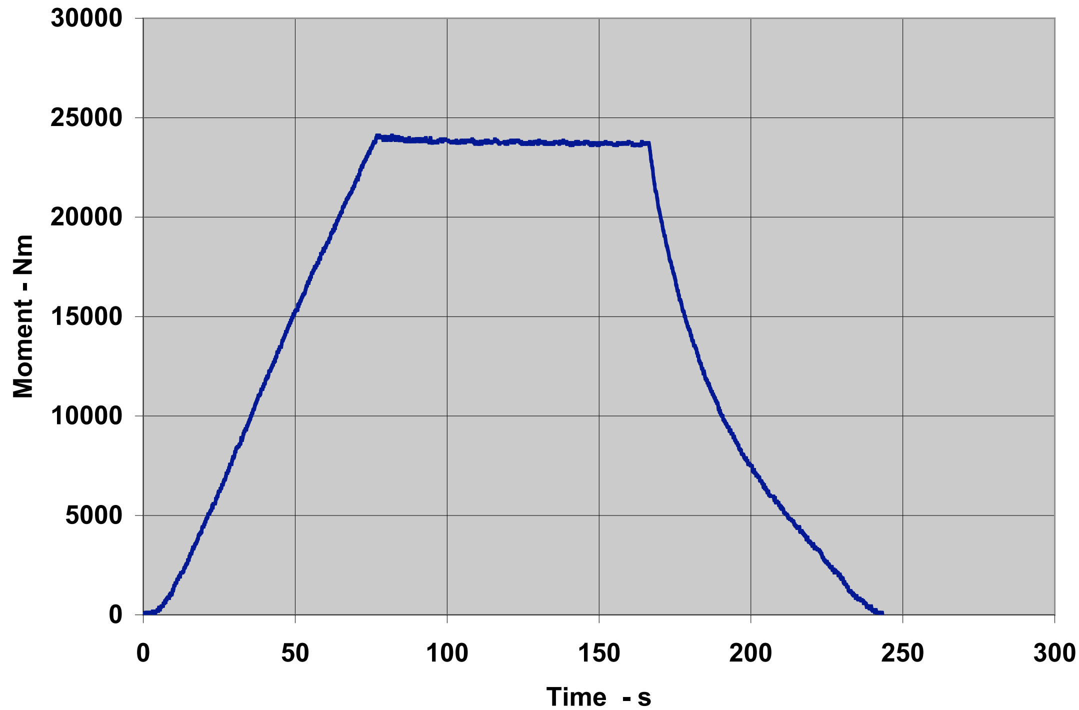


Figure 3. Bending moment at bottom end of housing type 2 with end fitting type F2
Max design moment at MPDSL: 23096 Nm

POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1518-H-10
H5 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 5

Seal Leak Rate

This report records the results of type tests made on H5 series 20 kA Line Discharge Class 5 arresters, rated up to 612 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.0, 2004, "Surge arresters - Part 4: Metal-oxide surge arresters without gaps for a.c. systems."

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

M.G. Comber
Manager, Engineering

Date: 9/23/2004

IEC TYPE TEST REPORT
Seal Leak Rate

Clause 8.11 of IEC 60099-4 requires that one complete arrester be subjected to a seal leak rate test, using any sensitive method suitable for the measurement of the specified seal leak test. Using the adopted method, the seal leak rate shall be lower than $1x10^{-6}$ $Pa.m^3s^{-1}$.

Clause 9.1 d) of this same standard requires that, for arrester units with sealed housing, all manufactured units be subjected to a seal leak test as a routine test. In this test, the method used for H5 series arresters is the "vacuum helium mass spectrometer" method. With this method, the internal air space of the arrester unit is evacuated, resulting in a one atmosphere pressure differential between outside and inside, under which conditions the outside of the arrester is flooded with helium. The evacuation port is monitored by a mass spectrometer tuned to detect helium, and any helium detected is quantitatively measured to provide a leak rate. The maximum leak rate accepted for H5 series arrester units is $1x10^{-7}$ $Pa.m^3s^{-1}$, one order of magnitude below the maximum allowed by IEC 60099-4. Routine test reports are provided on request verifying that this requirement has been met.

By performing the routine testing of units according to Clause 9.1 d), the type test requirements of Clause 8.11 are automatically met.

HUBBELL POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1518-H-11
H5 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 5

Radio Influence Voltage (RIV)

This report records the results of type tests made on H5 series 20 kA Line Discharge Class 5 arresters, rated up to 612 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.0, 2004, "Surge arresters - Part 4: Metal-oxide surge arresters without gaps for a.c. systems."

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

Michael G. Comber
M.G. Comber
Manager, Engineering

Date: 9/23/2004

IEC TYPE TEST REPORT
Radio Influence Voltage (RIV)

TESTS PERFORMED:
A fully-assembled arrester, with voltage rating U_r of 396 kV and continuous operating voltage U_c of 318 kV, was subjected to the RIV test according to Clause 8.11 of IEC 60099-4. The voltage application was as follows:

- raised to 366 kV (1.15 U_c)
- lowered to 334 kV (1.05 U_c)
- held at 334 kV for 5 min
- lowered in steps of approximately 0.1 U_c until reaching 0.5 U_c
- increased in similar steps until reaching 334 kV (1.05 U_c)
- held at 334 kV for 5 min
- lowered again in steps of approximately 0.1 U_c until reaching 0.5 U_c

RIV measurements were made at each voltage level. The variable-frequency RIV meter was tuned to 1 MHz for the measurements.

RESULTS:
Prior to installing the arrester in the test circuit, an open circuit test was run to determine the background noise of the circuit. The arrester was installed and the sequence of voltage applications described above was applied. Figure 1 shows the arrester installed for test. Results of the RIV measurements are shown in Table 1.

At all test voltage levels, the RIV was essentially at background noise level. IEC 60099-4 allows a maximum RIV level of 2500 μV.

Figure 1. 420 kV rated arrester (RIV coupling capacitor in rear)

Table 1. Measured RIV values

Test condition	Test voltage (kV rms)	RIV (µV)
Open circuit	334	6
Open circuit	400	15 – 40
Arrester installed	366	10
Arrester installed	334	6
Arrester installed	318	6
Arrester installed	286	6
Arrester installed	254	6
Arrester installed	223	6
Arrester installed	191	6
Arrester installed	159	6
Arrester installed	191	6
Arrester installed	223	6
Arrester installed	254	6
Arrester installed	286	6
Arrester installed	318	6
Arrester installed	334	6
Arrester installed	318	6
Arrester installed	286	6
Arrester installed	254	6
Arrester installed	223	6
Arrester installed	191	6
Arrester installed	159	6

IEC Type Test Report
Report No. EU1518-H-12.1
H5 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 5

Power Frequency Voltage Versus Time

This report records the results of type tests made on H5 series 20 kA Line Discharge Class 5 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.0, 2004, "Surge arresters - Part 4: Metal-oxide surge arresters without gaps for a.c. systems."

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

M.G. Comber
Manager, Engineering

Date: 2/2/2007

IEC TYPE TEST REPORT
Power Frequency Voltage Versus Time

TESTS PERFORMED:

Power frequency voltage versus time tests were performed on prorated test sections prepared based on the results of the tests to verify heat dissipation behavior of test sample. Each section consisted of two parallel columns of two resistors (75 mm diameter, 44 mm long) in each column. The resistors were selected to represent the lowest acceptable reference voltage level. The tests were conducted in accordance with Annex D of IEC 60099-4.

Prior to the test, measurements were made of the reference voltage of the section to determine its rated voltage U_r and continuous operating voltage U_c. Additional measurements were made of power dissipation at U_c, and an adjusted value U_c' was determined such that the power dissipation of the sample represented the maximum power dissipation of resistors that could be used in arrester assembly. The adjusted value Uc' was used in the thermal recovery portion of the test.

Tests were made for three different time durations of elevated voltage application. For each test, the section was placed in an oven and heated overnight to 60 ± 3 °C. After removal from the oven, the section was subjected to two long duration current impulses, with time between impulses being between 50 and 60 seconds. The parameters of the transmission line used to generate these impulses conformed to the requirements for Line Discharge Class 5 in Table 5 of Clause 8.4.2 of IEC 60099-4. Within 100 milliseconds of the second long duration current impulse, an elevated power frequency voltage (above U_r) was applied for a measured period of time, following which the voltage was reduced to the adjusted value U_c' for 30 min. During the 30 min period at U_c' the power dissipation was monitored to verify thermal stability.

Table 1 lists the parameters of the test section and the corresponding transmission line parameters used for the test.

Table 1. Test section and transmission line parameters

Parameter	Value
Reference Current (mA) I_{ref}	10
Reference Voltage (kV_c) V_{ref}	11.89
COV (kV rms) U_c	9.63
Adjusted COV 9kVrms) Uc’	10.02
Rating (kV rms) U_r	12.03
Arrester Classification (kA)	20
Line Discharge Class	5
Virtual Duration of Peak (µs, 90-90%) - min	3200
Surge Impedance (Ω) Z_g - max (0.8 U_r)	6.02
Charging Voltage (kV) U_L – min (2.6 U_r)	28.87

RESULTS:

A short circuit test was performed on the generator to confirm that generator impedance and duration of the current discharge met the requirements listed in Table 1. The oscillogram of Figure 1 shows

$$Z_g = 6{,}547 \ / \ 1{,}092 \text{ A} = 5.995\ \Omega \qquad \text{Virtual Duration of Peak} = 3239\ \mu\text{s}$$

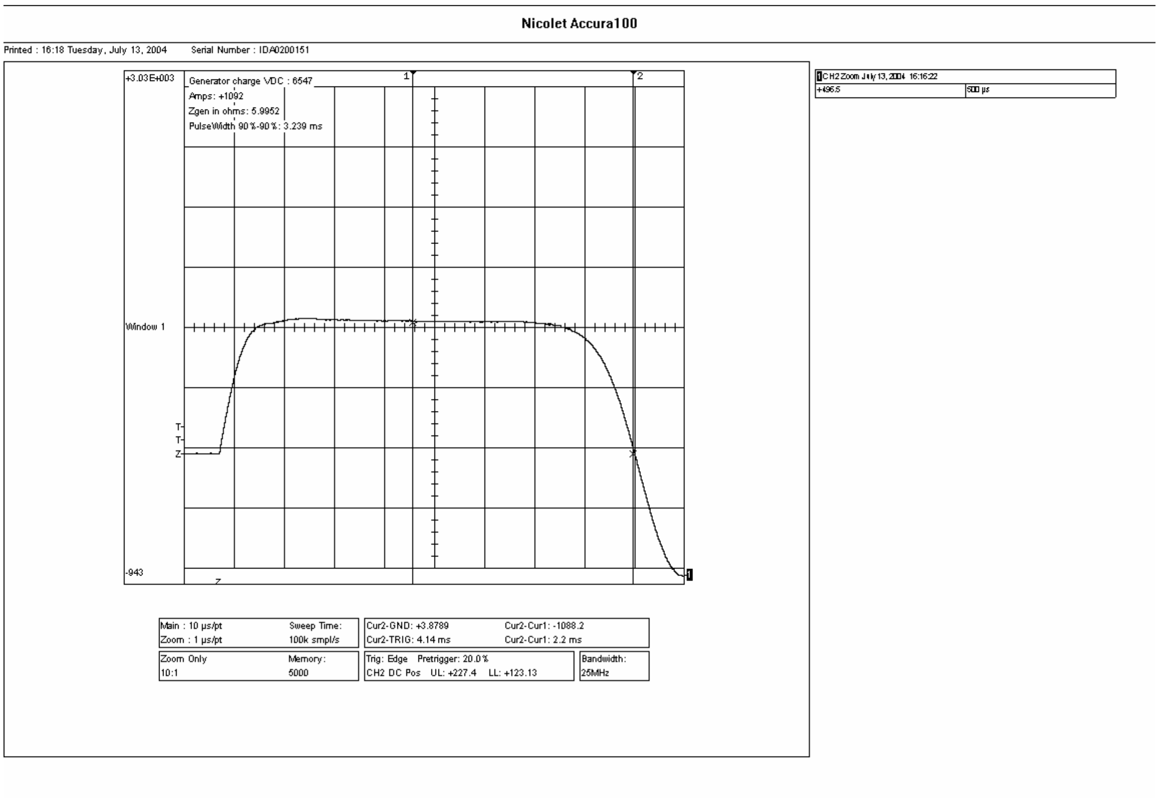


Figure 1. Oscillogram of discharge current for generator short circuit set up test

Tables 1 and 2, respectively, list measurements made during the application of elevated voltage and during the subsequent 30 min application of U_c'. Representative oscillograms made during this testing are shown in Figure 2 (beginning and end of 100 s application of elevated voltage) and Figure 3 (beginning and end of 30 min application of U_c' following 130 s application of elevated voltage).

Figure 4 shows the three test points (elevated voltage s for 2 s, 10 s and 130 s) superimposed on the characteristic of power frequency voltage vs. time for H5 series of arresters.

Table 1. Measurements of voltage and current during application of elevated voltage

2 s elevated voltage

Elapsed time (s)	Applied voltage (kV rms)	Applied voltage (pu Ur)	Current (A peak)
0.07	13.57	1.13	7.14
0.24	13.57	1.13	7.07
0.41	13.57	1.13	7.28
0.60	13.60	1.13	7.18
0.80	13.60	1.13	7.26
1.01	13.60	1.13	7.27
1.20	13.61	1.13	7.52
1.42	13.63	1.13	7.54
1.61	13.63	1.13	7.56
1.82	13.60	1.13	7.82
2.10	13.64	1.13	7.95

10 s elevated voltage

Elapsed time (s)	Applied voltage (kV rms)	Applied voltage (pu Ur)	Current (A peak)
0.07	13.17	1.09	2.19
1.03	13.16	1.09	2.20
2.02	13.16	1.09	2.21
3.00	13.16	1.09	2.21
4.01	13.16	1.09	2.21
5.06	13.16	1.09	2.23
6.00	13.15	1.09	2.26
7.08	13.14	1.09	2.29
8.06	13.14	1.09	2.32
9.22	13.14	1.09	2.39
10.20	13.14	1.09	2.48

130 s elevated voltage

Elapsed time (s)	Applied voltage (kV rms)	Applied voltage (pu Ur)	Current (A peak)
0	12.23	1.02	211
19	12.28	1.02	227
31	12.29	1.02	235
46	12.28	1.02	235
59	12.27	1.02	251
71	12.26	1.02	251
83	12.28	1.02	267
98	12.27	1.02	300
119	12.27	1.02	332
130	12.26	1.02	356

Table 2. Measurements of power dissipation and current made during 30 min at U_c'

2 s elevated voltage

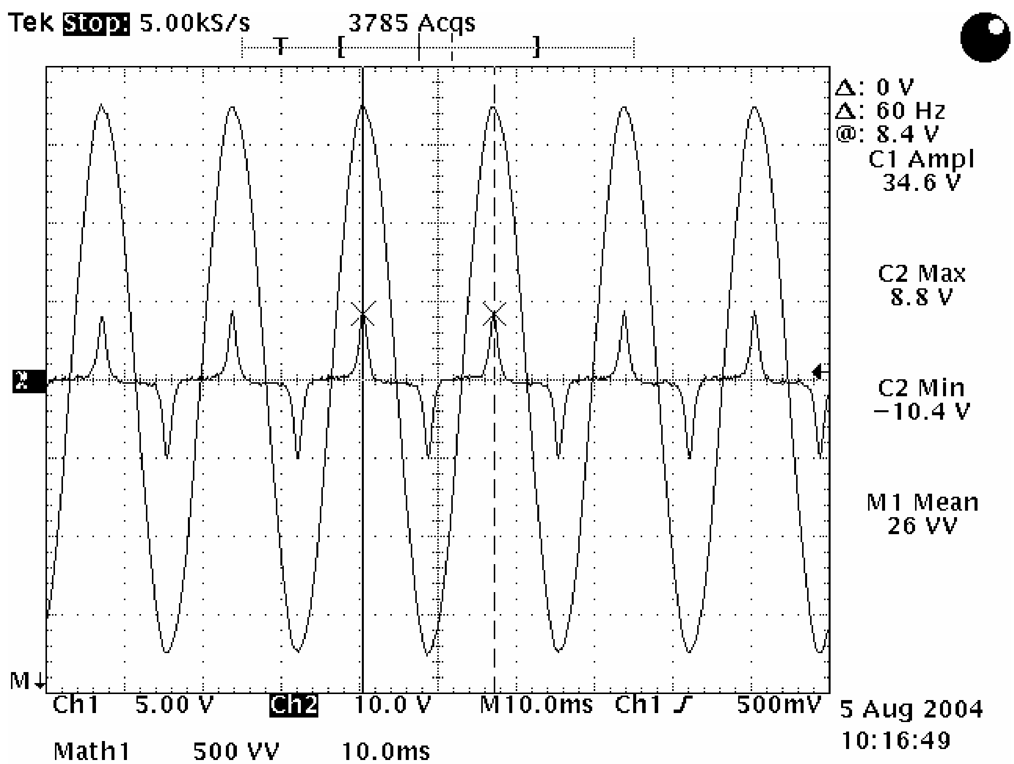
Elapsed time (s)	Applied voltage (kV rms)	(pu Ur)	Current (mA peak)
0.0	10.09	57.1	14.2
0.5	10.1	52.0	13.4
1.0	10.08	48.0	11.8
2.0	10.04	43.5	10.6
5.5	10.11	39.0	10.4
10.4	10.1	35.0	9.2
20.2	10.11	31.0	8.4
30.5	10.1	28.5	7.6

10 s elevated voltage

Elapsed time (min)	Applied voltage (kV rms)	Power dissipation (W)	Current (mA peak)
0.0	10.06	-	-
0.4	10.04	56.3	14.5
1.0	10.06	53.8	14.0
2.0	10.08	50.0	13.5
5.0	10.03	43.8	11.5
12.0	10.06	38.8	10.0
20.3	10.03	35.0	9.0
30.0	10.02	31.3	8.5

130 s elevated voltage

Elapsed time (s)	Applied voltage (kV rms)	(pu Ur)	Current (mA peak)
0.0	10.11	98.24	24.11
0.6	10.06	82.6	21.4
1.0	10.07	81.5	19.2
2.0	10.09	78.1	19.2
5.0	10.07	69.2	17.0
10.3	10.1	63.6	15.2
20.0	10.09	56.9	13.8
30.0	10.07	51.4	13.0



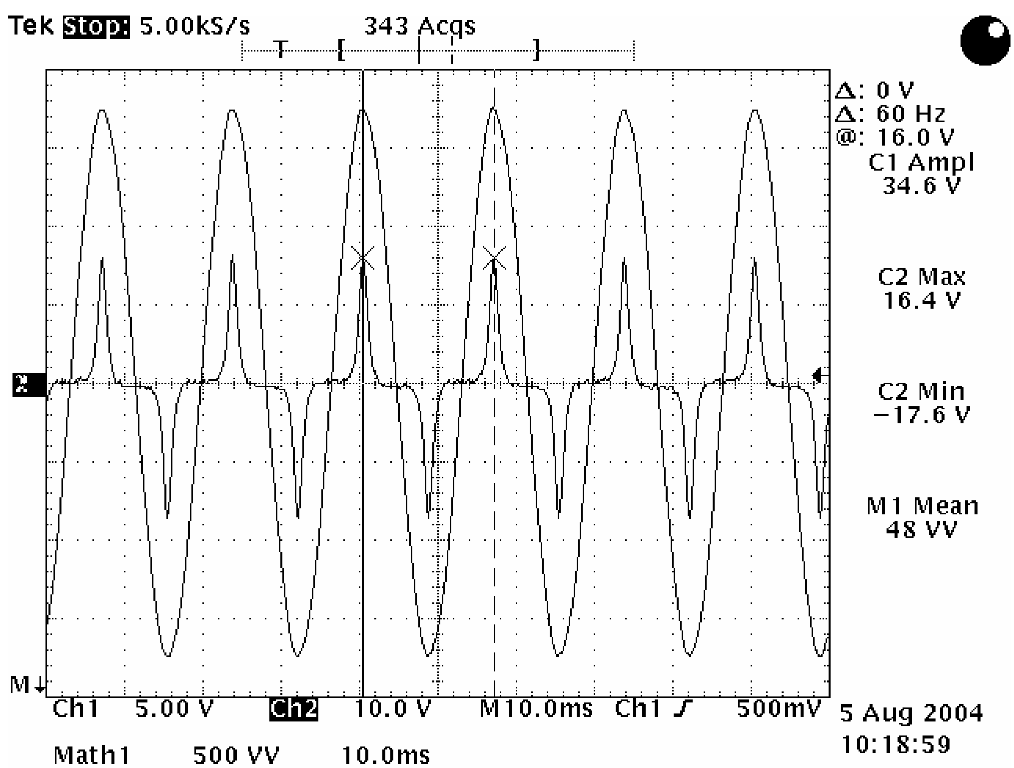
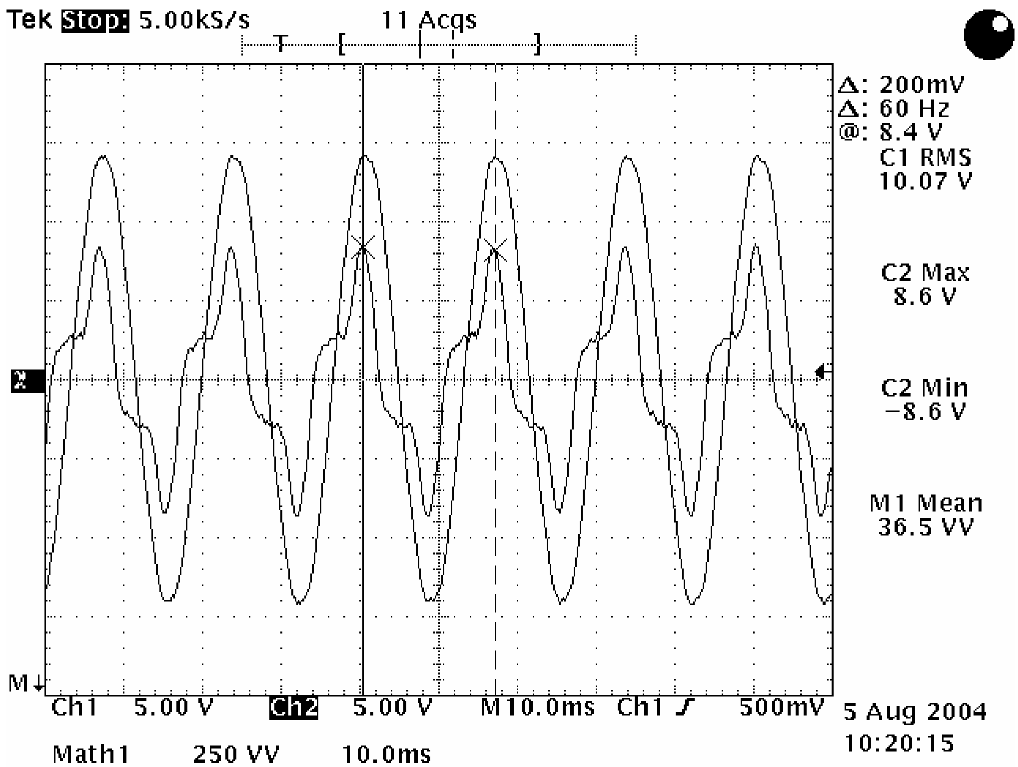


Figure 2. Oscillograms of voltage and current at the beginning and end of 130 s application of elevated voltage



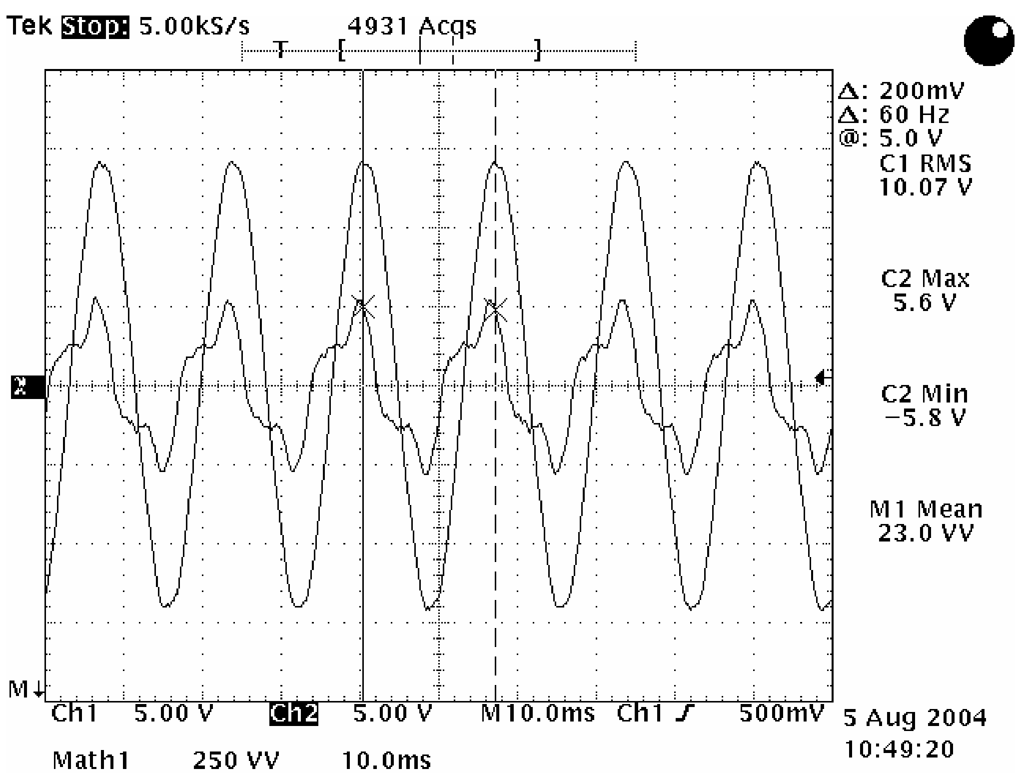


Figure 3. Oscillograms of voltage and current at the beginning and end of the 30 min application of U_c' following 130 s application of elevated voltage

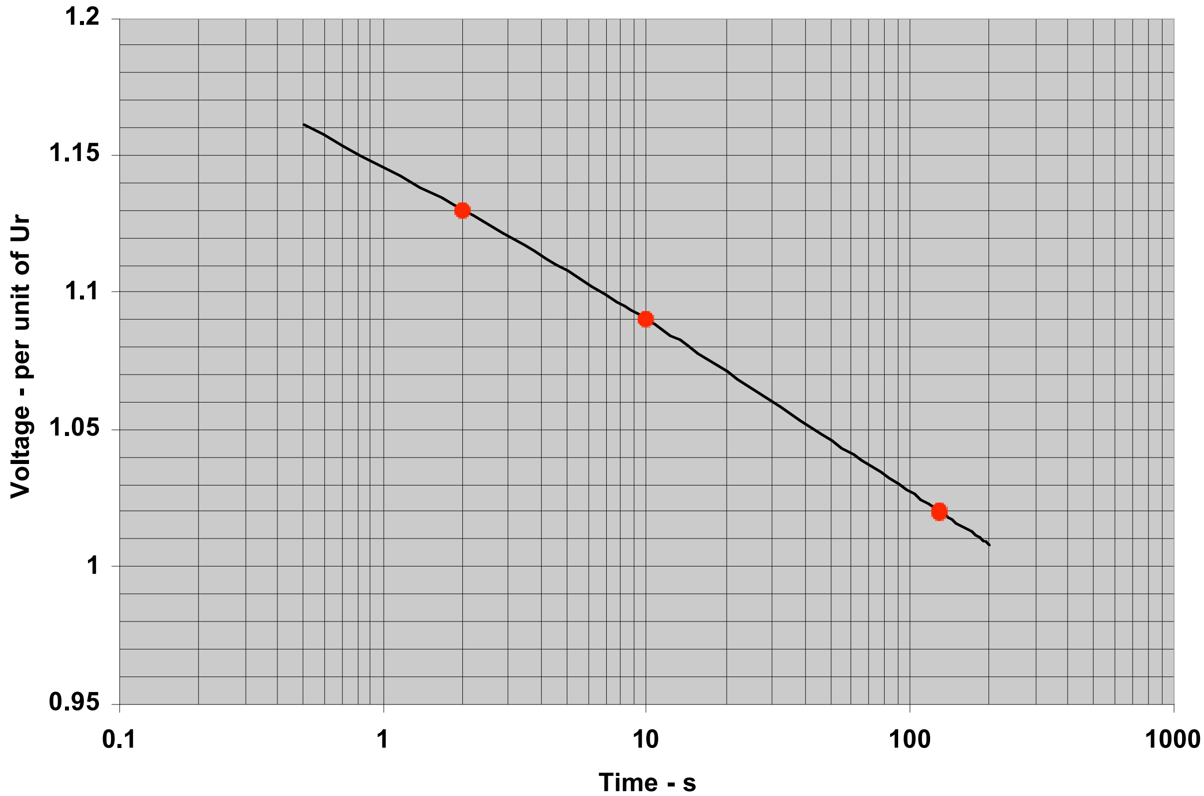


Figure 4. Power frequency voltage vs. time characteristic for H5 series arresters, with test points for 2 s, 10 s and 130 s

POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1518-H-13
H5 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 5

Artificial Pollution

This report records the results of type tests made on H5 series 20 kA Line Discharge Class 5 arresters, rated up to 612 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.0, 2004, "Surge arresters - Part 4: Metal-oxide surge arresters without gaps for a.c. systems."

To the best of our knowledge and within the usual limits of testing practice, tests performed on these arresters demonstrate compliance with the relevant clauses of the referenced standard.

M.G. Comber
Manager, Engineering

Date: 9/23/2004

IEC TYPE TEST REPORT
Artificial Pollution

INTODUCTION:

The H5 series of arresters are available with different specific creepage distances for application in environments with different pollution levels. IEC 60815 provides guidelines for specific creepage distances, namely: 16 mm / kV maximum system voltage for light pollution conditions; 20 mm / kV maximum system voltage for medium pollution conditions; 25 mm / kV maximum system voltage for heavy pollution conditions; and 31 mm / kV maximum system voltage for very heavy pollution conditions. Standard H5 series of arresters are available with specific creepage distances meeting the IEC 60815 guidelines for different pollution conditions.

Annex F of IEC 60099-4 prescribes procedures for determining the temperature rise of resistor elements when the arrester is subjected to different levels of artificial pollution. If the temperature rise is found to be greater than 40 K, then the pre-heating temperature for the operating duty test must be increased from 60^{o}C by an amount that the temperature rise exceeds 40 K. If the temperature rise is not greater than 40 K, no modification to the pre-heating temperature in the operating duty test is required. An analytical procedure is provided to determine the temperature rise in absence of performing physical tests. These procedures are used in the following to validate the H5 design for medium pollution conditions.

DEFINITION OF TERMS:

q_Z [C/hm] Mean external charge flowing on the surface of insulators and surge arrester housings during pollution events in service, relevant to a pollution event lasting a time t_Z. This parameter is used for the classification of the pollution severity of a site.

t_Z [h] Duration of a pollution event in service.

β [K/C] Ratio between the temperature rise of the internal parts of the arrester and the relevant charge flowing internally as determined in the preliminary heating test.

τ [h] Equivalent thermal time constant of the arrester as determined in the preliminary heating test.

D_m [m] Average diameter of the surge arrester housing: it is calculated according to the method reported in IEC 60815.

$\Delta T_{Z\ max}$ [K] Maximum theoretical temperature rise in service calculated as a function of β, q_Z, t_Z, D_m and τ.

U_r [kV] is the rated voltage of the surge arrester.

$U_{r\ min}$ [kV] is the minimum rated voltage among the surge arrester units.

PRELIMINARY HEATING TEST: MEASUREMENT OF THE THERMAL TIME CONSTANT τ AND CALCULATION OF β:

A procedure similar to that specified in Annex B of IEC 60099-4 was performed on an assembled arrester unit equipped with thermocouples at three locations distributed along the length of the resistors. The unit represented the maximum unit length used in the arrester design, and contained the maximum number of resistors used for this length unit. The following results were obtained:

- the ambient temperature (T_a) was 21.3 °C
- the heating time (t_h) was 7 min (required to be less than 10 min);
- the charge (Q_h) applied to the surge arrester during the heating was 25.3 C
- the temperature rise (ΔT_h) during the application of charge (Q_h) was 119.4 K
- the time (τ) derived from the cooling curve of the arrester between the temperatures of 60 °C and 22 + 0.63 T_a was 2.92 h (see cooling curve below)

The parameter β is calculated according to:

$$\beta = \frac{\Delta T_h}{Q_h} = 4.72 \ \text{KC}^{-1}$$

CALCULATION OF THEORETICAL MAXIMUM TEMPERATURE RISE OF RESISTORS:

This calculation assumes that all the charge expected in service (q_z) flows internally. In this hypothesis, $\Delta T_{z\,max}$ is derived as follows:

$$\Delta T_{z\,max} = \beta\, q_z\, D_m\, \tau \left(1 - e^{\left(-\frac{t_z}{\tau}\right)}\right)\left(\frac{U_r - U_{r\,min}}{U_r}\right) \qquad (1)$$

The average diameter (D_m) of the arrester unit is determined according to IEC 600815 as

$$D_m = (D_{e1} + D_{e2} + 2D_i)/4$$

For the housing used for this arrester

$$D_{e1} = 0.426 \text{ m}$$
$$D_{e2} = 0.380 \text{ m}$$
$$D_i = 0.281 \text{ m}$$

giving

$$D_m = 0.342 \text{ m}$$

The maximum rated voltage (U_r) of the H5 series "medium pollution" design is 612 kV, and the smallest unit used in the lowest specific creepage version of the arrester has a rated voltage (U_{rmin}) of 110 kV.

The values of t_z and q_z are obtained from Table F.1 of IEC 60099-4. For medium pollution zone, two sets of values are given:

$$t_z = 2\text{ h},\ q_z = 3.3\text{ C} \quad \text{and} \quad t_z = 6\text{ h},\ q_z = 2.4\text{ C}$$

Substituting the known, measured and provided values of parameters into (1), the calculated theoretical maximum temperature rise of resistors for medium pollution events is:

$$\_T_{zmax} = 6.3\text{ K} \quad \text{for a 2 h pollution event}$$
$$\_T_{zmax} = 8.1\text{ K} \quad \text{for a 6 h pollution event}$$

Since these calculated temperature rises are less than 40 K, it is not necessary to adjust the 60°C pre-heating temperature for the operating duty test.

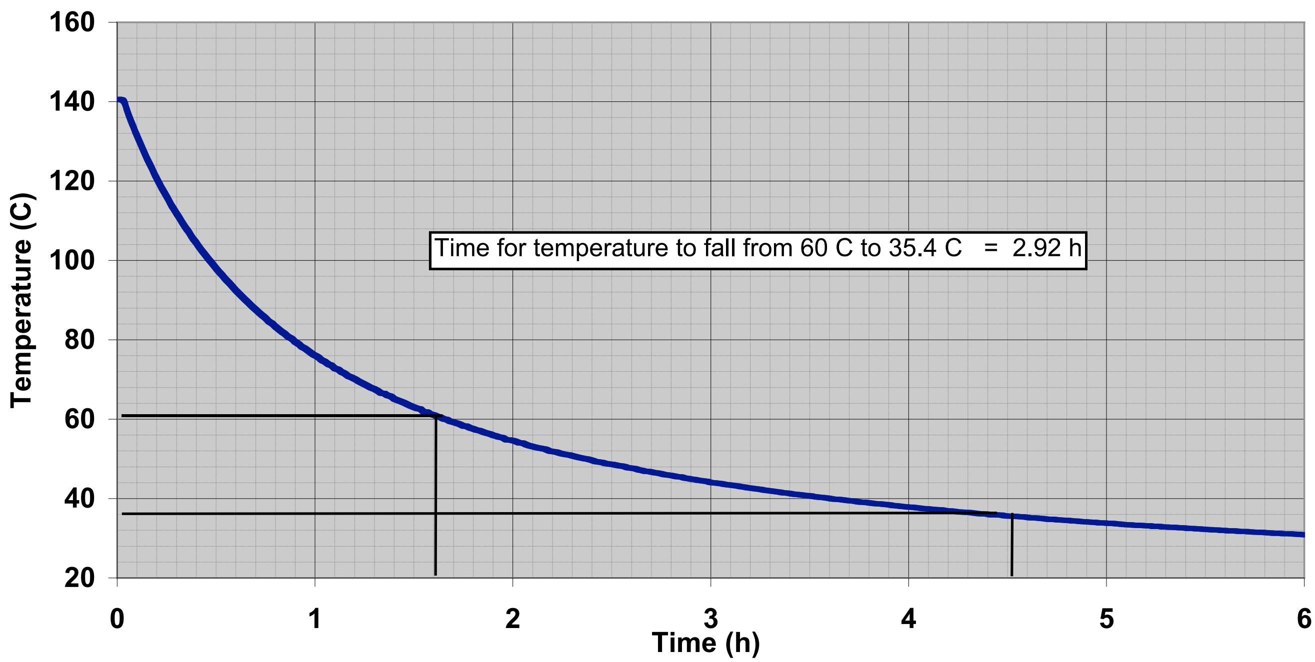


Figure 1. Resistor temperature vs. time after heating to 120°C