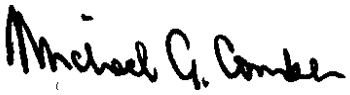
HUBBELL POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1522-H-00.1
PH4 Series Polymer-housed Arrester
20,000 A Line Discharge Class 4

This report records the results of type tests made on PH4 series 20 kA Line Discharge Class 4 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.1, 2006, "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: 4/12/2007

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

Report No.	Description	Clause	Issue date
EU1522-H-01.1	Insulation Withstand Test on Arrester Housing	10.8.2	4/12/2007
EU1522-H-02.1	Residual Voltage	10.8.3	4/12/2007
EU1522-H-03.1	Long Duration Current Withstand	10.8.4	4/12/2007
EU1522-H-04.1	Accelerated Aging Procedure	10.8.5	4/12/2007
EU1522-H-05.1	Heat Dissipation Behavior of Test Section	10.8.5	4/12/2007
EU1522-H-06.1	Switching Surge Operating Duty	10.8.5	4/12/2007
EU1522-H-07.1	Short Circuit	10.8.7	4/12/2007
EU1522-H-08.1	Internal Partial Discharge	10.8.8	4/12/2007
EU1522-H-09.1	Bending Moment	10.8.9	4/12/2007
EU1522-H-10.1	Seal Leak Rate	10.8.11	4/12/2007
EU1522-H-11.1	RIV	10.8.12	4/12/2007
EU1522-H-12.1	Moisture Ingress	10.8.13	4/12/2007
EU1522-H-13.1	Weather Ageing	10.8.14	4/12/2007
EU1522-H-14.1	Power Frequency Voltage Versus Time	Annex D	4/12/2007

HUBBELL® POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1522-H-01.1
PH4 Series Polymer-housed Arrester
20,000 A Line Discharge Class 4

Insulation Withstand Test on Arrester Housing

This report records the results of type tests made on PH4 series 20 kA Line Discharge Class 4 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.1, 2006, "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: 4/12/2007

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, in accordance with the requirements of clause 10.8.2 of IEC 60099-4. It is required that the external insulation withstand of the arrester housing conforms 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 PH4 series of arresters use four different housing lengths, all of the same individual weathershed geometry. The insulation withstand tests were performed on a sample constructed with the longest housing. The highest U_c used in this housing is 120 kV, for which the lightning impulse protective level is 377 kV at 20kA., and the maximum switching impulse protective level is 304 kV at 2kA.

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 377 = 490 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 304 = 380 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 304 = 323 kVpeak.

Tests were successfully performed at levels higher that exceeded 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	^{o}C	KPa	gm^{-3}	k_1	k_2	kV peak
Lightning impulse, pos	669	27.2	97.9	13.3	.943	1.027	690
Lightning impulse, neg	830	18.4	97.9	11.8	.971	1.005	850
Switching impulse, pos	500	18.7	98.1	Wet test	--	1.000	500
Switching impulse, neg	634	18.7	98.1	Wet test	--	1.000	634
60 Hz	502	18.6	98.0	Wet test	--	1.000	502

HUBBELL® POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1522-H-02.1
PH4 Series Polymer-housed Arrester
20,000 A Line Discharge Class 4

Residual Voltage

This report records the results of type tests made on PH4 series 20 kA Line Discharge Class 4 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.1, 2006, "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: 4/12/2007

IEC TYPE TEST REPORT
Residual Voltage

TESTS PERFORMED:
Residual voltage measurements were made on three single resistor elements. Tests were conducted in accordance with clause 10.8.3 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.

For each test sample, all measured voltages have been rationalized to the lightning impulse residual voltage of that sample at nominal discharge current (20 kA 8/20), and the results have been displayed in graphical form.

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 (20 kA, 8/20).

Table 1. Measurements made on test sample 1

Test Wave	Current magnitude	Waveshape	Residual Voltage		Oscillogram
	kA	_s	kV	p.u.	number
Steep current	20	1/2	12.03	1.104	28
Lightning impulse	10	8/20	10.07	0.924	4
	20		10.90	1.000	7
	40		12.13	1.113	10
Switching impulse	0.5	38/84	8.13	0.746	16
	2		8.69	0.797	22

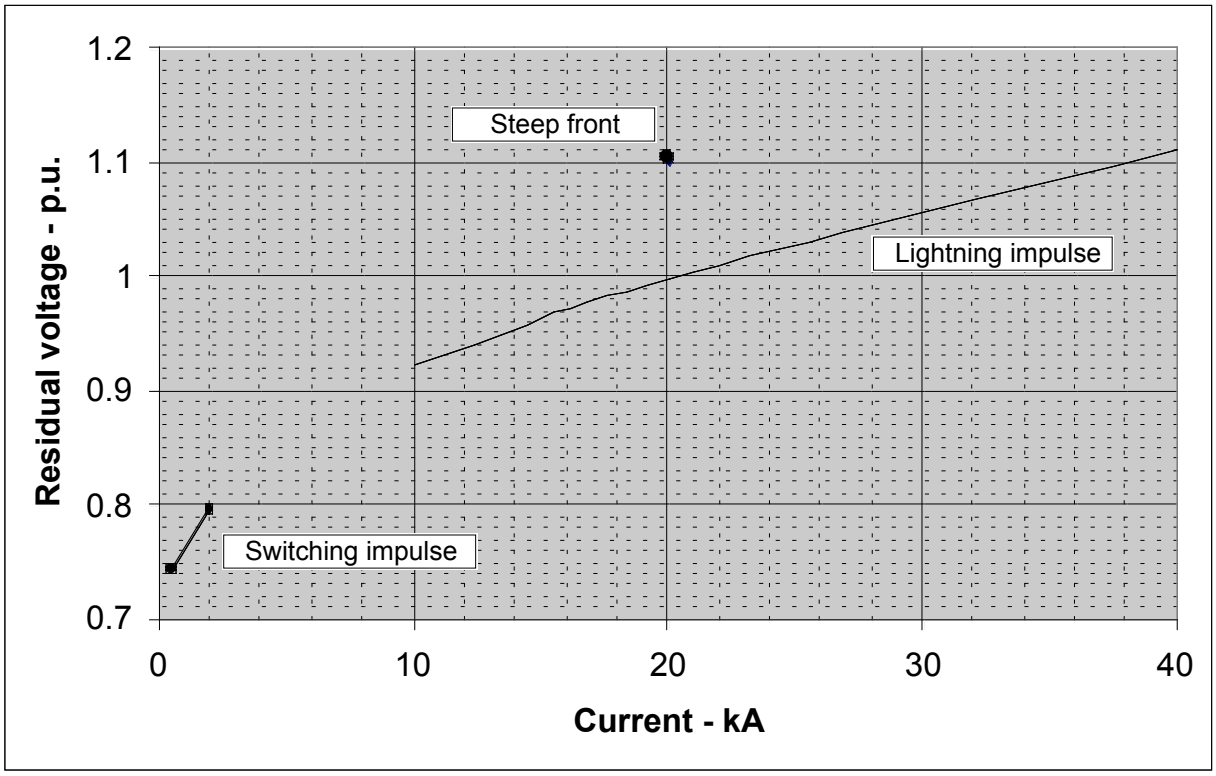
Table 2. Measurements made on test sample 2

Test wave	Current magnitude	Waveshape	Residual Voltage		Oscillogram
	kA	_s	kV	p.u.	number
Steep current	20	1/2	11.99	1.104	29
Lightning impulse	10	8/20	10.04	0.925	5
	20		10.86	1.000	8
	40		12.07	1.111	11
Switching impulse	0.5	38/84	8.07	0.743	17
	2		8.64	0.796	23

Table 3. Measurements made on test sample 3

Test wave	Current magnitude	Waveshape	Residual Voltage		Oscillogram
	kA	_s	kV	p.u.	number
Steep current	20	1/2	11.99	1.103	30
Lightning impulse	10	8/20	10.04	0.924	6
	20		10.87	1.000	9
	40		12.07	1.111	12
Switching impulse	0.5	38/84	8.09	0.744	18
	2		8.65	0.796	24

The results are shown graphically in the following 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 H4 series arresters. For the cases of switching impulse and lightning impulse residual voltages, the arrester residual voltages are calculated as follows:

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

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

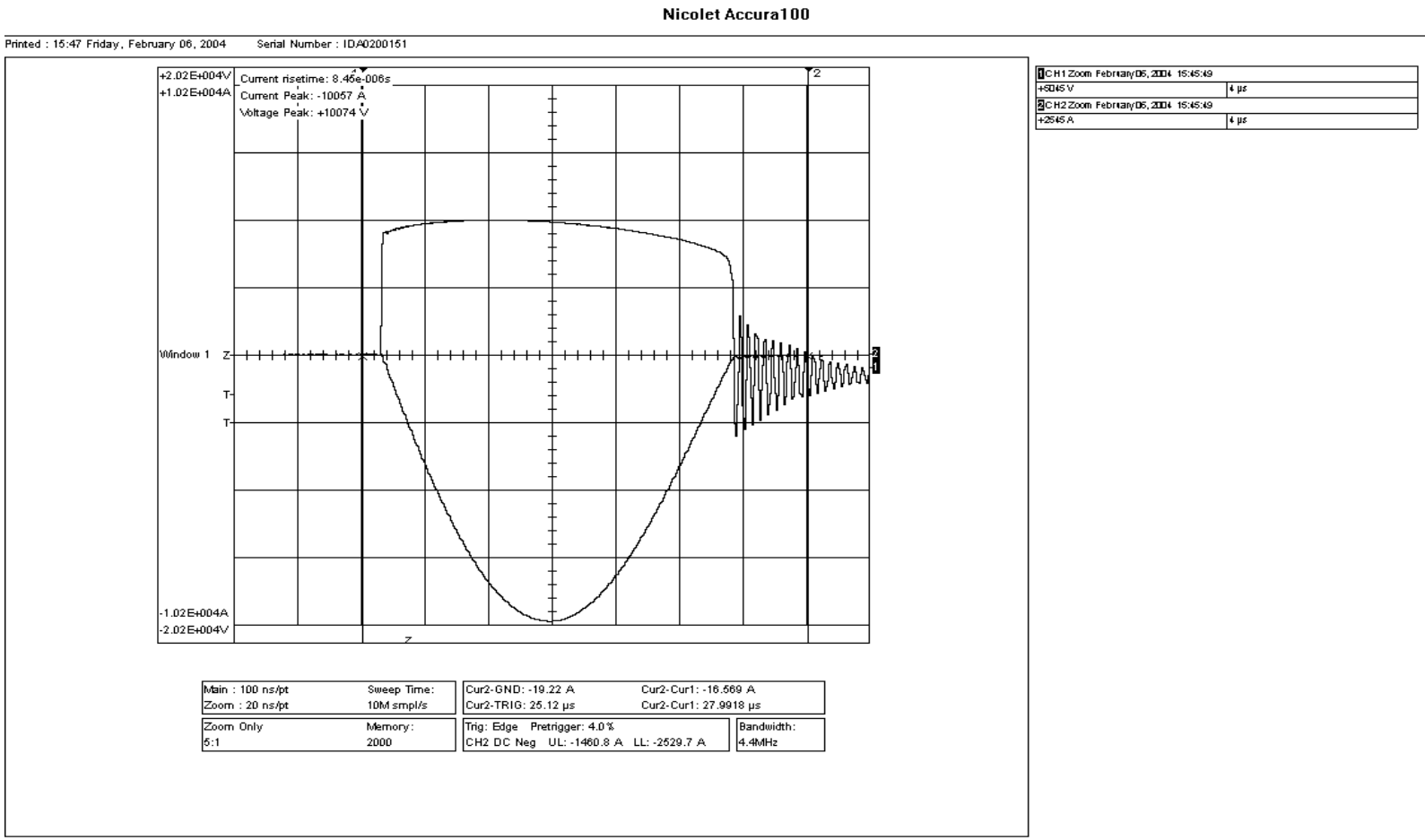
For the case of steep current impulse residual voltage, the arrester residual voltage is calculated as follows:

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

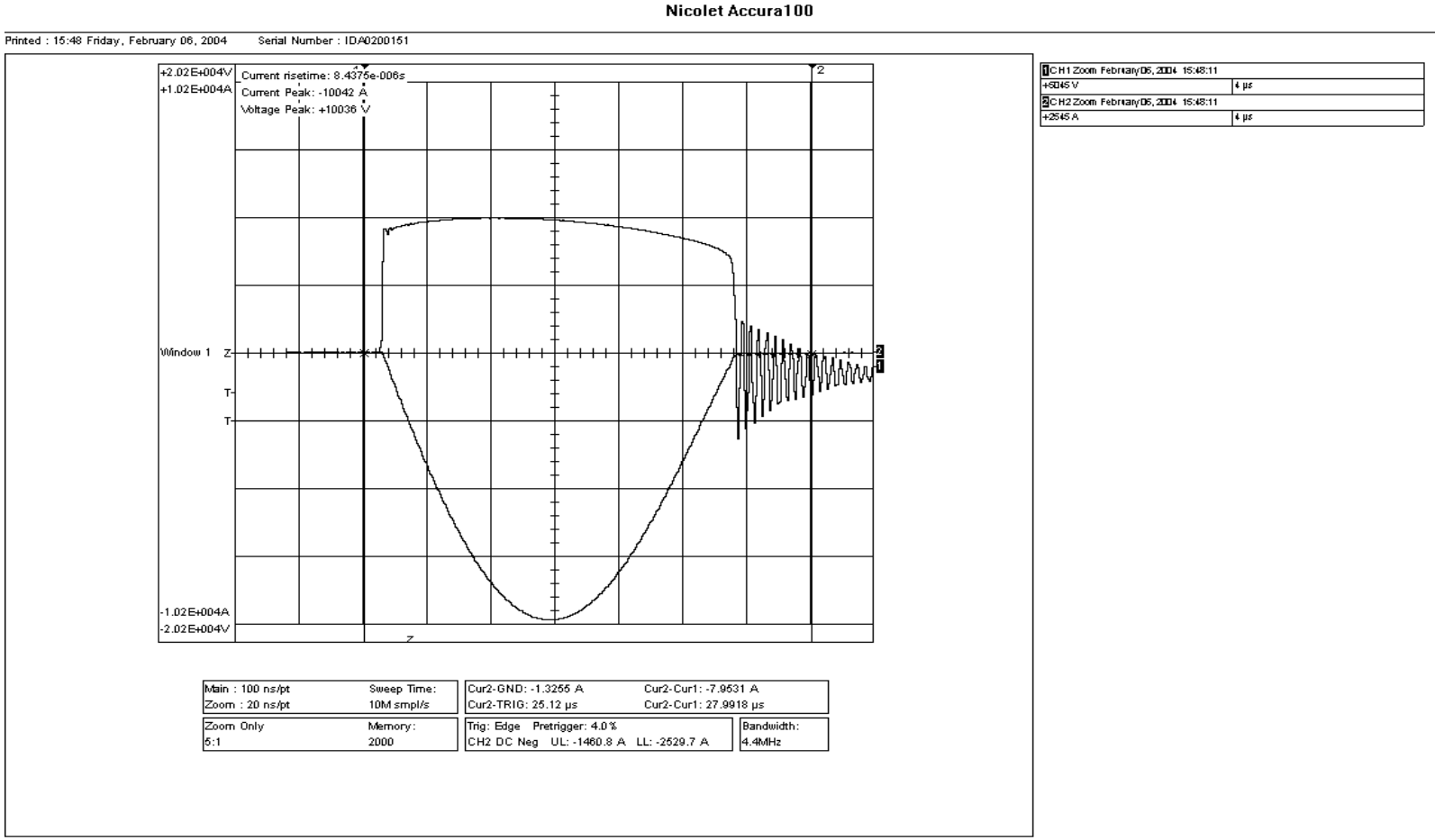
where
L' is the inductivity per unit length (= 1 μH/m)
h is the length of the arrester (excluding the resistors since resistor inductance is already included in the test measurements)
I_n is the nominal discharge current (= 20 kA)
T_f is the front time of the steep current impulse (= 1μs)

Oscillograms

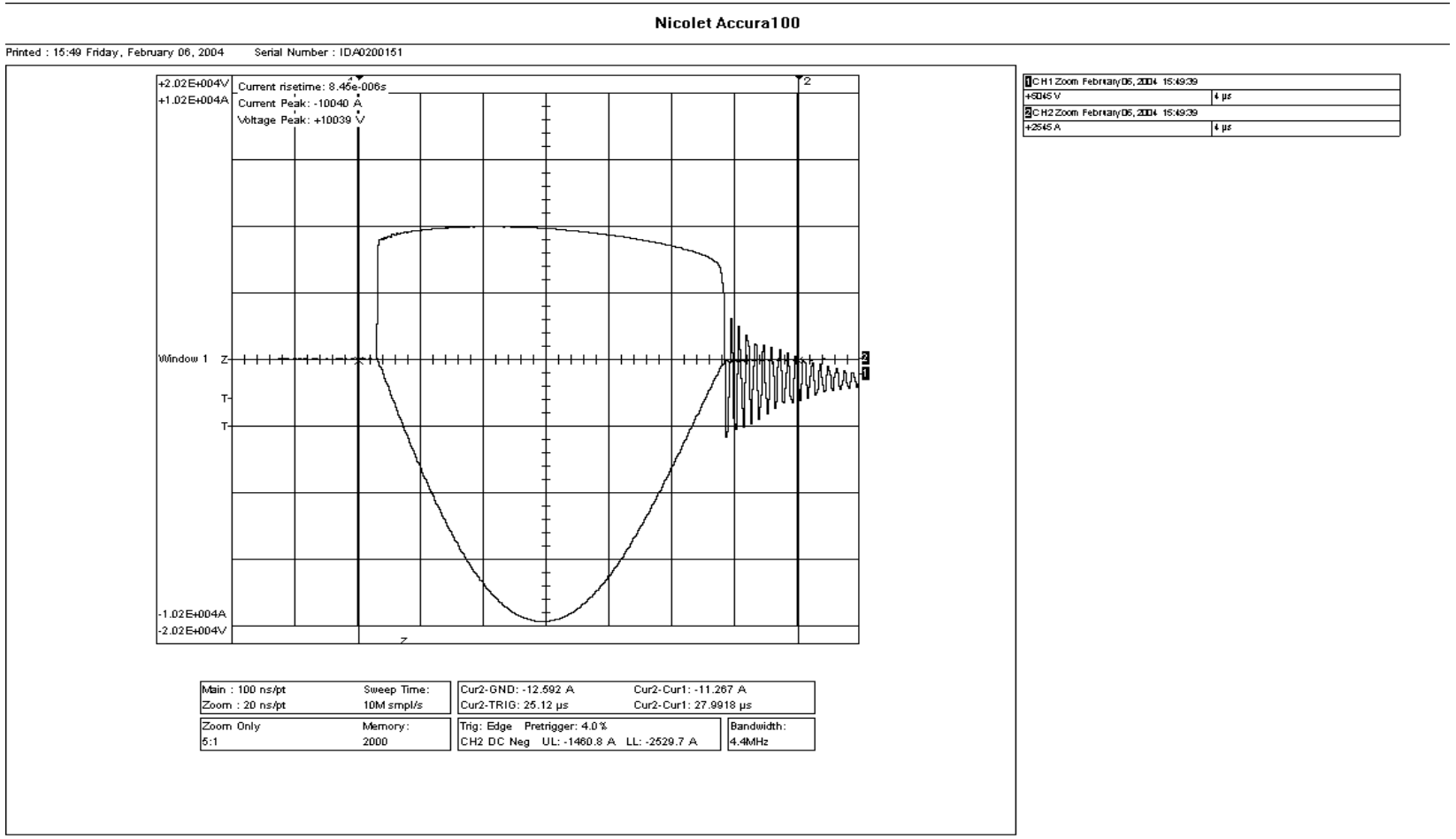
Oscillogram 4
Sample 1



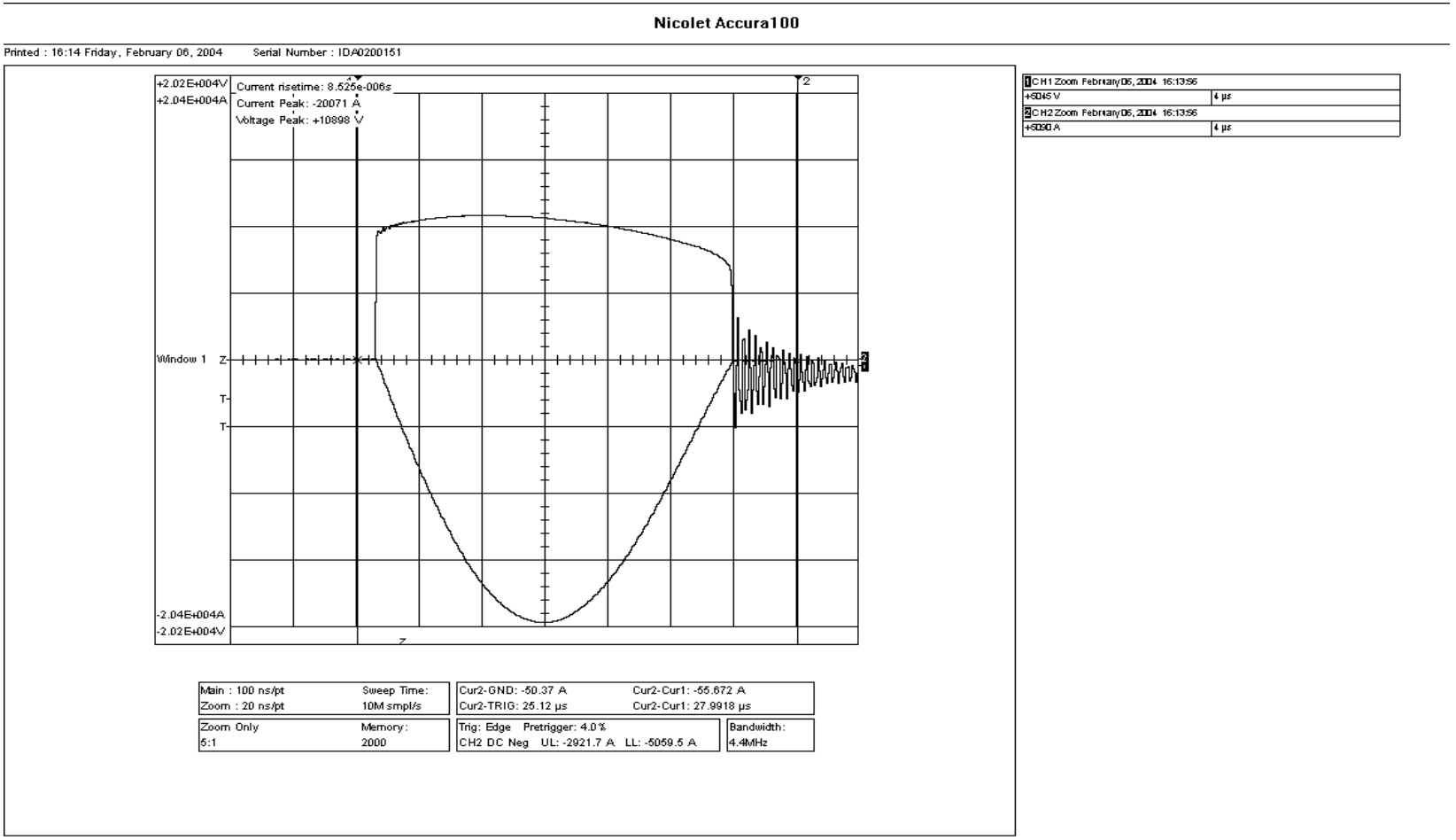
Oscillogram 5
Sample 2



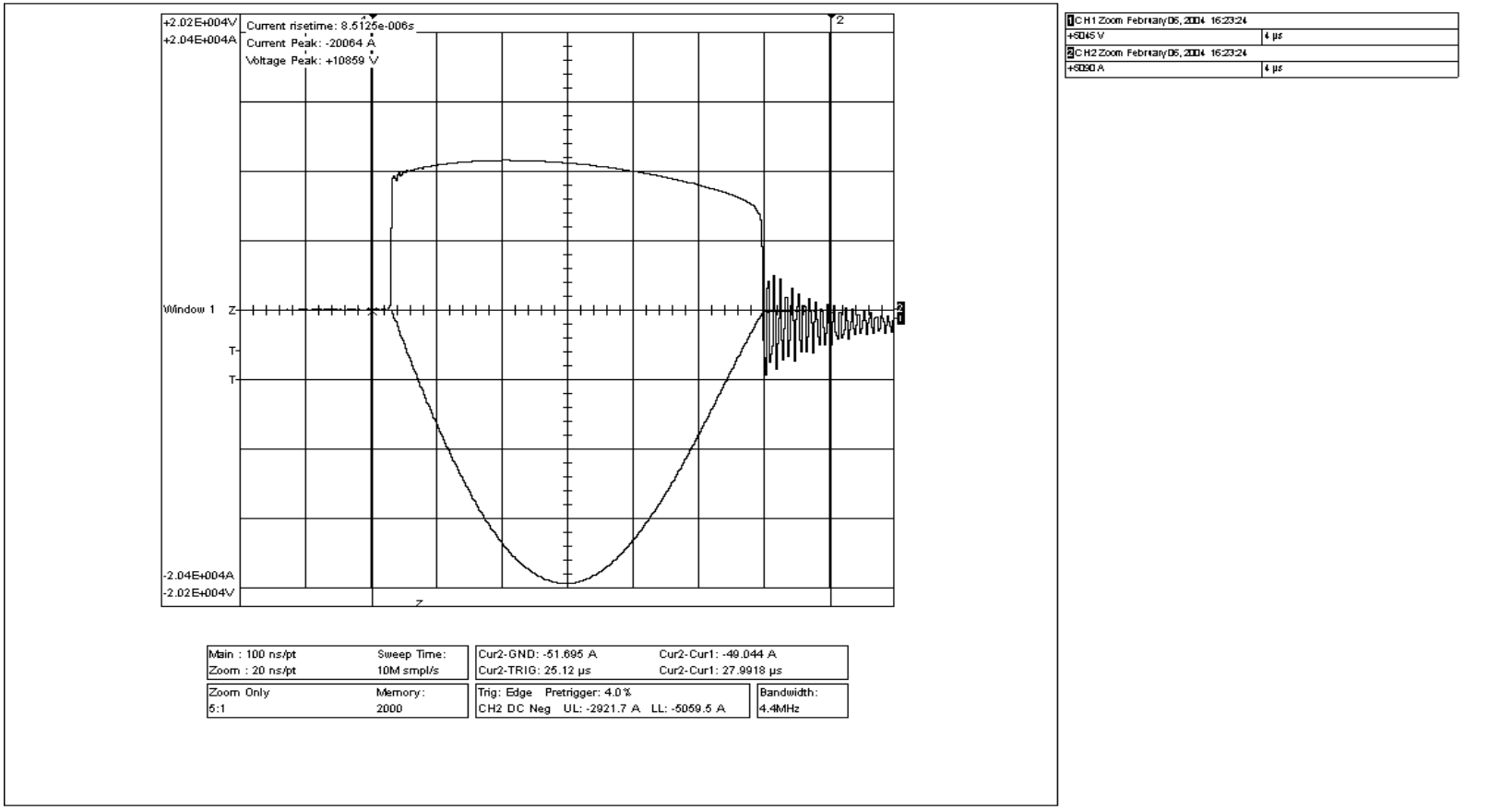
Oscillogram 6
Sample 3



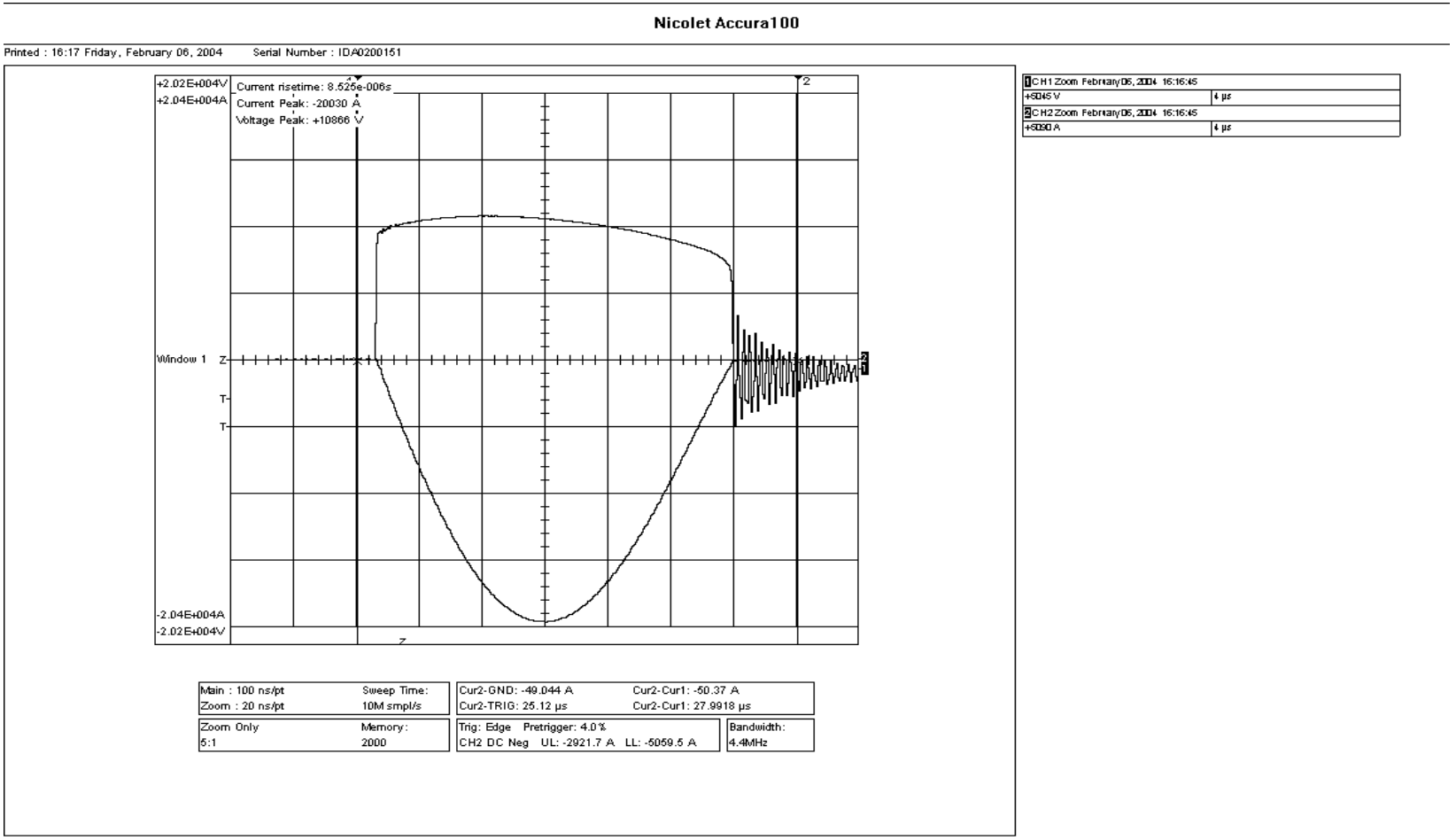
Oscillogram 7
Sample 1



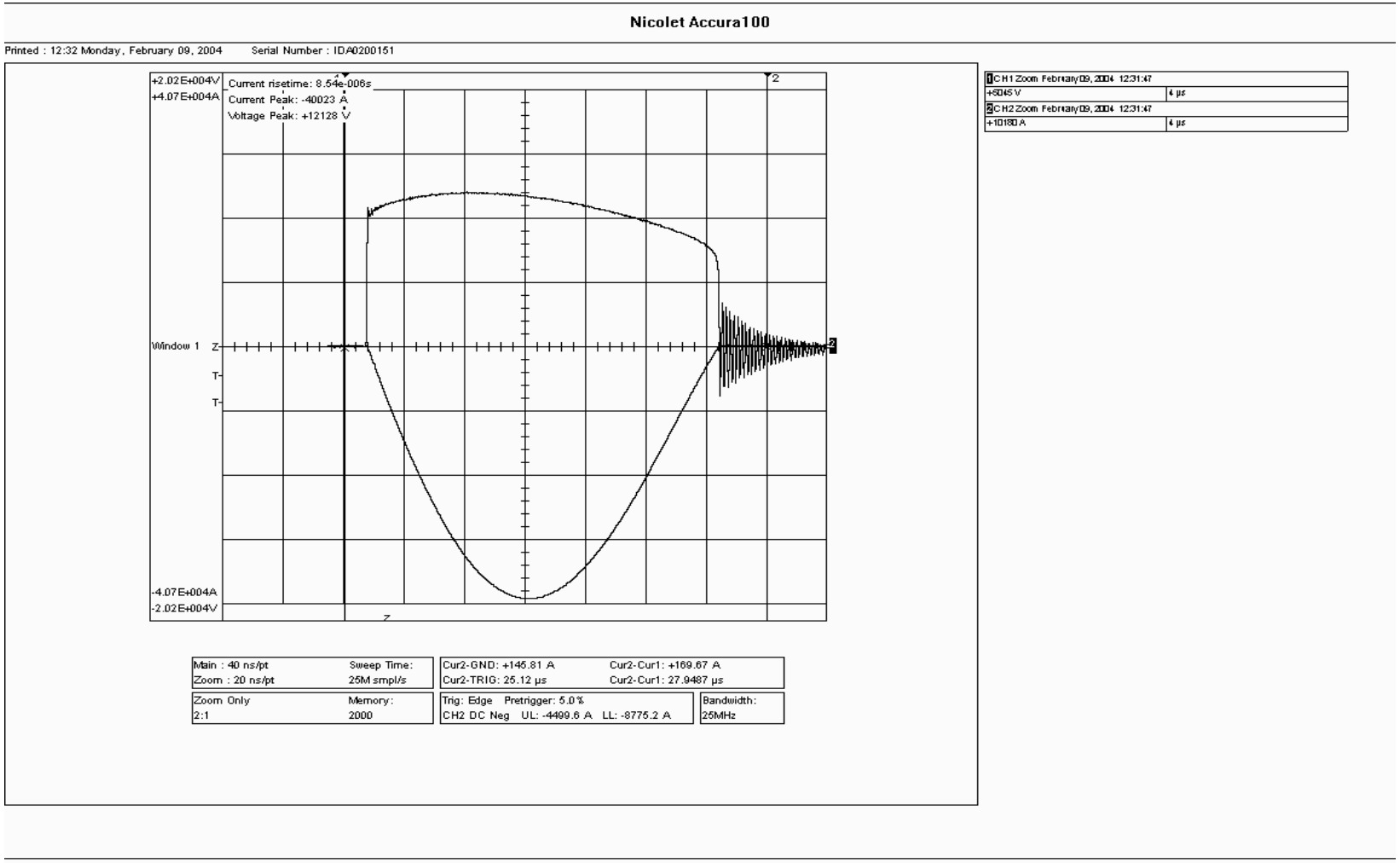
Oscillogram 8
Sample 2



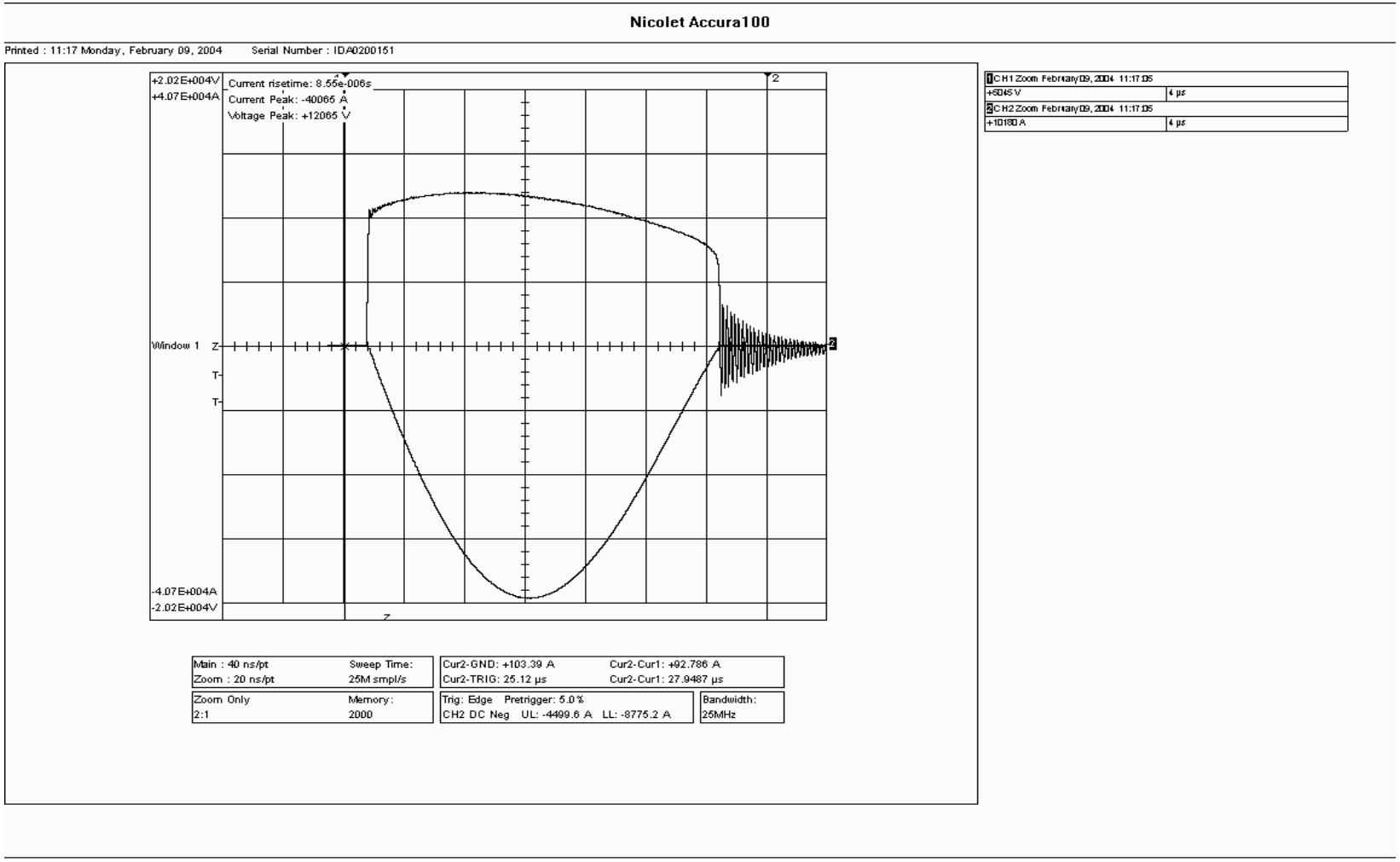
Oscillogram 9
Sample 3



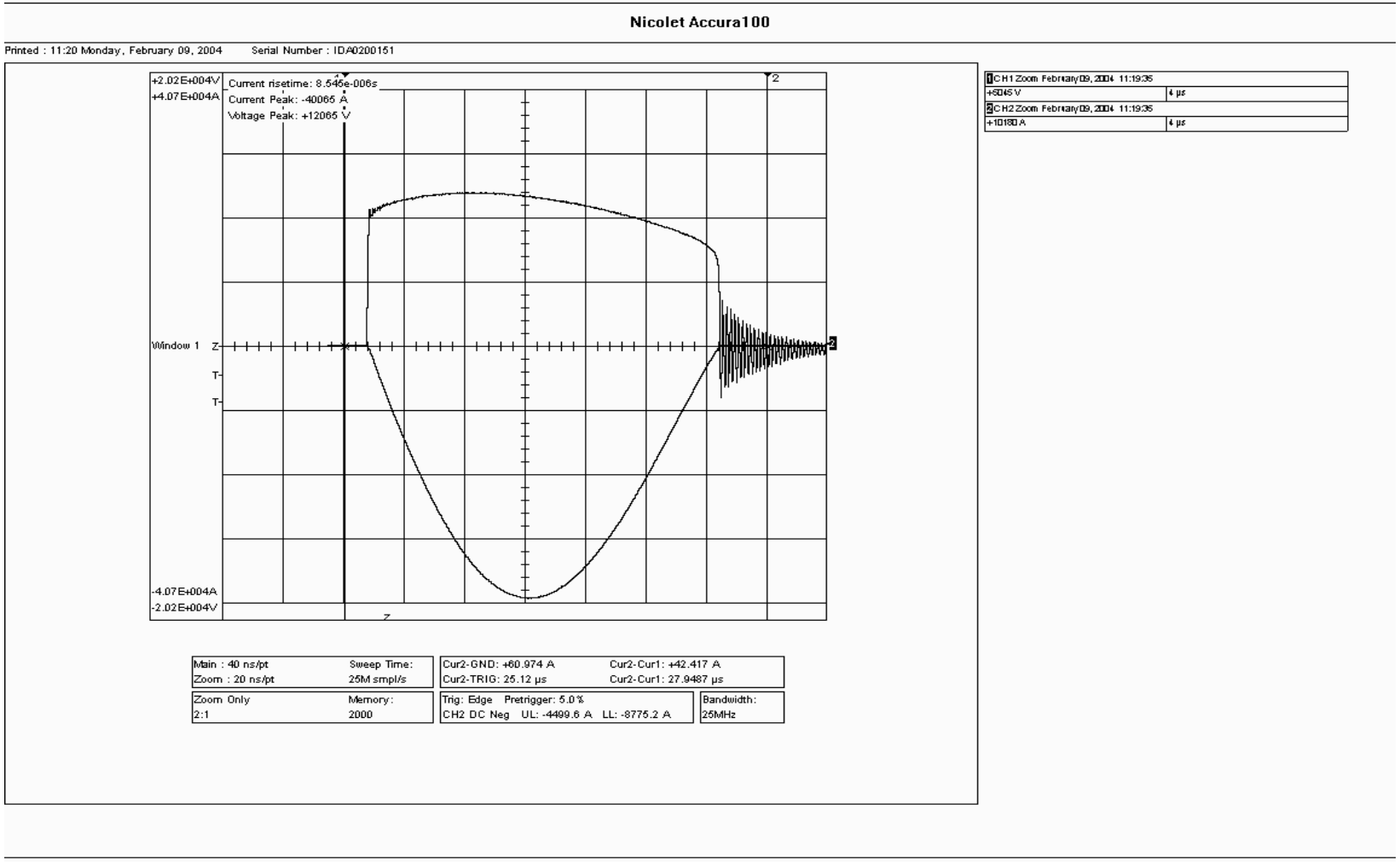
Oscillogram 10
Sample 1



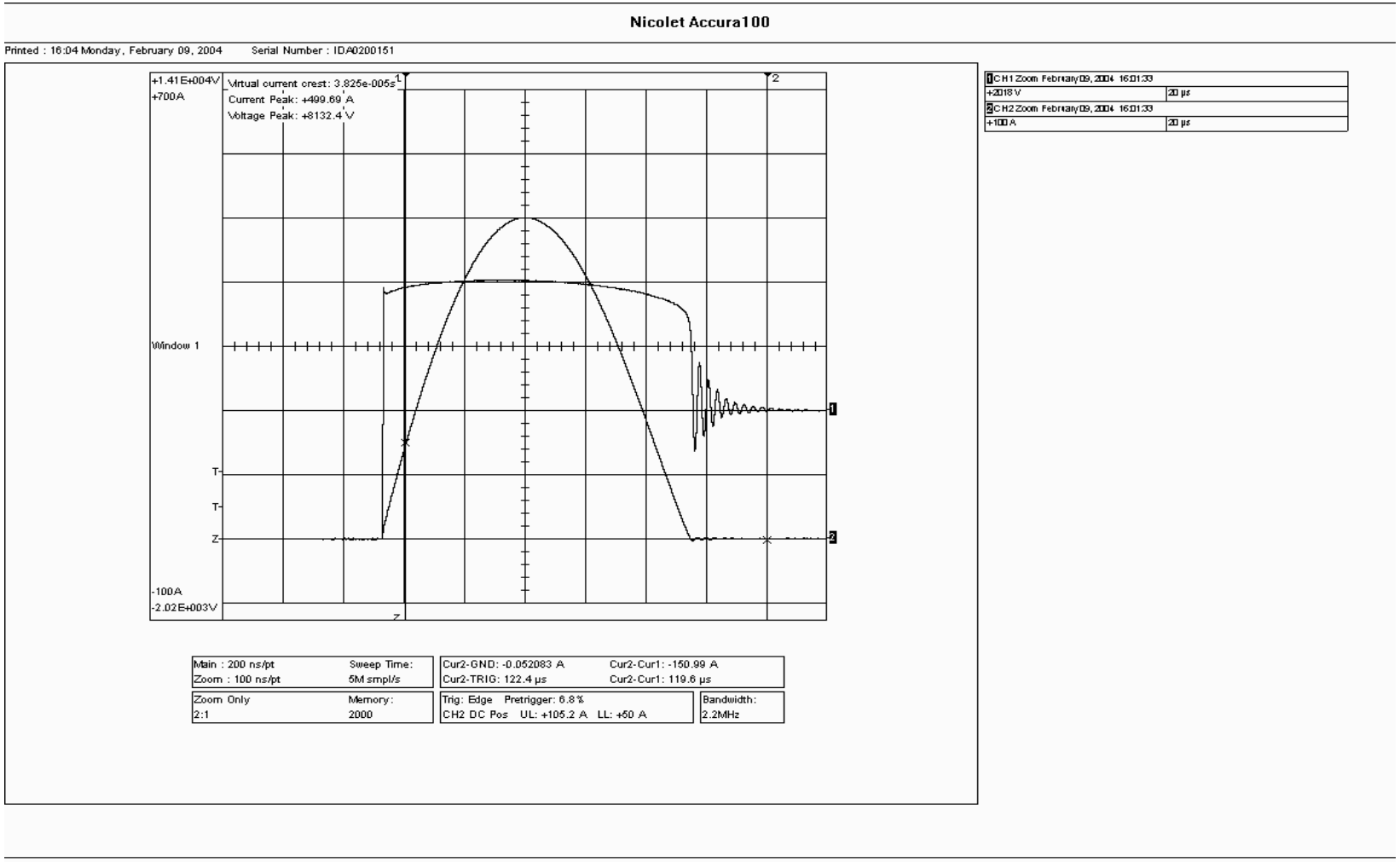
Oscillogram 11
Sample 2



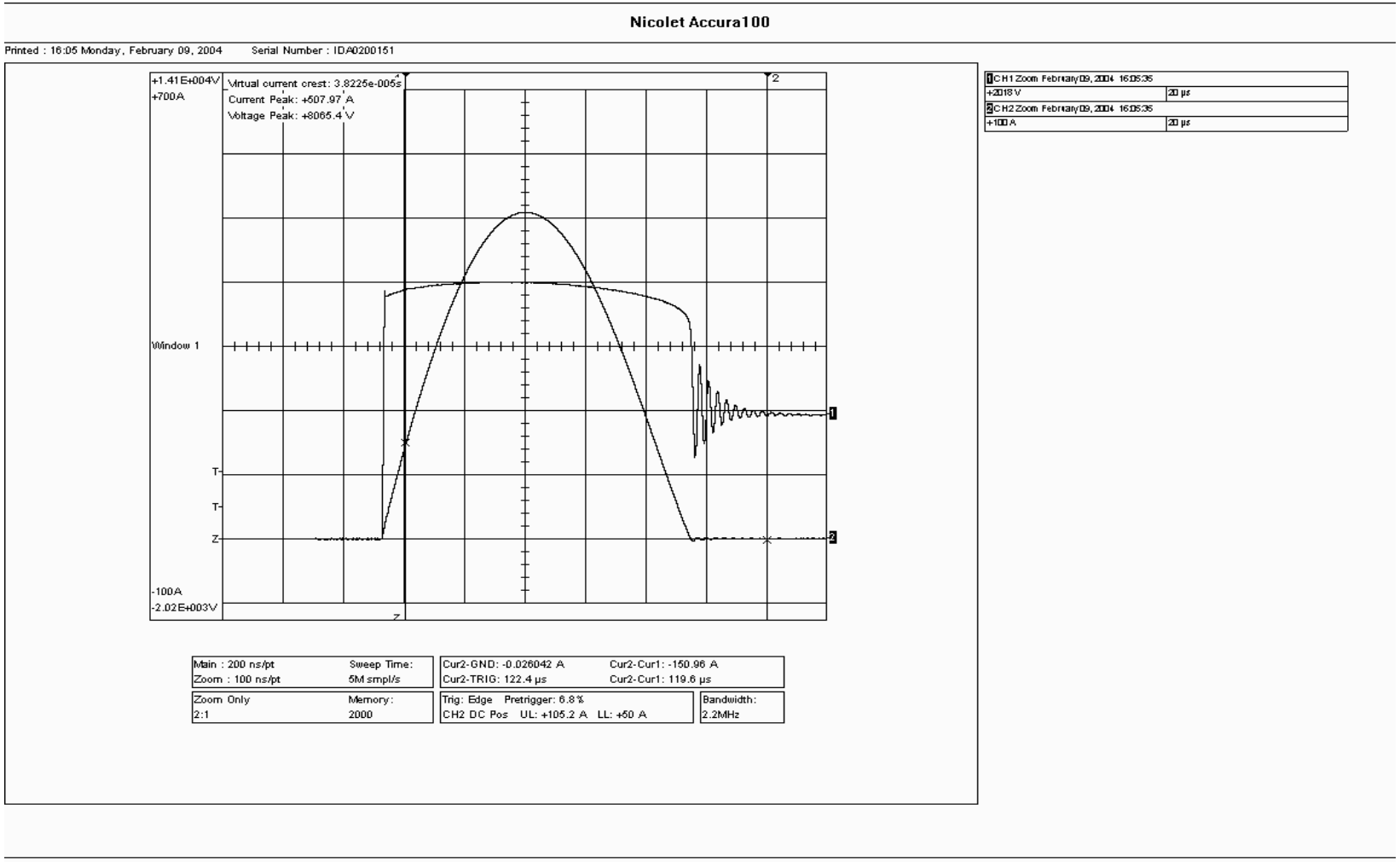
Oscillogram 12
Sample 3



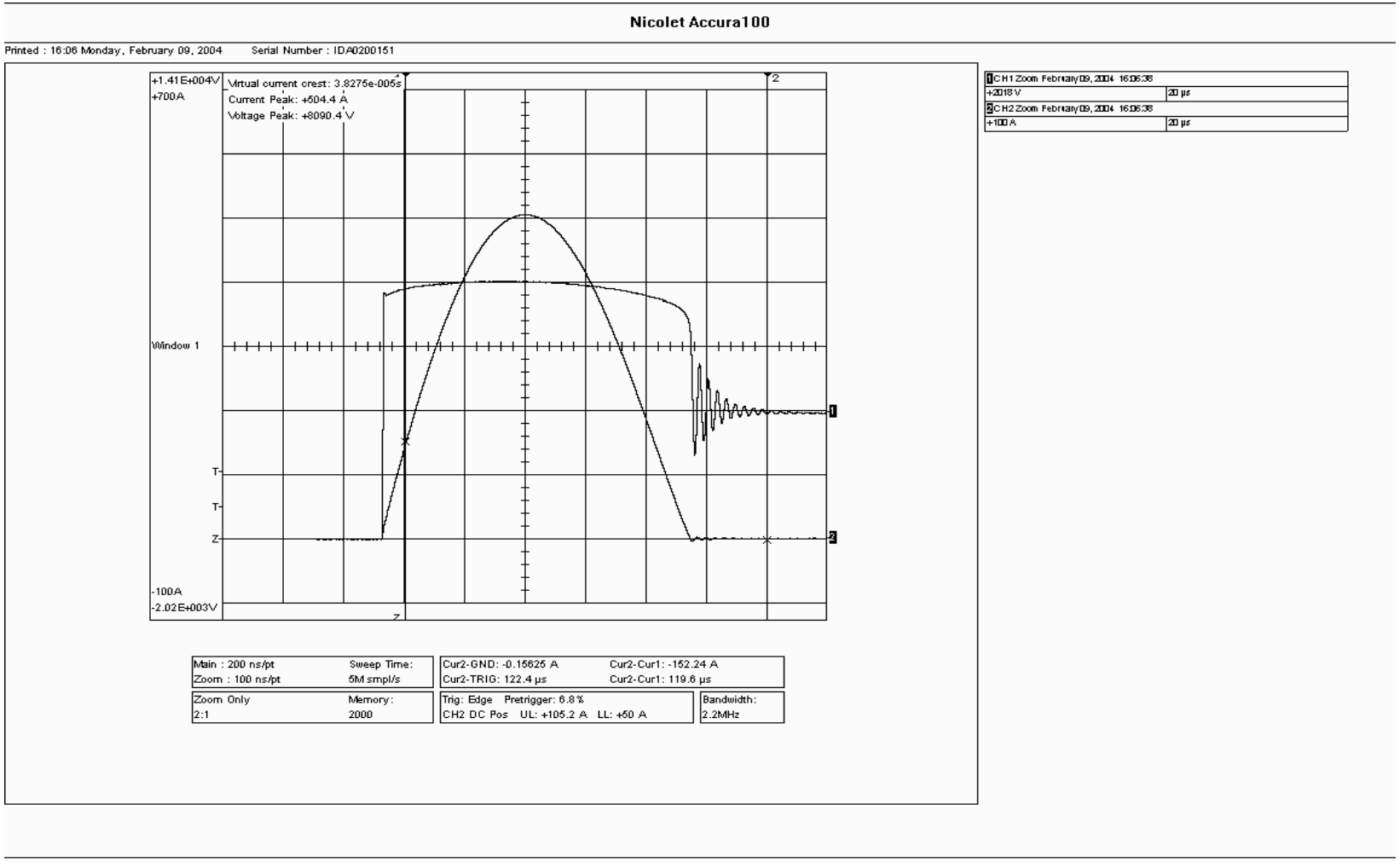
Oscillogram 16
Sample 1



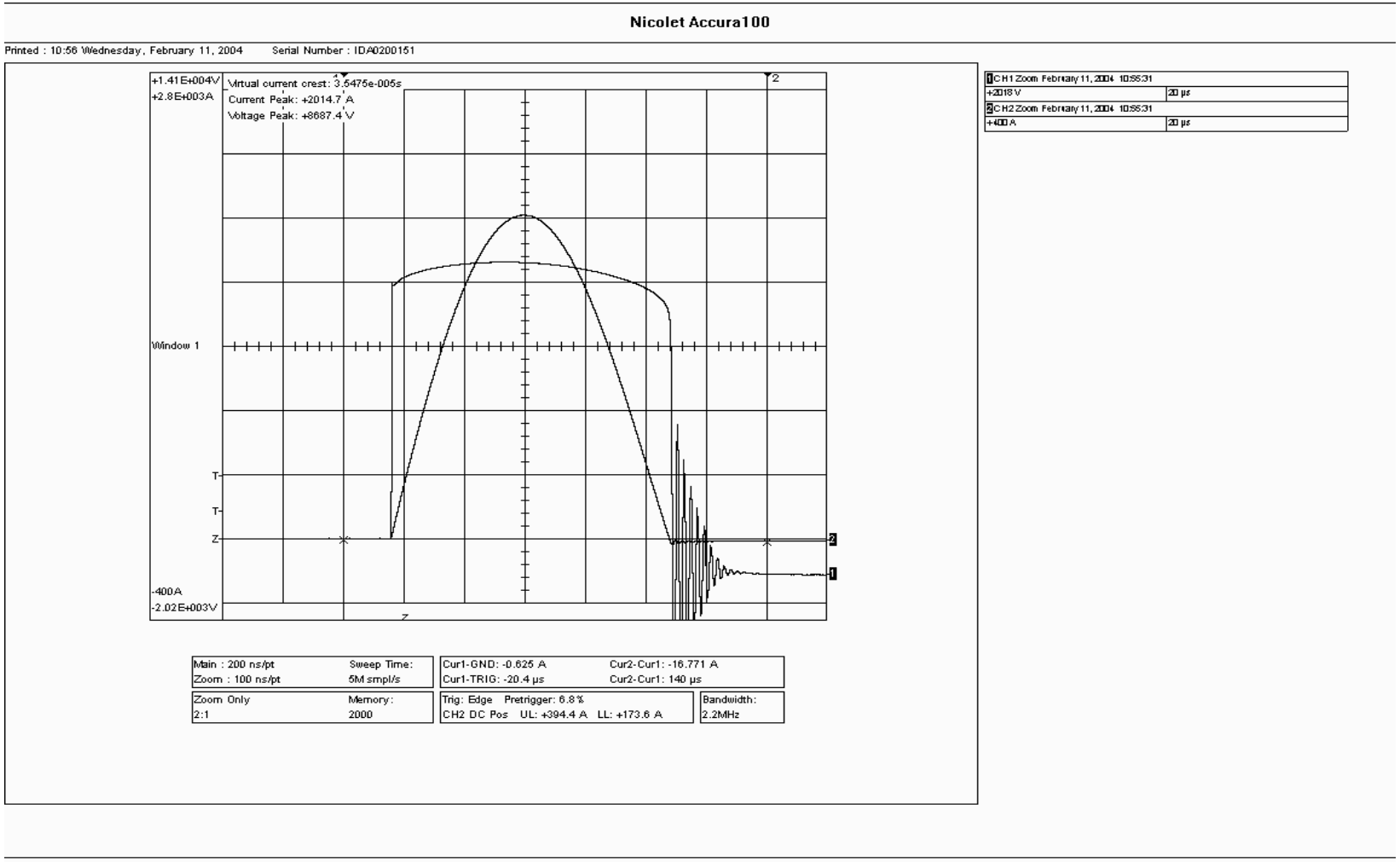
Oscillogram 17
Sample 2



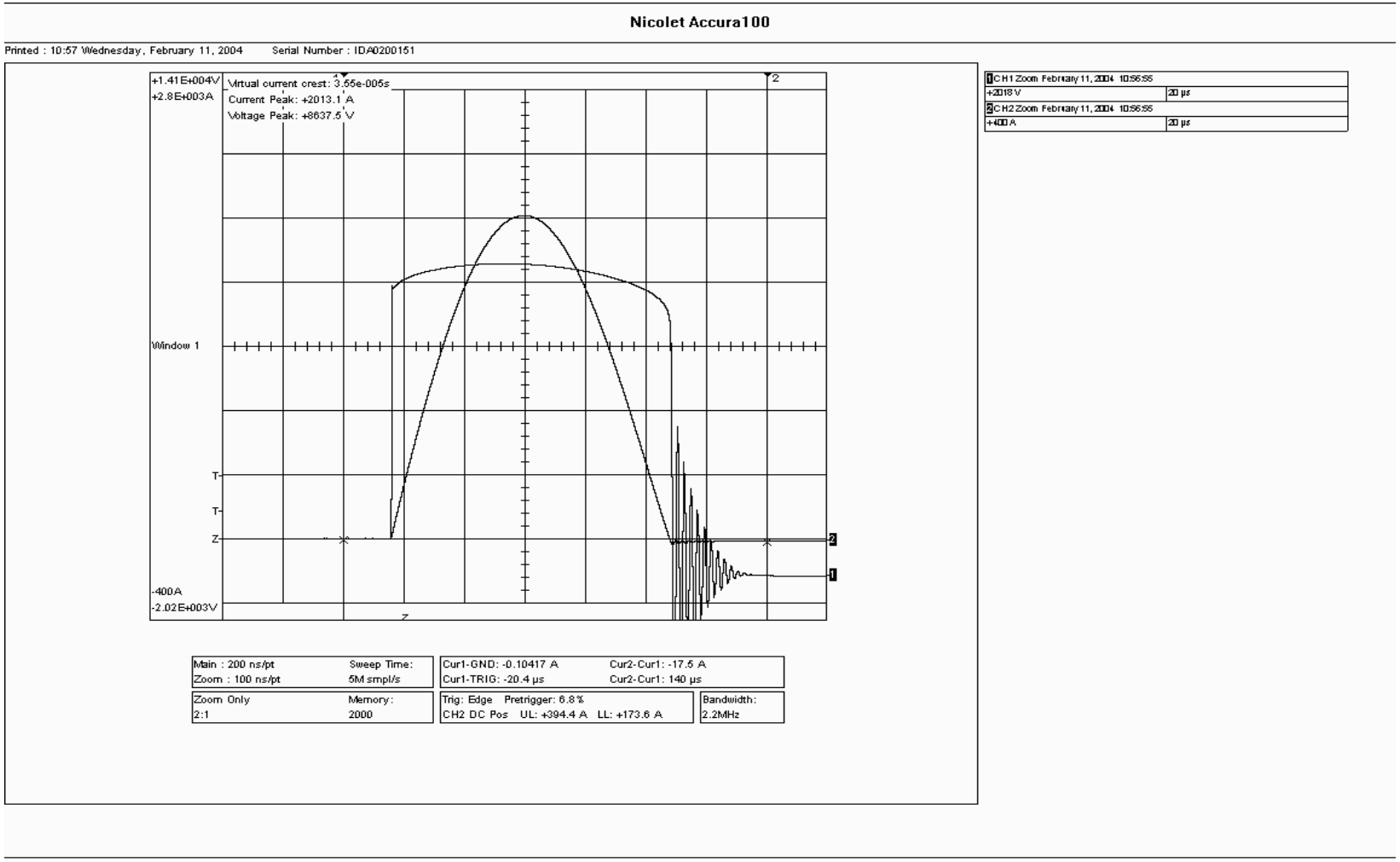
Oscillogram 18
Sample 3



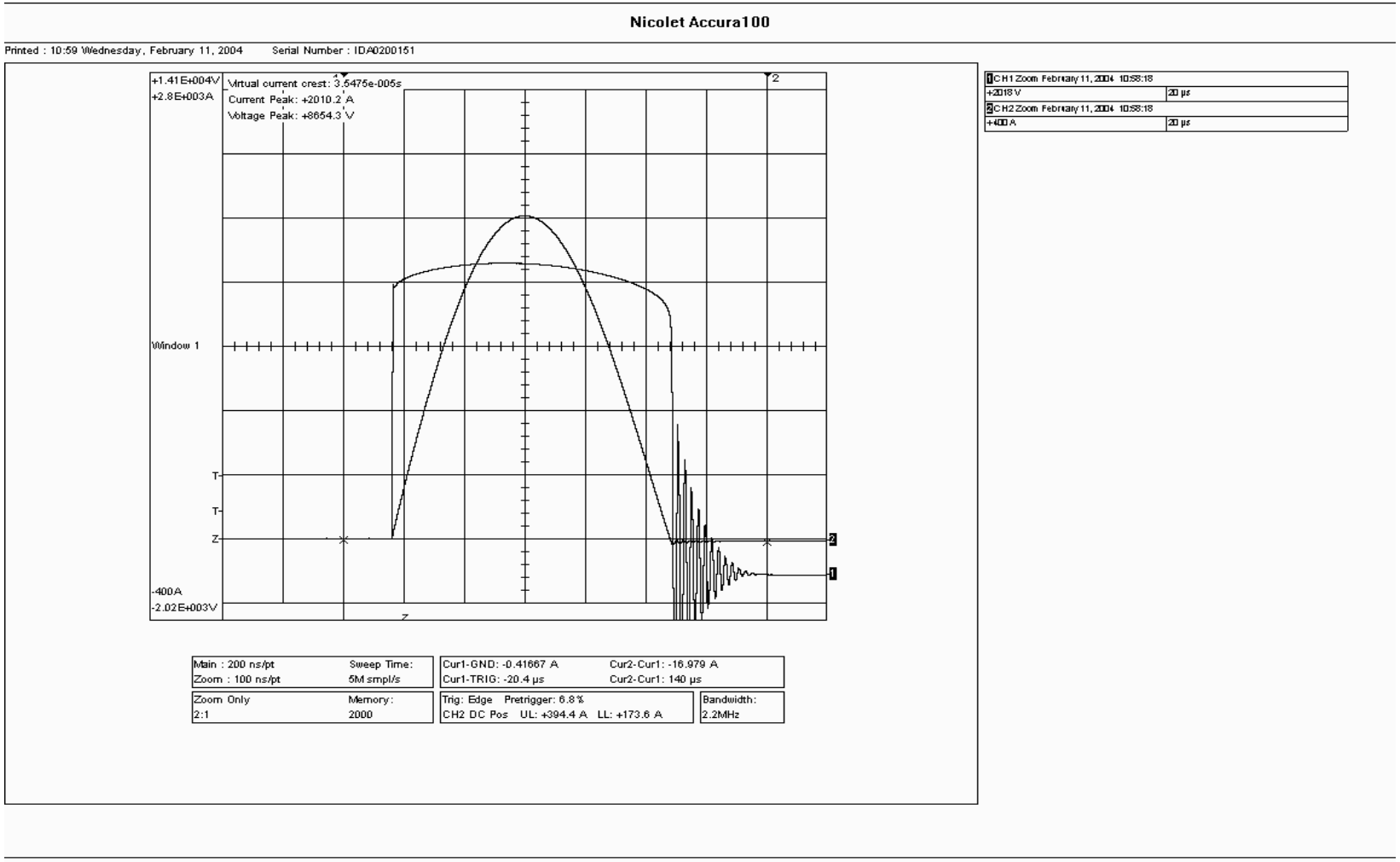
Oscillogram 22
Sample 1



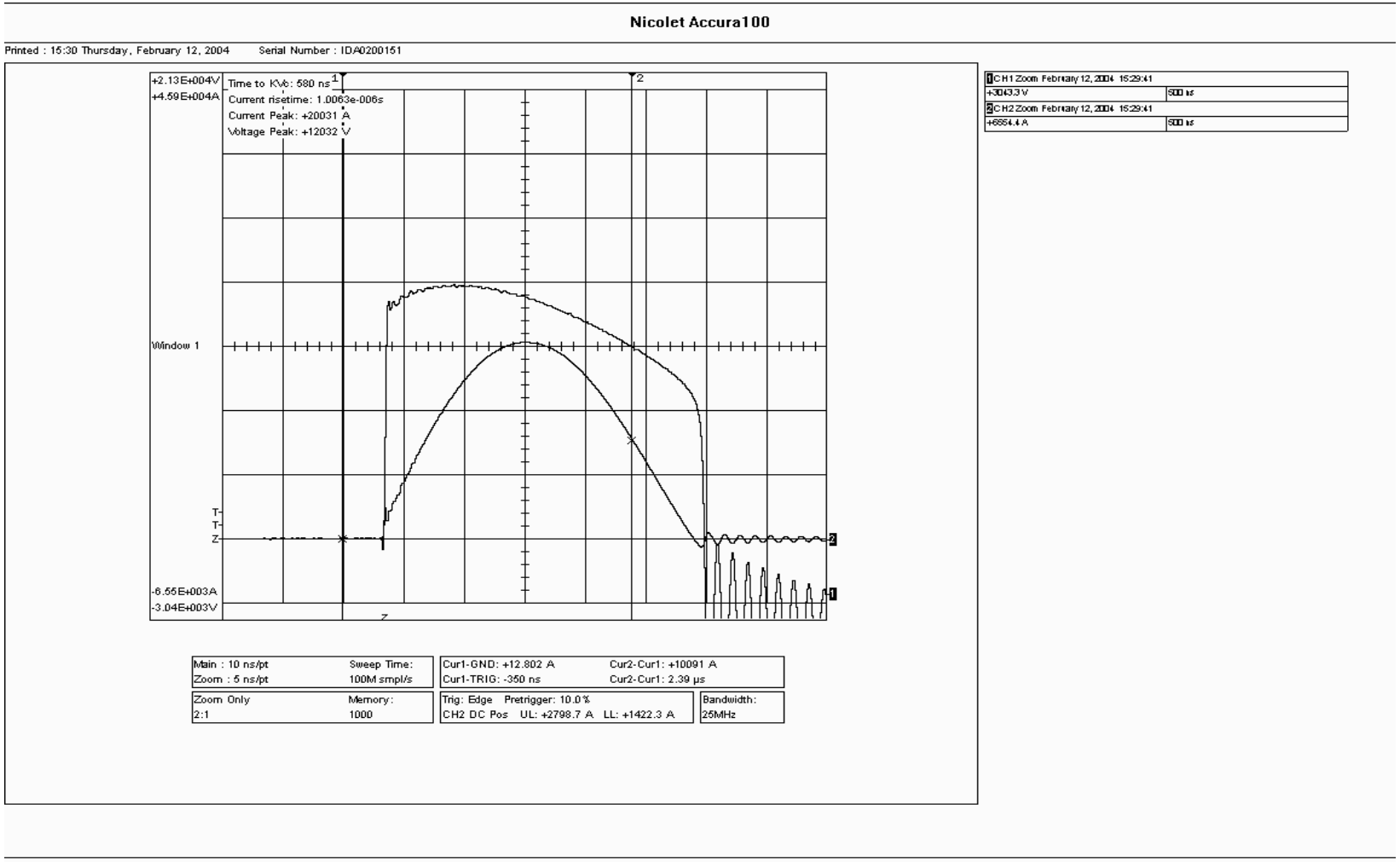
Oscillogram 23
Sample 2



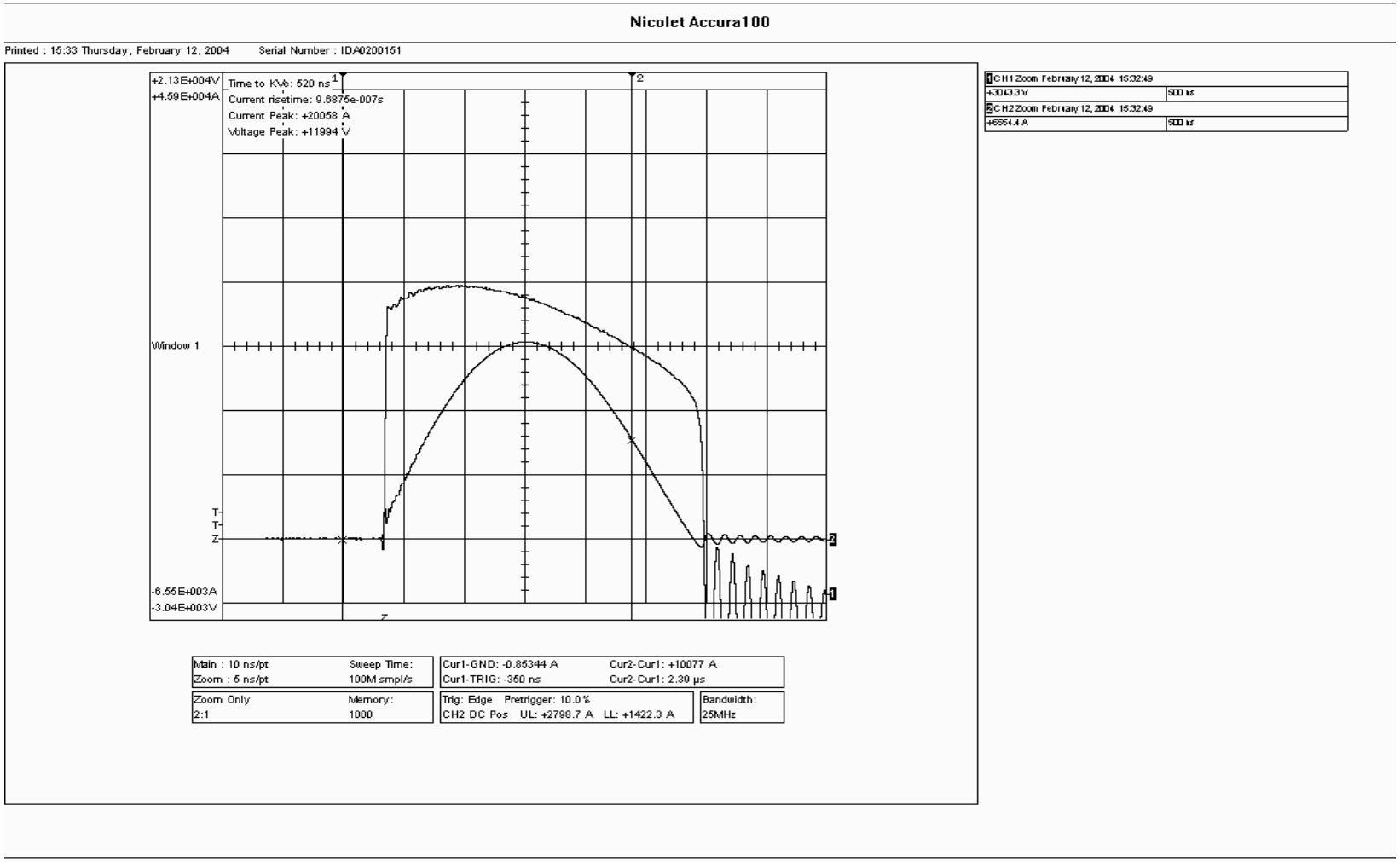
Oscillogram 24
Sample 3



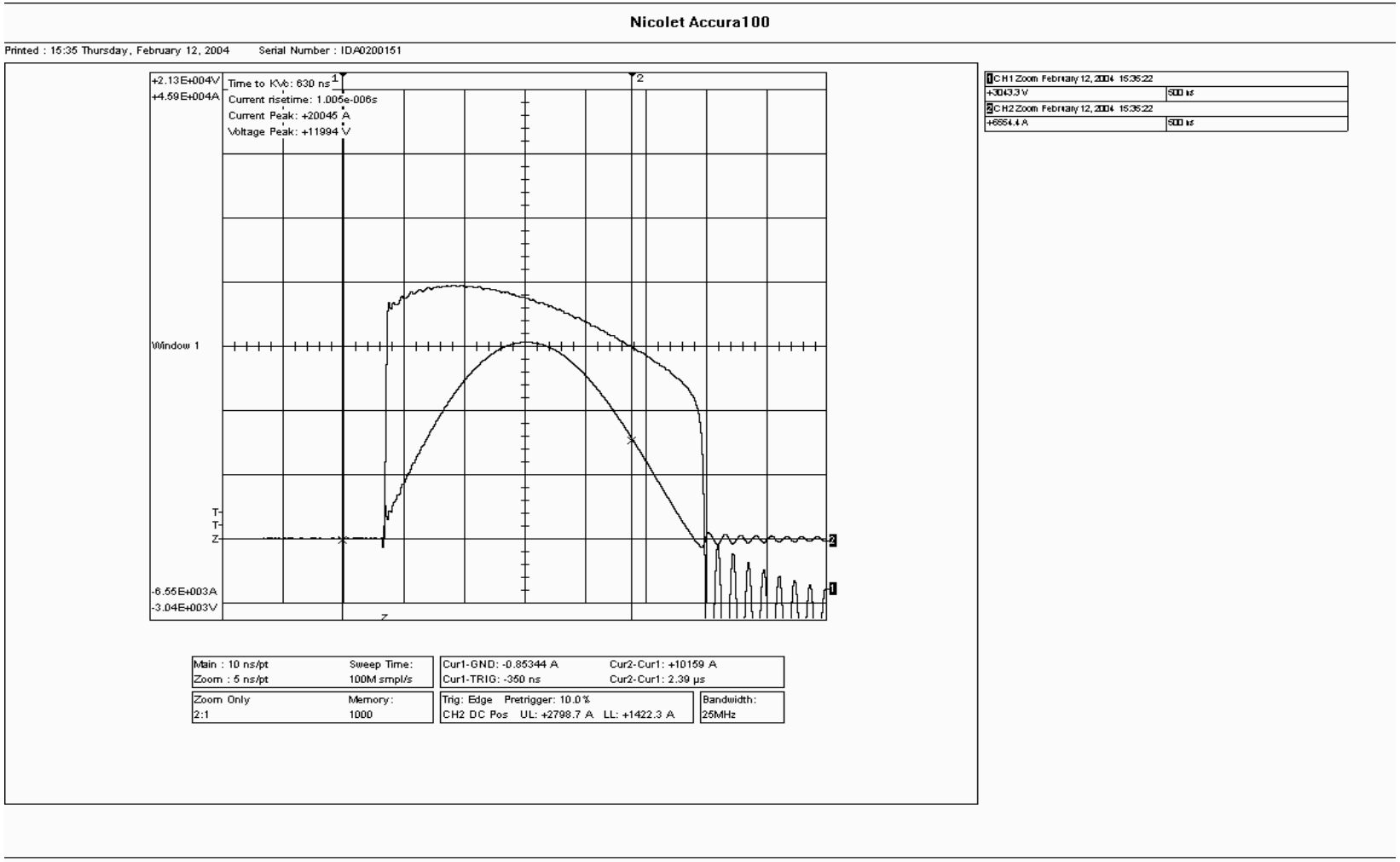
Oscillogram 28
Sample 1



Oscillogram 29
Sample 2



Oscillogram 30
Sample 3



HUBBELL POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1522-H-03.1
PH4 Series Polymer-housed Arrester
20,000 A Line Discharge Class 4

Long Duration Current Impulse Withstand Tests

This report records the results of type tests made on PH4 series 20 kA Line Discharge Class 4 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.1, 2006, "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: 4/12/2007

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 resistors in series. The resistors were selected to represent the lowest acceptable reference voltage level. The tests were conducted in accordance with clause 10.8.4 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 4 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. U_c for the PH4 series of arresters has been established as 0.78 times the lowest acceptable reference voltage in routine tests, and U_r has been established as 1.25 times U_c. This would normally be represented in the type test by assigning the test sample U_c equal to 0.78 x U_{ref} of the test sample, and test sample U_r at 1.25 times this value. However, in this particular test, U_c was set at a higher value than that used in the actual design (specifically, 0.795 x U_{ref}), thereby making the test more onerous.

The minimum energy required for each line discharge for Class 4 arresters is determined from the following formula given in Clause 8.4.2 of IEC 60099-4

$$W = U_{res} \times (U_L - U_{res}) \times 1/Z \times T$$

where U_{res} is the switching impulse residual voltage at 500 A.

Table 1. Parameters for Line Discharge Tests

Parameter	Sample 1	Sample 2	Sample 3
Switching impulse residual voltage (kV) U_{res}	21.623	21.528	21.581
Initial Residual Voltage (kV) @ 20 kA, 8/20	28.715	28.667	28.709
Reference Current (mA) I_{ref}	17	17	17
Reference Voltage (kV_c) V_{ref}	17.46	17.46	17.47
COV (kV rms) U_c	9.81	9.82	9.82
Rating (kV rms) U_r	12.26	12.40	12.40
Arrester Classification (kA)	20	20	20
Line Discharge Class	4	4	4
Virtual Duration of Peak (μs, 90-90%) - min	2800	2800	2800
Surge Impedance (Ω) Z_g - max (0.8 U_r)	9.81	9.82	9.82
Charging Voltage (kV) U_L – min (2.6 U_r)	31.75	32.24	32.24
Energy required (kJ) - min	62.5	65.8	65.6

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 = 8,092 V / 840.67 A = 9.628 Ω Virtual Duration of Peak = 2899 μs

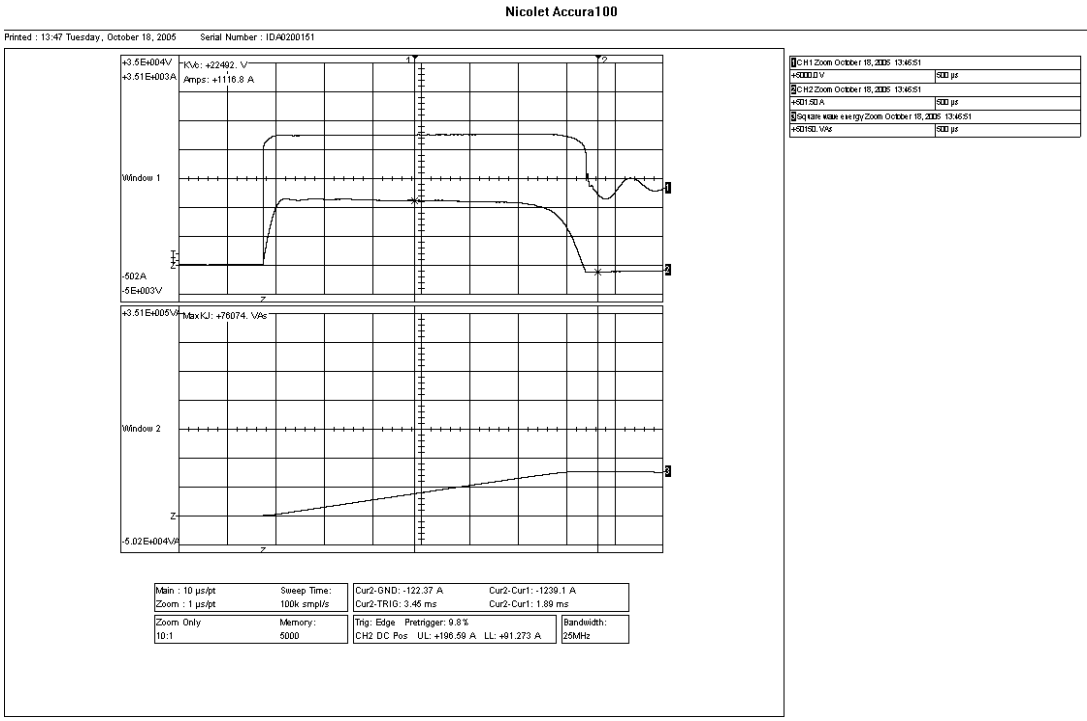
Figure 1. Oscillogram of discharge current for generator short circuit set up test

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 first and eighteenth discharges for each of the three samples, respectively. Ambient air temperature at the time of the test was 22 °C.

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	1117	22.49	76.1	1129	22.37	76.3	1121	22.37	75.9
2	1071	22.89	74.6	1079	22.78	74.8	1071	22.85	74.6
3	1035	23.22	73.3	1042	23.16	73.4	1039	23.24	73.2
4	1111	22.56	75.7	1121	22.45	76.0	1108	22.45	75.6
5	1071	22.93	74.3	1077	22.85	74.6	1073	22.89	74.4
6	1029	23.31	72.9	1042	23.20	73.3	1033	23.24	73.1
7	1123	22.50	76.3	1129	22.44	76.5	1125	22.40	76.4
8	1081	22.90	75.0	1083	22.81	75.1	1081	22.83	75.1
9	1039	23.31	73.7	1047	23.19	73.8	1041	23.23	73.7
10	1116	22.50	75.8	1125	22.40	76.0	1123	22.46	76.0
11	1074	22.85	74.4	1081	22.83	74.7	1077	22.83	74.5
12	1031	23.25	73.0	1037	23.30	73.3	1037	23.21	73.3
13	1108	22.54	75.5	1116	22.46	75.8	1114	22.48	75.8
14	1068	22.94	74.3	1079	22.83	74.5	1074	22.85	74.4
15	1033	23.33	72.9	1039	23.19	73.4	1035	23.23	73.1
16	1110	22.48	75.6	1114	22.44	75.8	1112	22.44	75.7
17	1064	22.90	74.2	1074	22.85	74.5	1068	22.83	74.3
18	1026	23.25	72.8	1037	23.21	73.2	1035	23.21	73.0

Sample 1, Discharge 1



Sample 1, Discharge 18

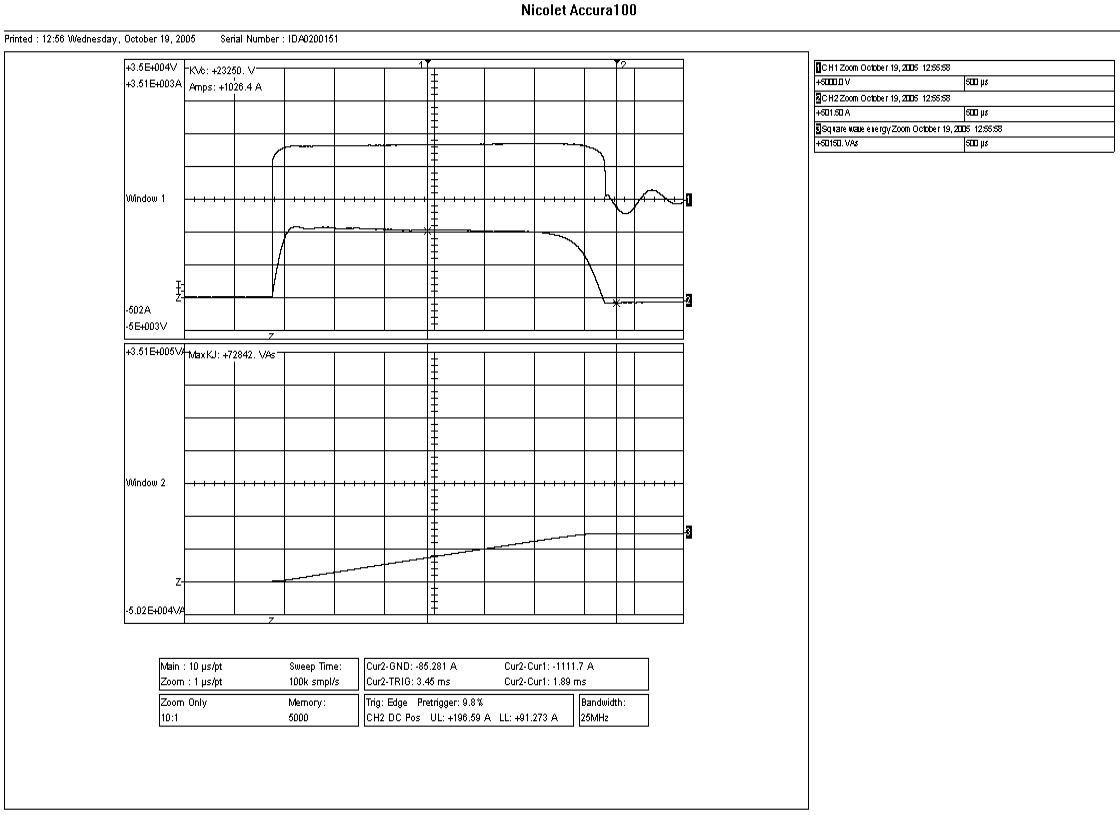
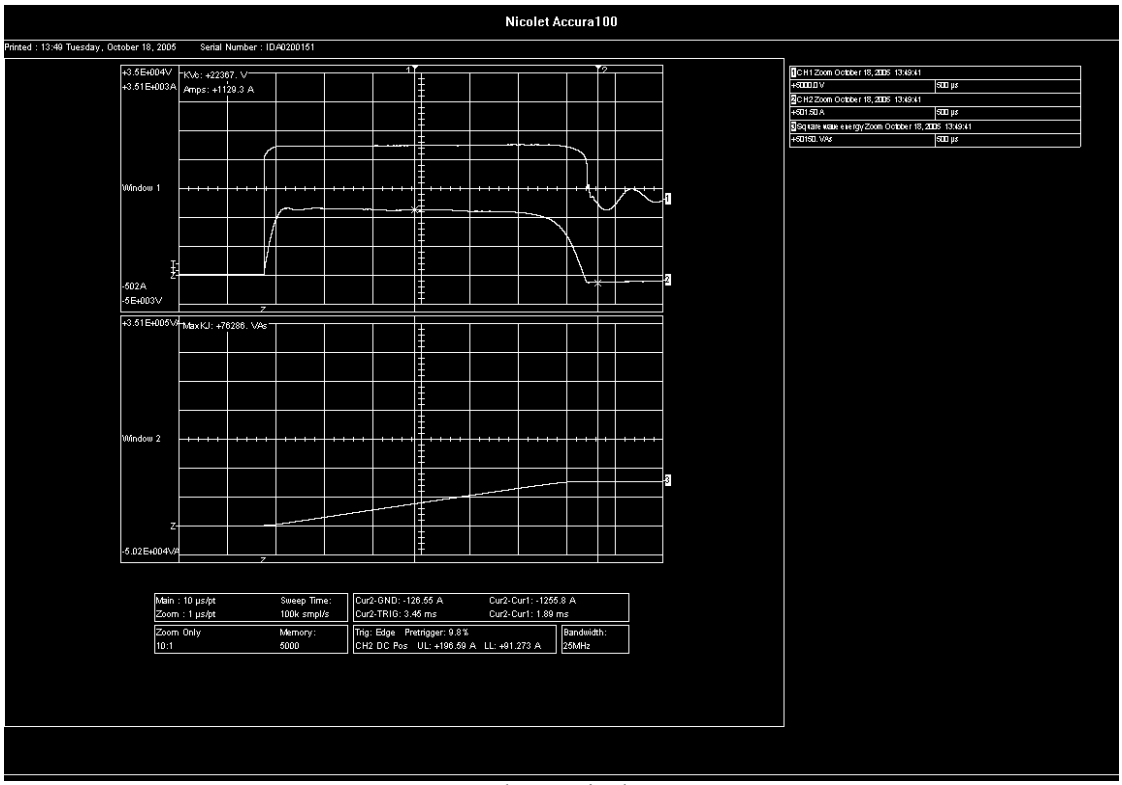


Figure 2. Oscillograms of line discharges for sample 1

Sample 2, Discharge 1



Sample 2, Discharge 18

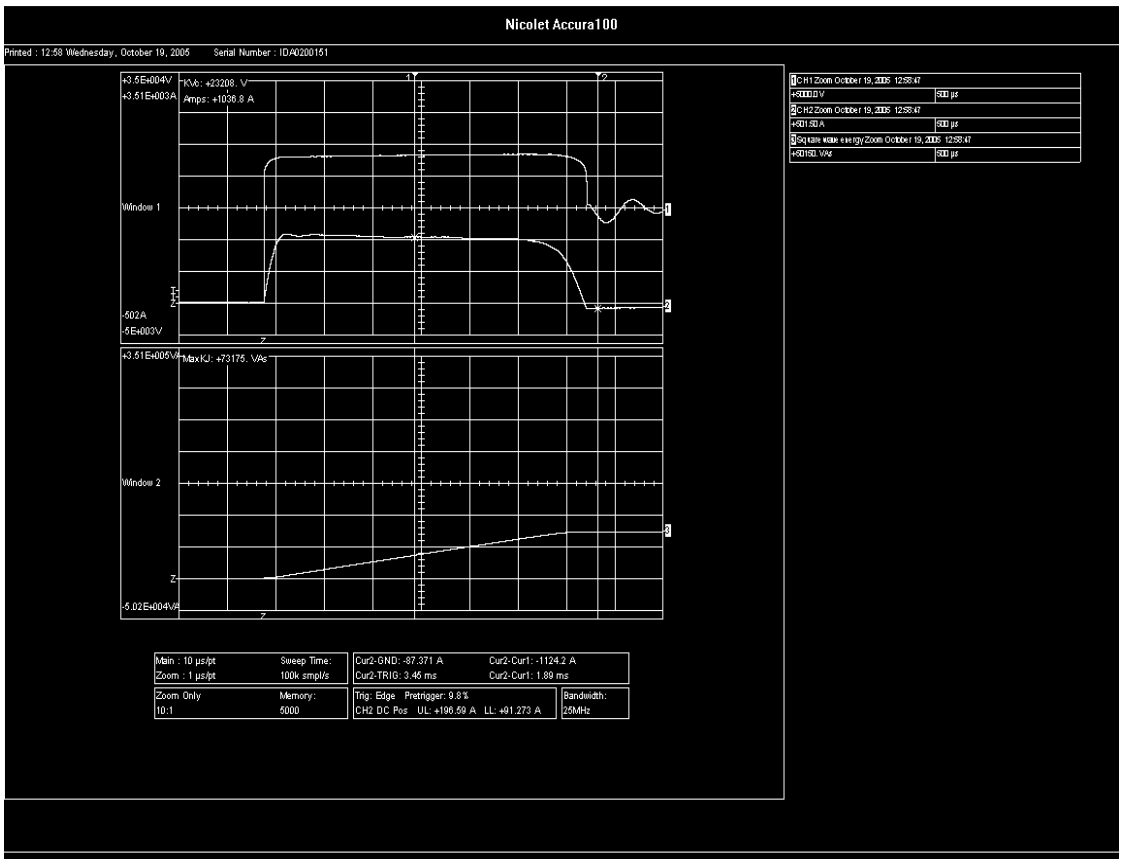
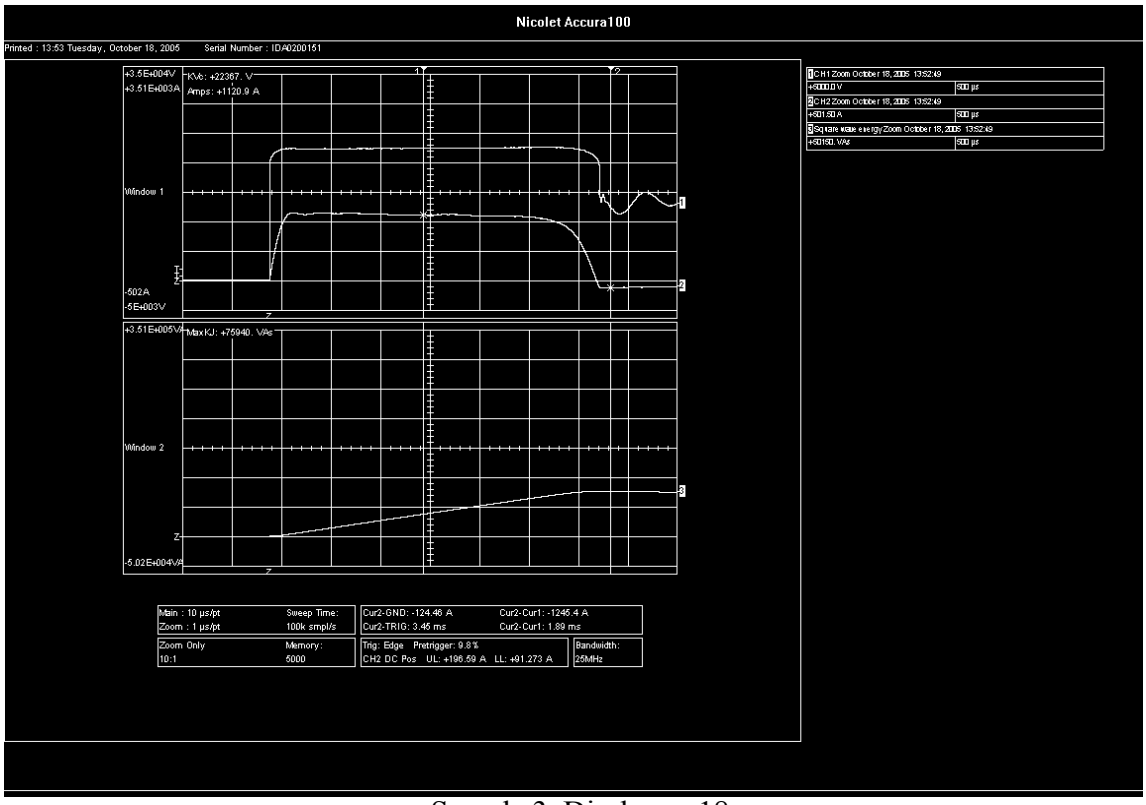


Figure 3. Oscillograms of line discharges for sample 2

Sample 3, Discharge 3



Sample 3, Discharge 18

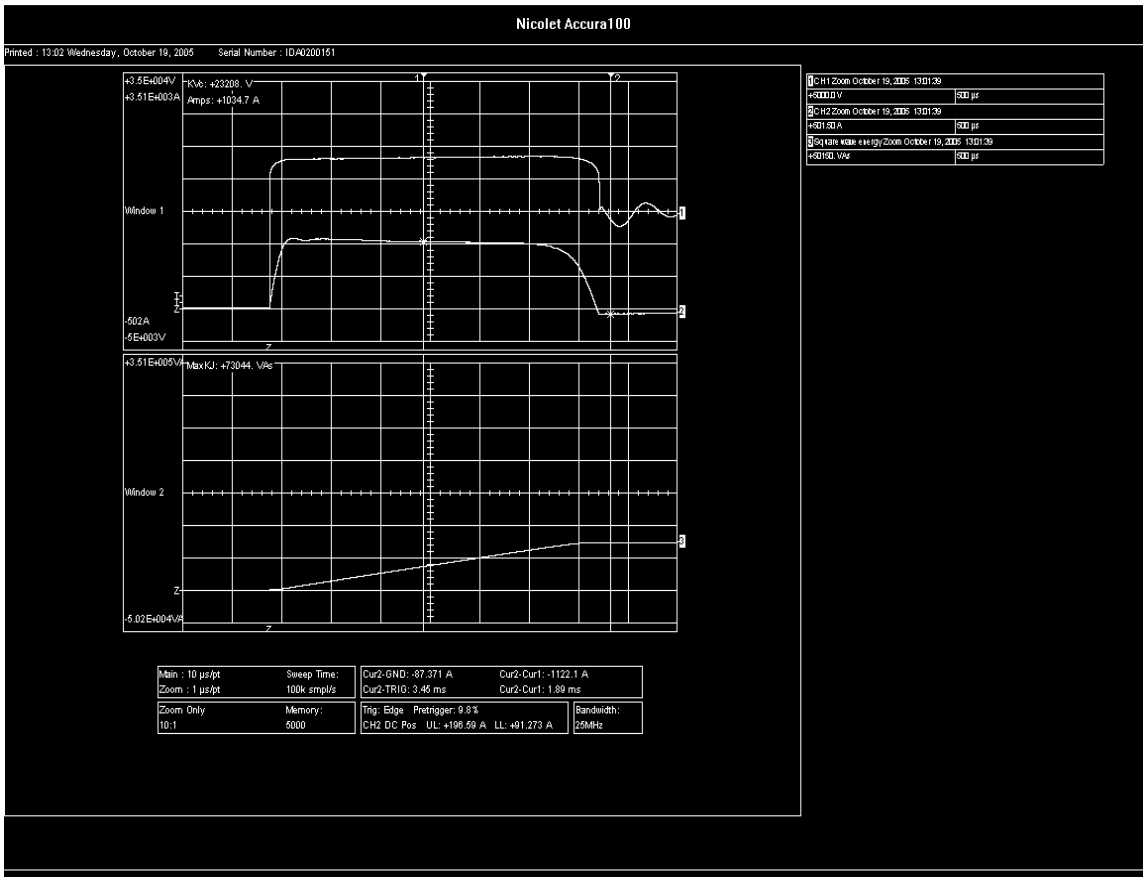


Figure 4. Oscillograms of line discharges for sample 3

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	28.715	28.767	+ 0.17%
2	28.667	28.741	+ 0.26%
3	28.709	28.814	+ 0.37%

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

HUBBELL POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1522-H-04.1
PH4 Series Polymer-housed Arrester
20,000 A Line Discharge Class 4

Accelerated Aging Procedure

This report records the results of type tests made on PH4 series 20 kA Line Discharge Class 4 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.1, 2006, "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: 4/12/2007

IEC TYPE TEST REPORT
Accelerated Ageing Procedure

TESTS PERFORMED:

Accelerated aging tests were performed on two resistor elements. The tests were conducted in accordance with the requirements of clause 10.8.5 of IEC 60099-4 (requiring the accelerated ageing procedure of clause 8.5.2 to be administered). 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

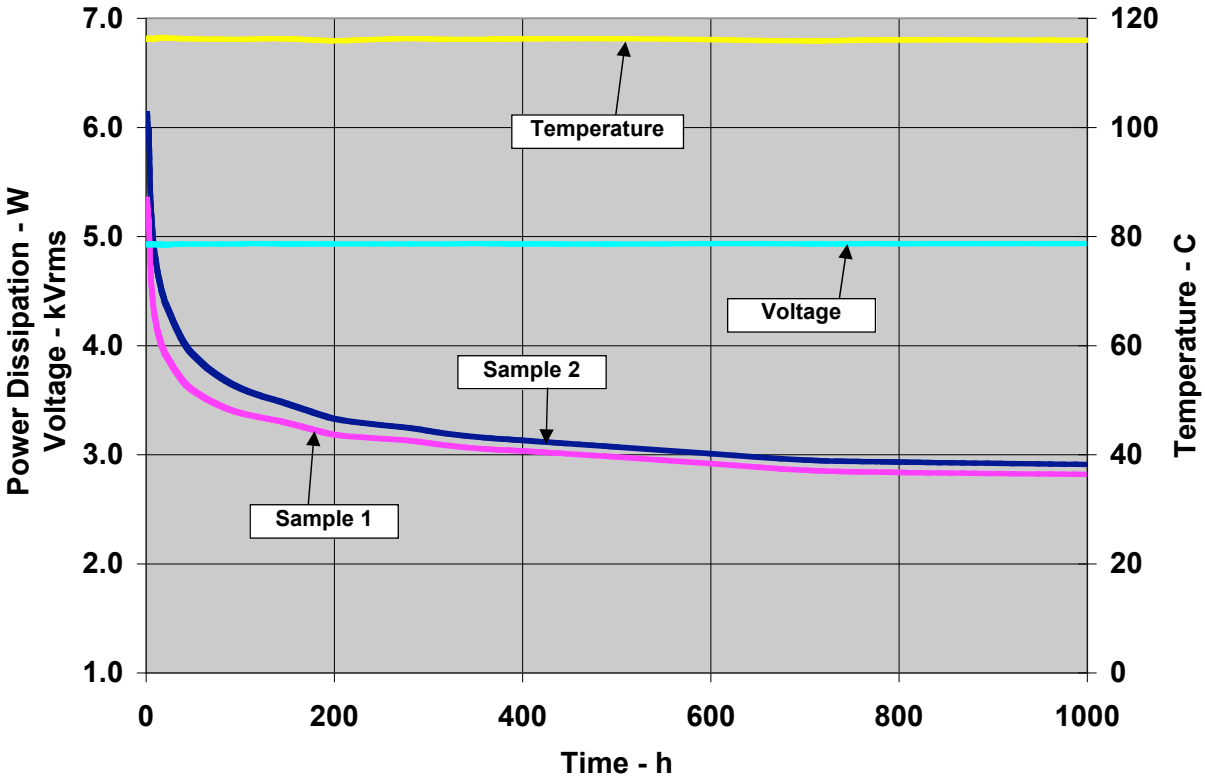


Figure 1. Power dissipation, voltage and temperature measurements during 1000 h test period

HUBBELL POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1522-H-05.1
PH4 Series Polymer-housed Arrester
20,000 A Line Discharge Class 4

Heat Dissipation Behaviour of Test Section

This report records the results of type tests made on PH4 series 20 kA Line Discharge Class 4 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.1, 2006, "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: 4/12/2007

IEC TYPE TEST REPORT
Heat Dissipation Behaviour of Test Section

TESTS PERFORMED:

Tests were performed as required by clause 10.8.5 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, a specially modified arrester unit with U_r = 150 kV unit and a test section with U_r = 10.6 kV were prepared. The 150 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, was equipped with a thermocouple located between one-third and one-half of the unit length from the top of the resistor stack. The test section was comprised of two resistor elements 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:

The resistors in both the assembled unit and the test section were heated by applying a voltage sufficiently above U_r to raise the resistor temperature to 120^{o}C in approximately 4 min. Figure 1 graphically displays the cooling of both samples over a period of approximately 6.5 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 slightly 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.

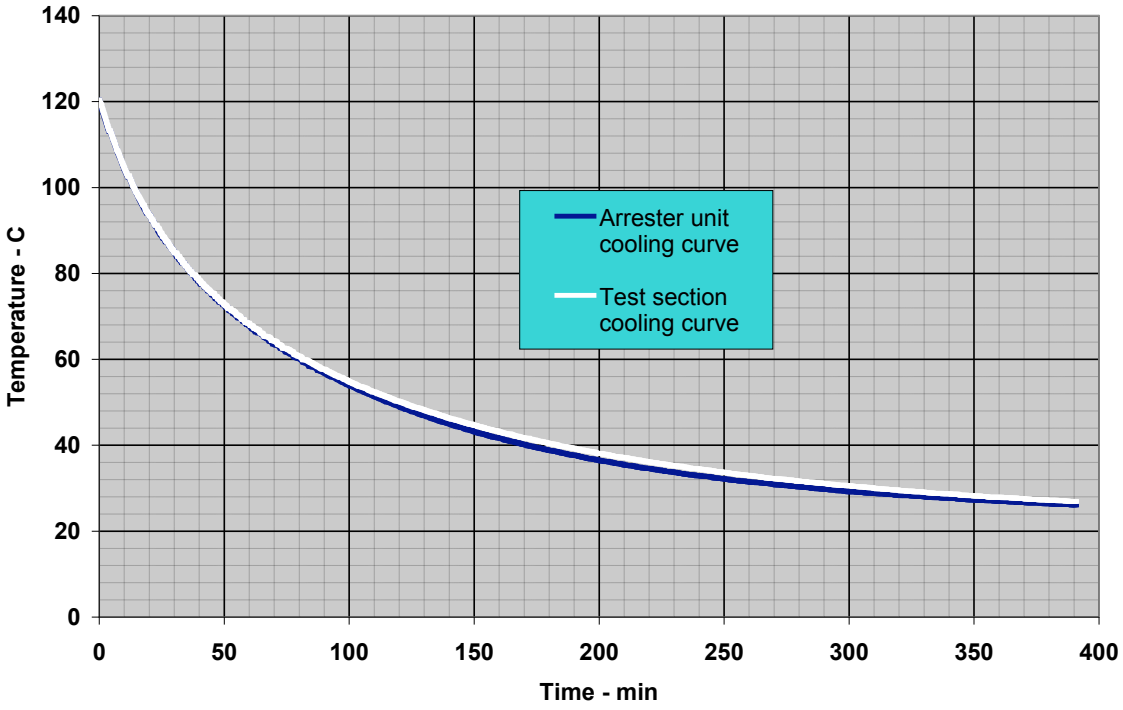


Figure 1. Cooling curves of fully assembled unit and test section

HUBBELL POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1522-H-06.1
PH4 Series Polymer-housed Arrester
10,000 A Line Discharge Class 4

Switching Surge Operating Duty Test

This report records the results of type tests made on PH4 series 20 kA Line Discharge Class 4 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.1, 2006, "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: 4/12/2007

IEC TYPE TEST REPORT
Switching Surge Operating Duty Test

TESTS PERFORMED:

Switching surge operating duty tests, in accordance with the requirements of clause 10.8.5 of IEC 60099-4, were performed on three prorated test sections. The test sections were prepared based on the results of the tests to verify heat dissipation behaviour of test sample (see EU1522-H-05 section of PH4 type test report). Each section consisted of two resistors in series. The resistors were selected to represent the lowest acceptable reference voltage level. The tests were conducted in accordance with. 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 4 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. U_c for the PH4 series of arresters has been established as 0.78 times the lowest acceptable reference voltage in routine tests, and U_r has been established as 1.25 times U_c.

The minimum energy required for each line discharge for Class 4 arresters is determined from the following formula given in Clause 8.4.2 of IEC 60099-4

$$W = U_{res} \times (U_L - U_{res}) \times 1/Z \times T$$

where U_{res} is the switching impulse residual voltage at 500 A.

Table 1. Initial Measurements and Parameters for Line Discharge Tests

Parameter	Sample 1	Sample 2	Sample 3
Switching impulse residual voltage (kV) U_{res}	21.602	21.623	21.665
Initial Residual Voltage (kV) @ 20 kA, 8/20	28.767	28.767	28.783
Reference Current (mA) I_{ref}	17	17	17
Reference Voltage (kV_c) V_{ref}	17.475	17.476	17.476
COV (kV rms) U_c	9.64	9.64	9.64
Adjusted COV (kVrms) Uc'	9.91	10.01	10.00
Rating (kV rms) U_r	11.57	11.57	11.57
Arrester Classification (kA)	20	20	20
Line Discharge Class	4	4	4
Virtual Duration of Peak (μs, 90-90%) - min	2800	2800	2800
Surge Impedance (Ω) Z_g - max (0.8 U_r)	9.256	9.256	9.256
Charging Voltage (kV) U_L – min (2.6 U_r)	30.08	30.08	30.08
Energy required (kJ) - min	55.4	55.3	55.2

RESULTS:

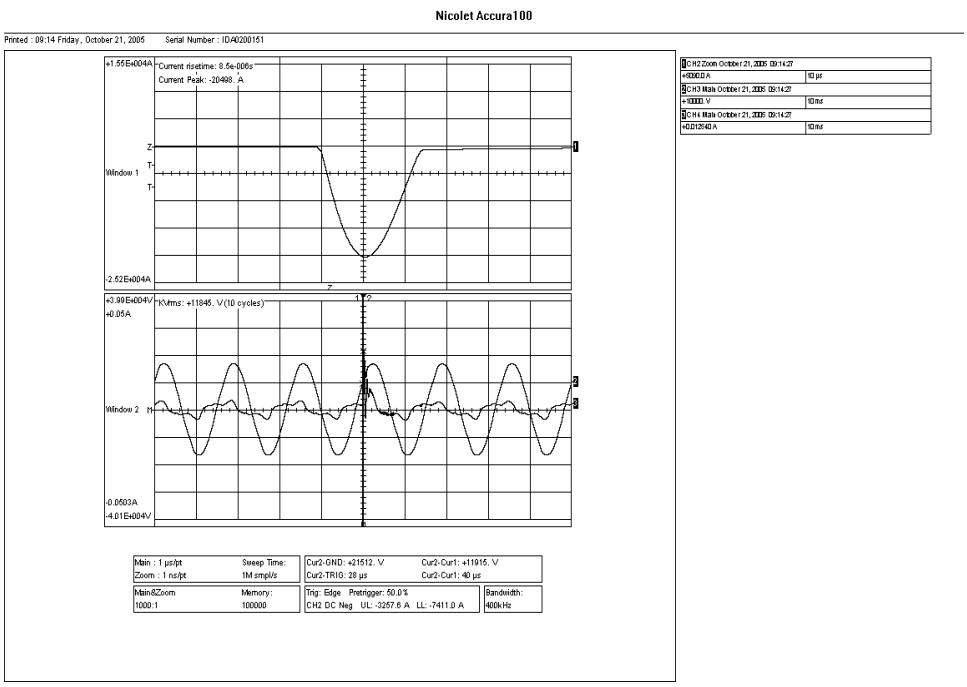
Representative voltage and current waveforms for lightning impulse conditioning discharges and high current conditioning impulses are shown in Figures 1 and 2, respectively.

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 3 shows

Z_g = 8,092 V / 840.67 A = 9.628 Ω Virtual Duration of Peak = 2899 μs

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.

Section 1: 5th conditioning impulse



Section 1: 20th conditioning impulse

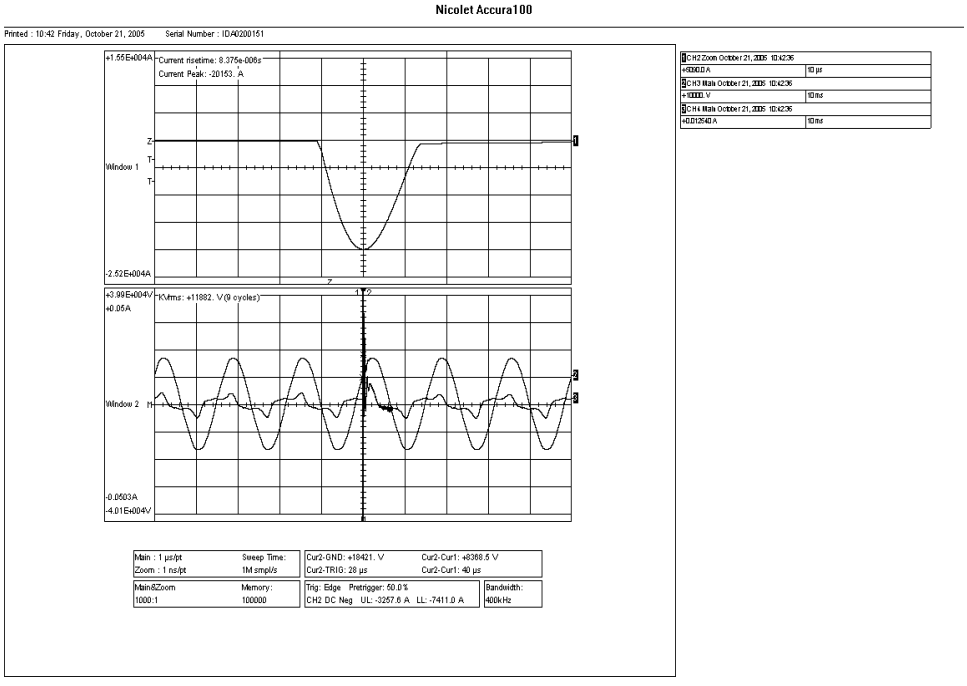
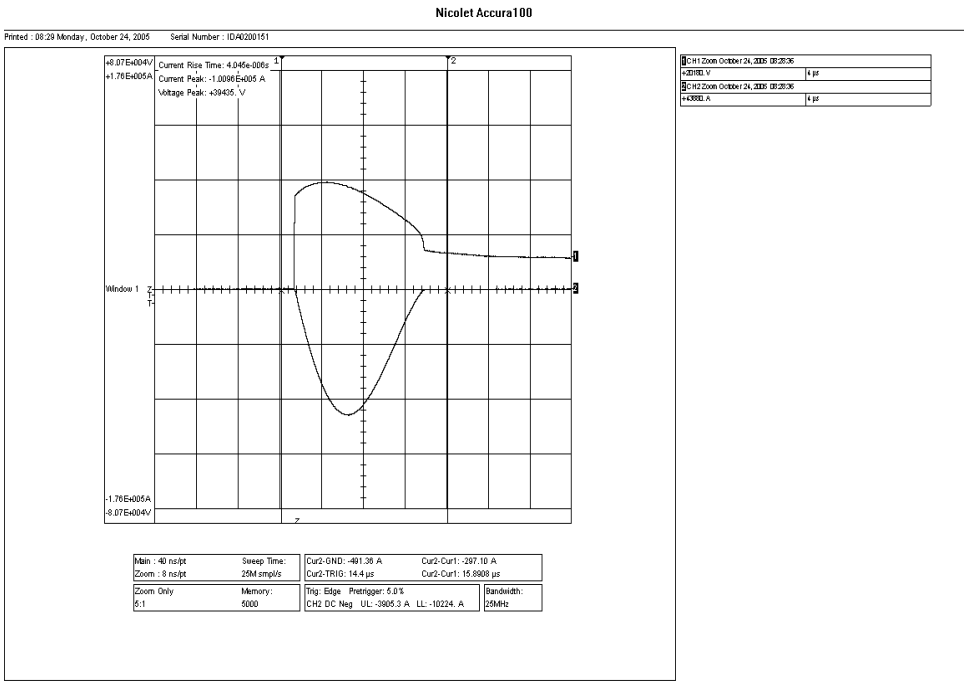


Figure 1. Representative oscillograms of 20kA 8/20 conditioning impulses

Section 2: 1st conditioning impulse



Section 2: 2nd conditioning impulse

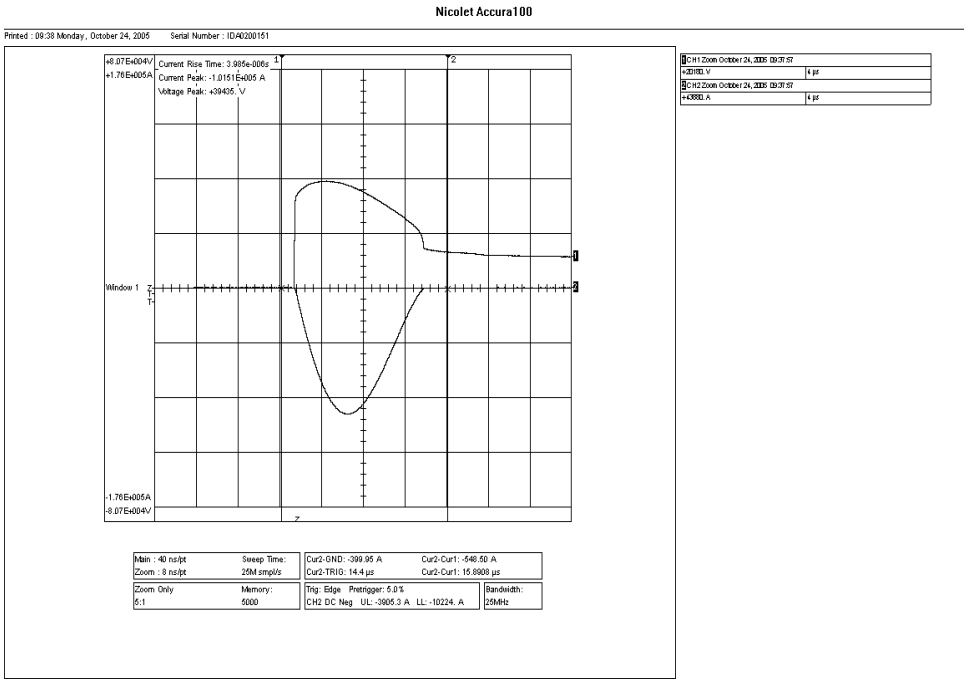


Figure 2. Representative oscillograms of 100kA conditioning impulses

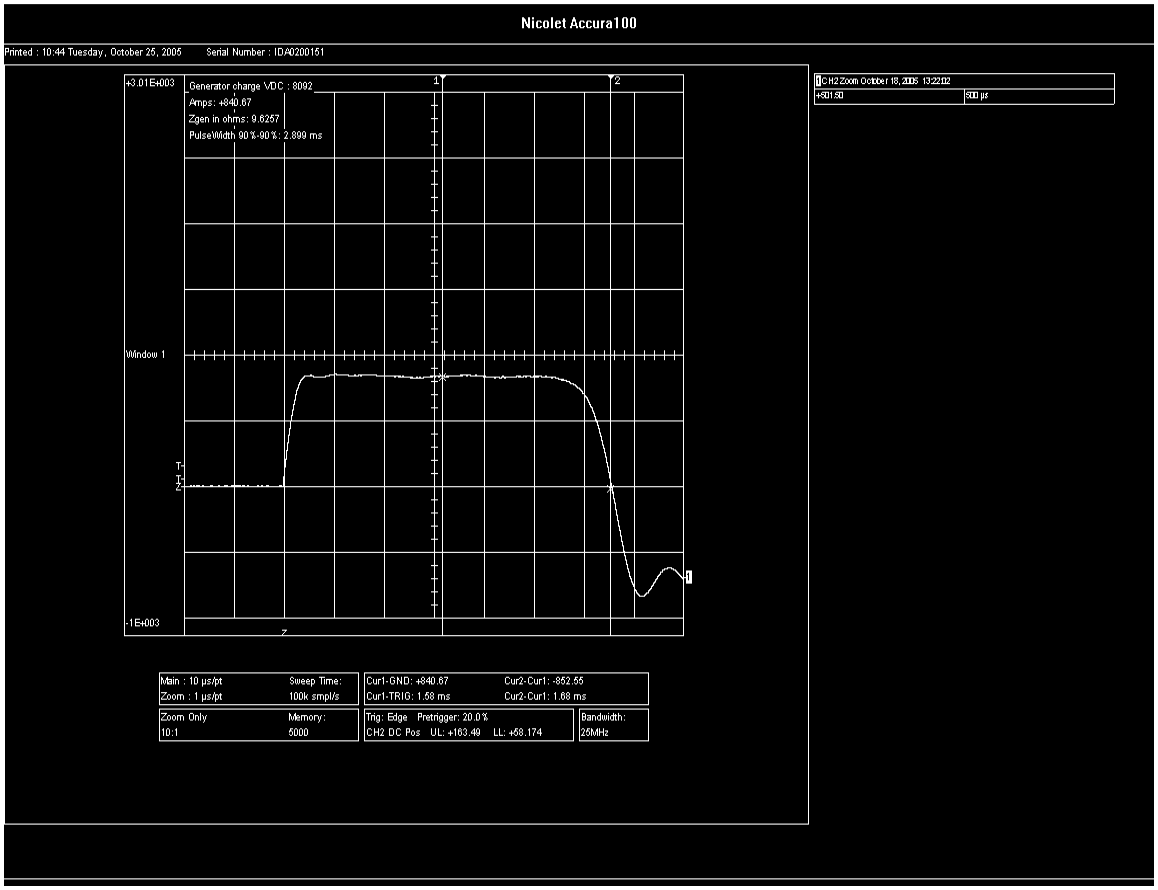


Figure 3. Oscillogram of discharge current for generator short circuit set up test

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	918	22.45	63.1	908	22.50	62.8	922	22.57	63.7
2	880	22.82	61.6	914	22.89	64.1	889	22.86	62.3

Representative waveforms of voltage and current during for line discharges and the 10 s application of U_r are shown in Figure 4. Ambient air temperature at the time of the test was 22 °C. Table 3 lists measurements made during this period. Voltage applied during the 10 s was approximately 4% above the rated voltage of the sections.

Figure 4. Oscillogram of second line discharge and application of U_r for section 1

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	17.21	41.8	0	17.14	48.9	0	16.96	37.5
1	17.25	39.6	1	17.13	48.5	1	17.06	32.9
2	17.22	39.2	2	17.12	43.9	2	17.08	31.2
4	17.22	38.0	4	17.10	43.0	4	17.12	31.2
6	17.26	38.0	6	17.09	41.8	6	17.12	29.9
8	17.21	35.8	8	17.09	40.9	8	17.12	29.9
10	17.24	35.8	10	17.10	41.3	10	17.12	29.1
Avg rms voltage during 10s	12.06 kV		Avg rms voltage during 10s	12.10 kV		Avg rms voltage during 10s	12.09 kV	

Figure 5 shows representative oscillograms of voltage and current at the beginning and end of the 30 min application of U_c'. Table 4 lists measurements of power dissipation made during this period.

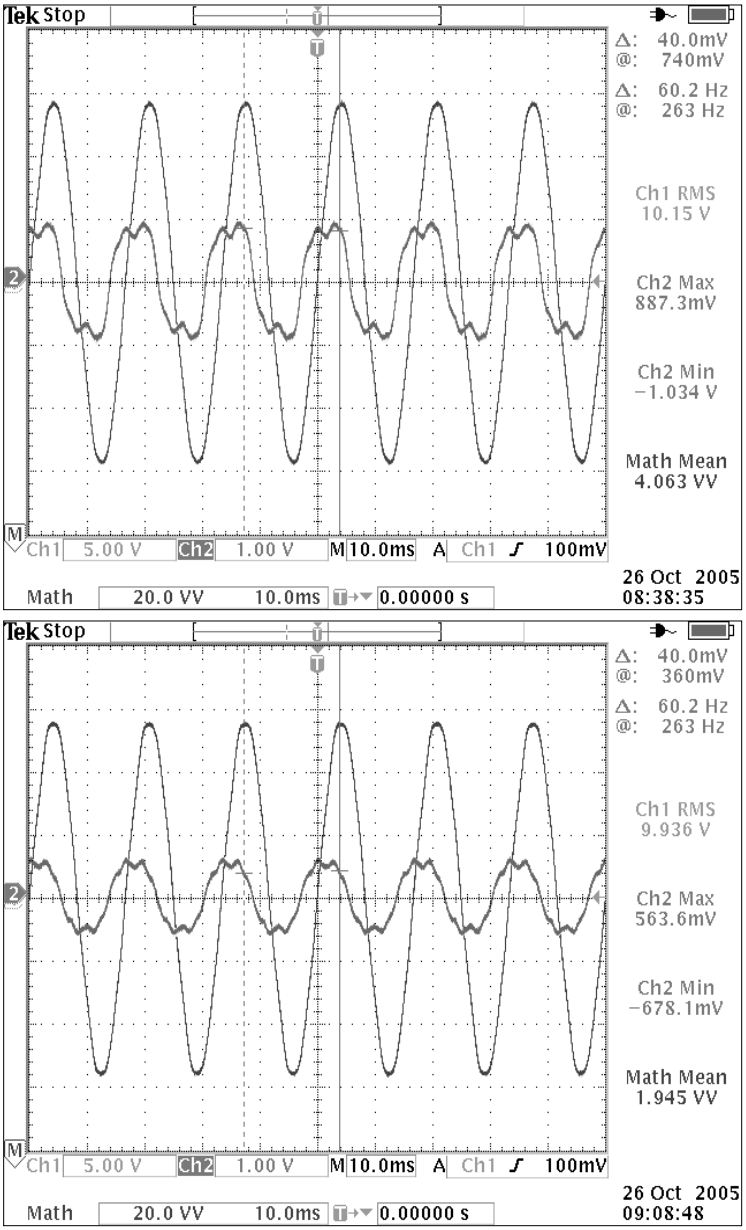


Figure 5. Oscillograms of voltage and current at the beginning and end of the 30 min application of U_c' for section 1

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	13.79	19.59	12.93
0.5	12.74	18.46	11.90
1	10.42	17.86	10.77
2	10.14	17.38	9.95
5	8.45	16.36	9.35
10	7.82	15.73	8.59
20	6.93	15.43	7.59
30	6.58	15.22	6.98

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	28.767	29.093	+ 1.1 %
2	28.767	29.061	+ 1.0 %
3	28.783	29.088	+ 1.1 %

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

HUBBELL POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1522-H-07.1
PH4 Series Polymer-housed Arrester
20,000 A Line Discharge Class 4

Short Circuit

This report records the results of type tests made on PH4 series 20 kA Line Discharge Class 4 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.1, 2006, "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: 4/12/2007

IEC TYPE TEST REPORT
Short Circuit

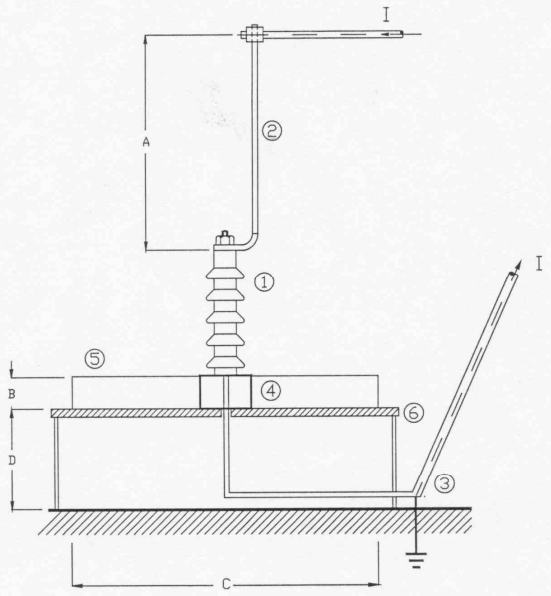
TESTS PERFORMED:
High current short circuit tests were performed at the CESI high power laboratory in Milan, Italy according to the procedures described in Clause 8.7, of IEC 60099-4. The PH4 series of arresters has a rated short circuit capability of 63000 A symmetrical. Verification of capability requires three high current tests, performed with rated short circuit current and two reduced short circuit currents (25000 A and 12000 A). For these tests, 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 used in the PH4 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 had a unit length of 1352 mm (1495 mm with terminal cap), the maximum length unit used in PH4 series arresters. Figure 1 shows the general arrangement of the test set up. Figure 2 shows one of the units in the test chamber.

All three samples successfully withstood their respective short circuit current tests with no rupturing of their housings, and with no release of components. Actual prospective rms values of test currents were 14400 A, 28000 A and 68500 A. For the rated current test, the peak of the first half cycle of test current was 162500 A, meeting the requirement that this be at least 2.5 times the rms value of the rated short circuit current (2.5 x 63000 = 157500 A). Data sheets for the tests are shown in Figures 3– 5, and associated oscillograms are shown in Figures 6 - 9.

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 : 3,00 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 2,9 m in diameter. The circular enclosure was positioned on an insulating wood platform. The pressure relief device was positioned inside of 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

D1232IG

High-current short-circuit tests with 13,7 kA for 0,20 s

Test circuit : See D046 Power factor : <0,15 Frequency : 50 Hz

Test arrangement : See D8045
To achieve the internal discharge, the Client supplied CESI with the surge arrester having the non-linear resistors bypassed by a fuse wire.
A photo resistor was used as detector of the opening time of the explosion vent.

Prospective test current			
Oscillogram		rms value	Peak value
No.	Sheets	kA	kA
16	1	14,4	41,1

Condition of the apparatus before the tests: new

Date: October 20, 2005

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.
6	17	1	PR1	0,21	26	30,5	13,7	5,10		

Condition of the apparatus after the tests:
The arrester remained connected to the supply and return circuits
No pieces were projected inside and outside the circular enclosure
The arrester structure remained almost intact

Figure 3. Data sheet for 12000 A test

D12321G

High-current short-circuit tests with 26,8 kA for 0,20 s

Test circuit : See D046 Power factor : <0,15 Frequency : 50 Hz

Test arrangement : See D8045
To achieve the internal discharge, the Client supplied CESI with the surge arrester having the non-linear resistors bypassed by a fuse wire.
A photo resistor was used as detector of the opening time of the explosion vent.

Prospective test current			
Oscillogram		rms value	Peak value
No.	Sheets	kA	kA
14	1	28,0	76,1

Condition of the apparatus before the tests: new

Date: October 20, 2005

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.
5	15	1	PR4	0,21	26	58,3	26,8	4,50		

Condition of the apparatus after the tests:
The arrester remained connected to the supply and return circuits
No pieces were projected inside and outside the circular enclosure
The arrester structure remained almost intact

Figure 4. Data sheet for 25000 A test

D1232IG

High-current short-circuit tests with 65,0 kA for 0,20 s

Test circuit : See D046 Power factor : <0,15 Frequency : 50 Hz

Test arrangement : See D8045
To achieve the internal discharge, the Client supplied CESI with the surge arrester having the non-linear resistors bypassed by a fuse wire.
A photo resistor was used as detector of the opening time of the explosion vent.

Prospective test current			
Oscillogram		rms value	Peak value
No.	Sheets	kA	kA
-	-	68,5	-

Condition of the apparatus before the tests: new

Date: October 20, 2005

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	11	1	PR5	0,21	15	162,5	65,0	3,60		

Condition of the apparatus after the tests:
The arrester remained connected to the supply and return circuits
No pieces were projected inside and outside the circular enclosure
The arrester structure remained almost intact

Figure 5. Data sheet for 63000 A test

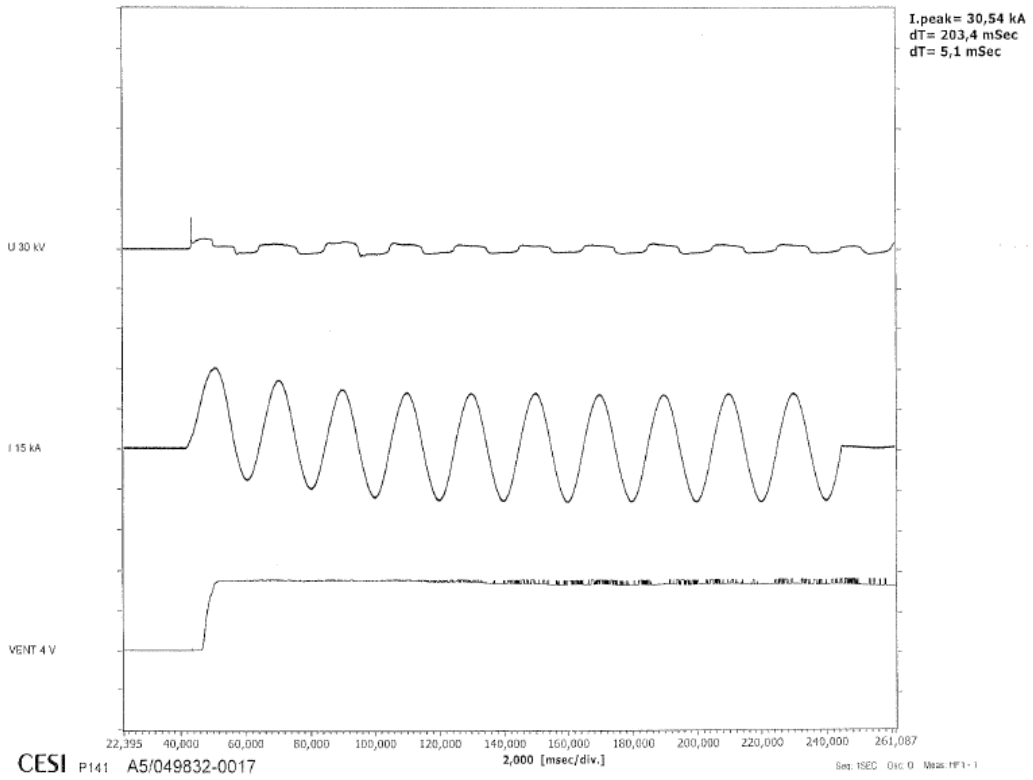


Figure 6. Oscillograms for 12000A test

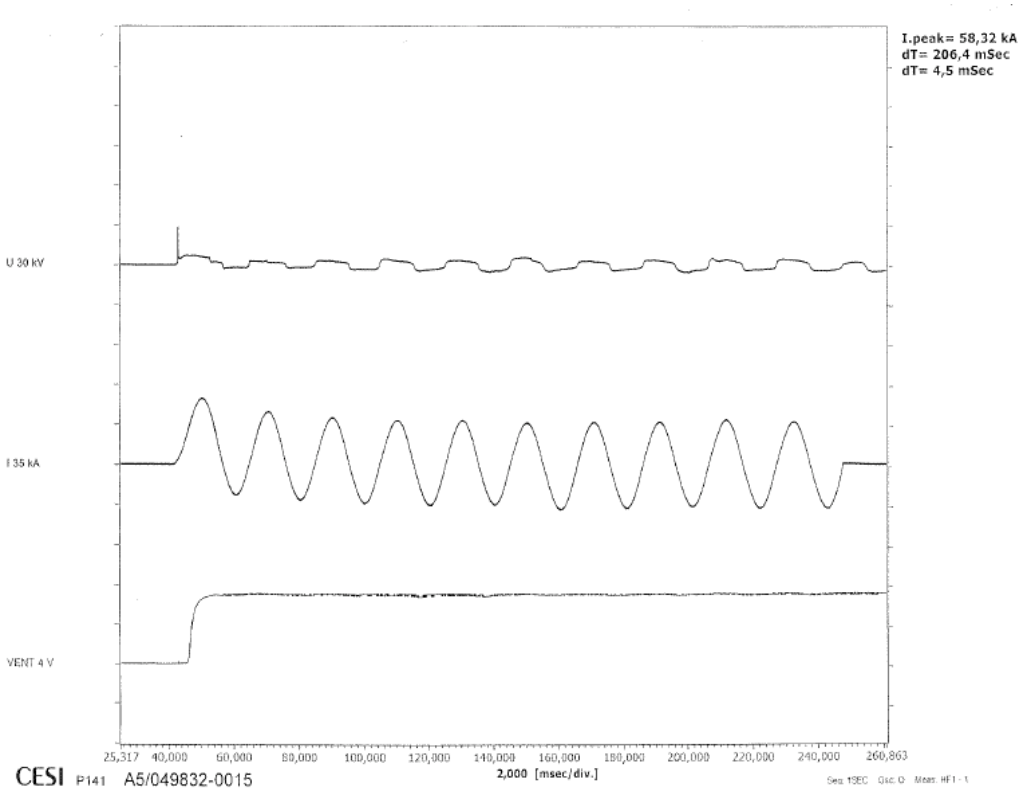


Figure 7. Oscillograms for 25000A test

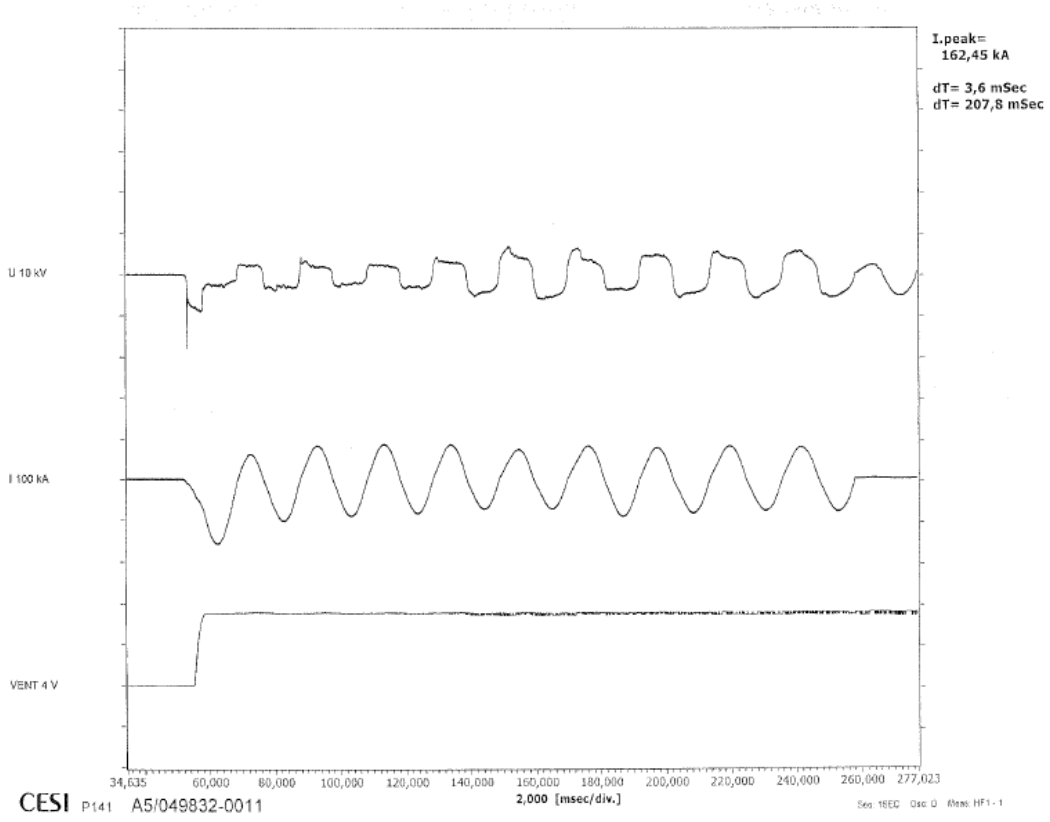


Figure 8. Oscillograms for 63000A test

HUBBELL POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1522-H-08.1
PH4 Series Polymer-housed Arrester
20,000 A Line Discharge Class 4

Internal Partial Discharge

This report records the results of type tests made on PH4 series 20 kA Line Discharge Class 4 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.1, 2006, "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: 4/12/2007

IEC TYPE TEST REPORT
Internal Partial Discharge

Clause 10.8.8 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 10.8.8 are automatically met.

Furthermore, internal partial discharge measurements performed as part of other type tests (bending moment, moisture ingress and weather ageing) confirm that the requirements of Clause 10.8.8 are met.

HUBBELL POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1522-H-09.1
PH4 Series Polymer-housed Arrester
20,000 A Line Discharge Class 4

Bending Moment

This report records the results of type tests made on PH4 series 20 kA Line Discharge Class 4 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.1, 2006, "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: 4/12/2007

IEC TYPE TEST REPORT
Bending Moment

TESTS PERFORMED:

A bending moment test was performed as described in Clause 10.8.9 of IEC 60099-4, for polymer-housed arresters with enclosed gas volume and a separate sealing system, on a fully assembled arrester unit that had been seal leak tested according to 9.1 d) of the standard. Prior to the mechanical testing, the unit was subjected to tests to determine watts loss, partial discharge, and residual voltage.

The test unit was securely mounted to the horizontal base of the test equipment and lateral (horizontal) loading was applied to the free end of the unit, in a direction perpendicular to the axis of the unit, at a rate necessary to reach the bending moment corresponding to the maximum permissible service load (MPSL) in approximately 50 s. The load was then maintained at not less than this level for about 90 s. Deflection was measured prior to release of the load. After release of load, the test sample was inspected to verify that no mechanical damage had occurred, and the load-deflection curve was examined to verify that there was no discontinuity, and that the strain condition after release of load was within allowed limits.

The sample was then subjected to the complete Moisture Ingress test described in 10.8.13 of the standard). At the conclusion of the Moisture Ingress test, the electrical and seal leak tests were repeated to verify that any changes were within allowed limits, and a visual inspection was made to verify that no mechanical damage had occurred.

RESULTS:

The PH4 series of arresters uses one, two or three units (depending on voltage rating and overall creepage distance requirements), with all units using one general polymer housing type (all housings have the same diameter and weathershed profile, differing only in height) and only one design of end fitting. The greatest bending stress is always at the bottom end of the bottom unit of the arrester, and according to the requirements of IEC 60099-4, it is therefore necessary only to perform a test on one unit.

The tested unit was the longest electrical section used in PH4 arresters, with U_r = 150 kV and U_c = 120 kV. Results of initial tests are shown in Table 1.

Table 1. Results of initial measurements

Test Parameter	Result
Watts loss at U_c	13.8 W
Residual voltage at 10 kA 8/20	340.4 kV
Internal partial discharge at 1.05 x U_c	< 10 pC
Seal leak	< 1x 10^{-7} $Pa.m^3s^{-1}$

The MPSL declared for PH4 arresters is 8000 Nm. A loading curve for the bending test is shown in Figure 1. Examination of the loading curve shows no discontinuity during the load application.

Maximum deflection of the top end of the unit during application of MPSL was 57 mm, and after the load was released the residual deflection was zero.

The unit was then subjected to the Moisture Ingress test (see EU1522-H-12 section of the PH4 arrester type test report for details and results of this test). At the conclusion of the Moisture Ingress test, initial tests conducted on the unit (watts loss, partial discharge, residual voltage and seal leak) were repeated, with results shown in Table 2.

Table 2. Results of final measurements

Test Parameter	Result	Change from initial test
Watts loss at U_c	15.0 W	+ 8.7%
Residual voltage at 10 kA 8/20	338.5 kV	- 0.6 %
Internal partial discharge at 1.05 x U_c	< 10 pC	--
Seal leak	< 1x 10^{-7} $Pa.m^3s^{-1}$	--

The change in watts loss and residual voltage from the values initially measured were well within the maximum allowed change of 20% and 5%, respectively. Additionally, partial discharge and seal leak rate were found to be below the allowed limits of 10 pC and 1x 10^{-7} $Pa.m^3s^{-1}$, respectively.

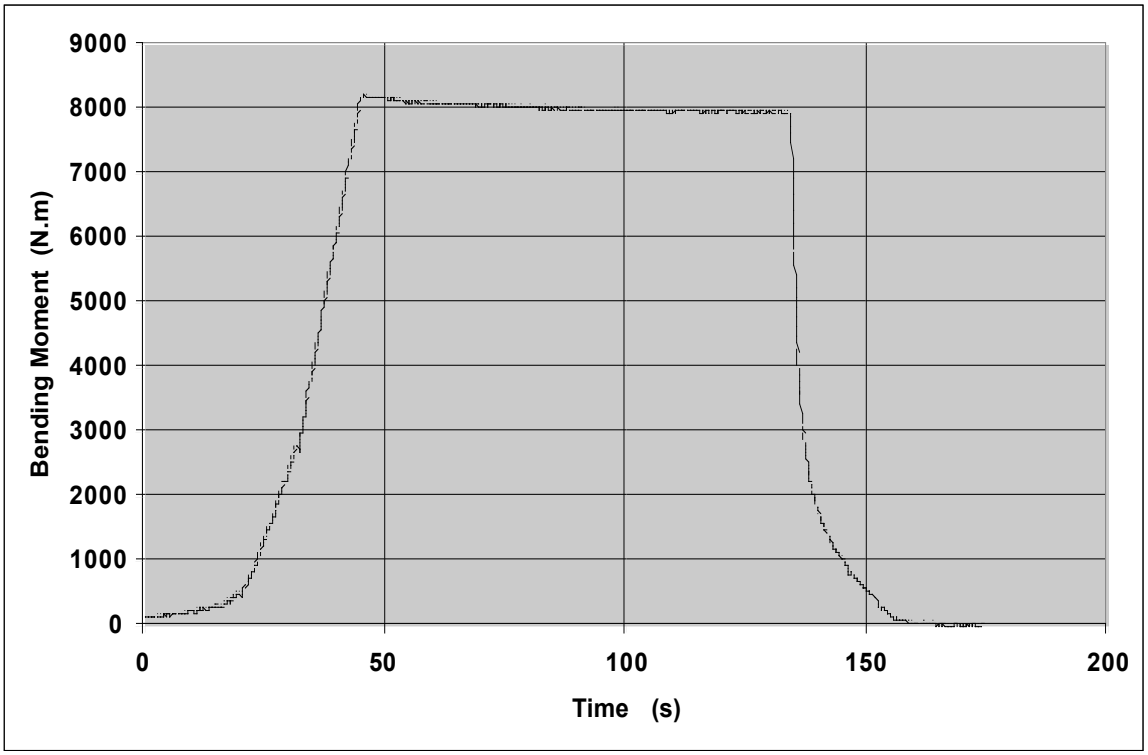


Figure 1. Bending moment at bottom end of unit
Max design moment at MPSL: 8000 Nm

HUBBELL POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1522-H-10.1
PH4 Series Polymer-housed Arrester
20,000 A Line Discharge Class 4

Seal Leak Rate

This report records the results of type tests made on PH4 series 20 kA Line Discharge Class 4 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.1, 2006, "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: 4/12/2007

IEC TYPE TEST REPORT
Seal Leak Rate

Clauses 10.8.11 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 PH4 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 PH4 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 10.8.11 are automatically met.

HUBBELL POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1522-H-11.1
PH4 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 4

Radio Influence Voltage (RIV)

This report records the results of type tests made on PH4 series 20 kA Line Discharge Class 4 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.1, 2006, "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: 4/12/2007

IEC TYPE TEST REPORT
Radio Influence Voltage (RIV)

TESTS PERFORMED:
A fully-assembled arrester, with voltage rating U_r of 312 kV and continuous operating voltage U_c of 249.6 kV, was subjected to the RIV test as prescribed in Clause 8.11 of IEC 60099-4. This sample represents an arrester of the longest length and highest voltage stress in the PH4 series of arresters. The voltage application was as follows:

- raised to 287 kV (1.15 U_c)
- lowered to 262 kV (1.05 U_c)
- held at 262 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 262 kV (1.05 U_c)
- held at 262 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 only marginally above the background noise level. IEC 60099-4 allows a maximum RIV level of 2500 µV.

Figure 1. 312 kV rated arrester

Table 1. Measured RIV values

Test condition	Test voltage (kV rms)	RIV (µV)
Open circuit		2-4
Arrester installed	287	6-20
Arrester installed	262 (0 min)	4-10
Arrester installed	262 (5 min)	4-10
Arrester installed	235	4-10
Arrester installed	208	2-4
Arrester installed	181	2-4
Arrester installed	154	2-4
Arrester installed	125	2-4
Arrester installed	154	2-4
Arrester installed	181	2-4
Arrester installed	208	4-10
Arrester installed	235	4-10
Arrester installed	262 (0 min)	4-10
Arrester installed	262 (5 min)	4-10
Arrester installed	235	4-10
Arrester installed	208	2-10
Arrester installed	181	2-4
Arrester installed	154	2-4
Arrester installed	125	2-4

HUBBELL POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1522-H-12.1
PH4 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 4

Moisture Ingress

This report records the results of type tests made on PH4 series 20 kA Line Discharge Class 4 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.1, 2006, "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: 4/12/2007

IEC TYPE TEST REPORT
Moisture Ingress

TESTS PERFORMED:

A fully-assembled arrester unit, with voltage rating U_r of 150 kV and continuous operating voltage U_c of 120 kV, was subjected to the Moisture Ingress test as prescribed in Clause 10.8.13 of IEC 60099-4. The overall height of the unit was 1350 mm, representing the longest mechanical unit used in the PH4 series of arresters.

Initial measurements were made of watts loss at U_c, partial discharge at 1.05 times U_c after 10 s at U_r, and residual voltage at 10 kA. The sample was then subjected to a bending moment test at MPSL of 8000 N.m (as part of the Bending Moment test described in the EU1522-H-09 section of the PH4 type test report), and was subsequently subjected to thermomechanical preconditioning, consisting four 24 h periods at, respectively, +60°C, -25°C, +45°C and –40°C. During each of the 24 h periods, cantilever load was applied to the top end of the sample to produce a bending moment at the bottom end of at least 4 kNm, the maximum continuous bending moment defined for PH4 arresters. The load was applied in a different direction, designated respectively as 0°, 180°, 270°, and 90°, for each of the four periods.

The sample was then immersed in boiling water, with initial salt concentration of 1 kg/m^3, for 42 h. At the end of this period, the sample remained immersed until the water had cooled to 50°C, after which time the initial measurements of watts loss, partial discharge and residual voltage were repeated.

RESULTS:

Table 1 shows the results of initial measurements. Table 2 shows the deflections measured during each of the four 24 h periods of preconditioning. Table 3 shows the results of the electrical measurements conducted after removal of the sample from the water.

Table 1. Results of initial measurements

Test Parameter	Result
Watts loss at U_c	13.8 W
Residual voltage at 10 kA 8/20	340.4 kV
Internal partial discharge at 1.05 x U_c	< 10 pC

Table 2. Deflections measured during 24 h periods

Period	Temperature	Load direction	Beginning of period		End of period		
			Bending moment	Maximum deflection	Bending moment	Maximum deflection	Residual deflection
			(Nm)	(mm)	(Nm)	(mm)	(mm)
1	+ 65 °C	0°	4531	23.4	4483	25.4	0
2	- 25 °C	270°	4629	24.2	4671	25.1	4.4
3	+ 45 °C	180°	4552	24.1	4465	27.6	5.4
4	- 40 °C	90°	4629	24.1	4647	26.3	4.3

Table 3. Results of final measurements

Test Parameter	Result	Change from initial test
Watts loss at U_c	15.0 W	+ 8.7%
Residual voltage at 10 kA 8/20	338.5 kV	- 0.6 %
Internal partial discharge at 1.05 x U_c	< 10 pC	--

The change in watts loss and residual voltage from the values initially measured were well within the maximum allowed change of 20% and 5%, respectively.

HUBBELL POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1522-H-13.1
PH4 Series Porcelain-housed Arrester
20,000 A Line Discharge Class 4

Weather Ageing

This report records the results of type tests made on PH4 series 20 kA Line Discharge Class 4 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.1, 2006, "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: 4/12/2007

IEC TYPE TEST REPORT
Weather Ageing

TESTS PERFORMED:
A fully-assembled arrester unit, with voltage rating U_r of 144 kV and continuous operating voltage U_c of 115.2 kV, was subjected to the Weather Ageing test series A (1000 h salt fog) as prescribed in Clause 10.8.14 of IEC 60099-4. The test was performed at the CESI high voltage laboratory in Milan, Italy.

An initial measurements were made of reference voltage, at reference current of 17 mA_{pk}, and internal partial discharge at 1.05 times U_c after 10 s at U_r.

The test sample, was energized at U_c = 115.2 kV_{rms} for a total of 1000 h in the test room filled with salt fog having the following characteristics:

- Salinity of water solution: 10 kg/m^3
- Water flow rate: 0.4 ± 0.1 $l/h*m^3$

The salt fog was not directly spayed on the test sample. A schematic of the test arrangement is shown in Figure 1 (two other arrester units were tested at the same time).

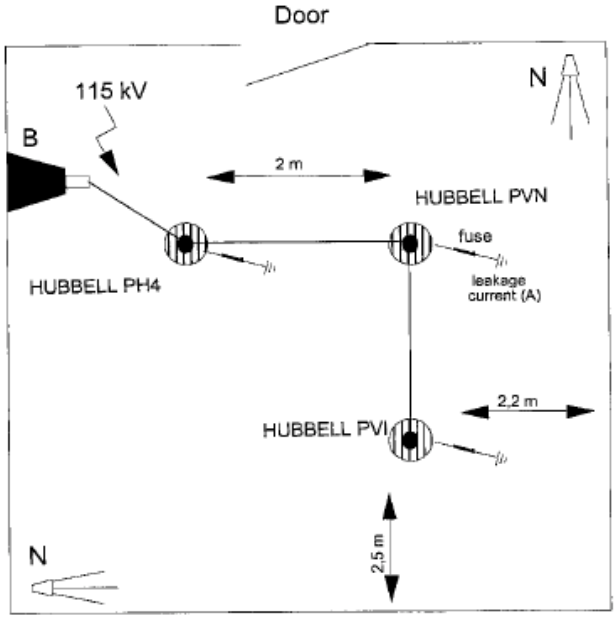


Figure 1. Test chamber layout

Visual observations of the condition of the silicone rubber housing were made after 500 h and at 1000 h. Measurements of reference voltage and internal partial discharge were repeated at the conclusion of the 1000 h test period.

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.

No tracking or shed puncture, and only very light erosion occurred in the first 500 h. No tracking or shed puncture, and only light erosion occurred during the remaining 500 h. No flashovers occurred during the 1000 h test period.

Table 1 shows the initial and final values of reference voltage and internal partial discharge. The requirements of not more than 5% change in reference voltage and partial discharge levels of less than 10 pC were met.

Table 1. Initial and final electrical measurements

Measured quantity	Initial	Final	Result
Reference voltage	147.6 kV	151.5 kV	+ 2.6% change
Partial discharge	1.2 pC	1.6 pC	< 10 pC

HUBBELL POWER SYSTEMS, INC.

IEC Type Test Report
Report No. EU1522-H-14.1
PH4 Series Polymer-housed Arrester
20,000 A Line Discharge Class 4

Power Frequency Voltage Versus Time

This report records the results of type tests made on PH4 series 20 kA Line Discharge Class 4 arresters, rated up to 420 kV. Tests were performed in accordance with procedures of IEC Standard 60099-4, Ed. 2.1, 2006, "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: 4/12/2007

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 resistors in series. 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 each 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 one time duration of elevated voltage application on each test section. A different duration was used for each test section. 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 4 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 sections and the corresponding transmission line parameters used for the test. U_c for the PH4 series of arresters has been established as 0.78 times the lowest acceptable reference voltage in routine tests, and U_r has been established as 1.25 times U_c.

The minimum energy required for each line discharge for Class 4 arresters is determined from the following formula given in Clause 8.4.2 of IEC 60099-4

$$W = U_{res} \times (U_L - U_{res}) \times 1/Z \times T$$

where U_{res} is the switching impulse residual voltage at 500 A.

Table 1. Test section and transmission line parameters

Parameter	Sect 1	Sect 2	Sect 3
Switching impulse residual voltage (kV) U_{res}	21.707	21.707	21.707
Reference Current (mA) I_{ref}	17	17	17
Reference Voltage (kV_c) V_{ref}	17.50	17.50	17.50
COV (kV rms) U_c	9.65	9.65	9.65
Adjusted COV 9kVrms) Uc'	9.98	10.16	9.77
Rating (kV rms) U_r	12.06	12.06	12.06
Arrester Classification (kA)	20	20	20
Line Discharge Class	4	4	4
Virtual Duration of Peak (μs, 90-90%) - min	2800	2800	2800
Surge Impedance (Ω) Z_g - max (0.8 U_r)	9.65	9.65	9.65
Charging Voltage (kV) U_L – min (2.6 U_r)	31.36	31.36	31.3
Energy required (kJ) - min	60.8	60.8	60.8

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 = 8,092 V / 840.67 A = 9.628 Ω Virtual Duration of Peak = 2899 μs

Tables 2 and 3, 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 Figures 2 and 3 (oscillograms for test section 3, subjected to 129 s of elevated voltage).

Figure 4 shows the three test points (elevated voltages for 1s, 10 s and 129 s) superimposed on the characteristic of power frequency voltage vs. time for PH4 series of arresters.

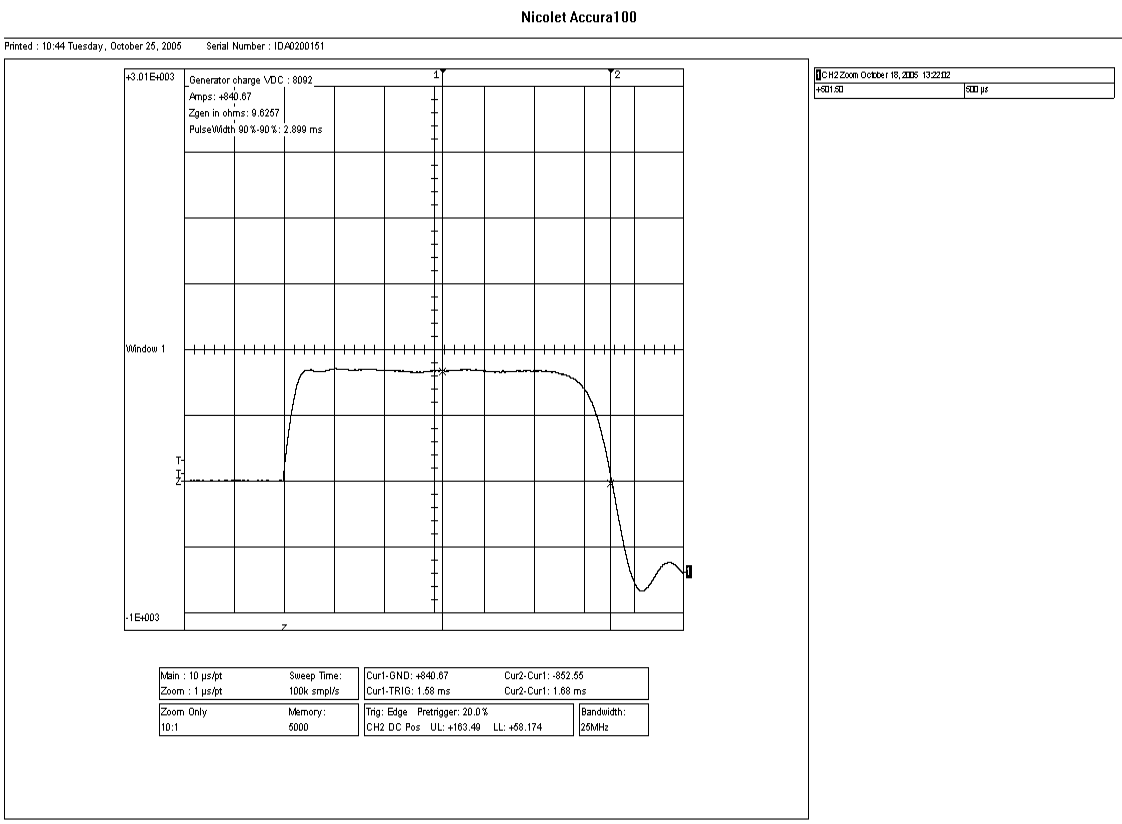


Figure 1. Oscillogram of discharge current for generator short circuit set up test

Table 2. Measurements of voltage and current during application of elevated voltage

Elapsed Time	Applied voltage		Current
(s)	(kV rms)	(pu Ur)	(mA peak)
0.1	13.75	1.14	8200
0.1	13.72	1.13	8253
0.2	13.82	1.14	8084
0.3	13.86	1.15	7968
0.4	13.87	1.15	7968
0.5	13.86	1.15	7915
0.6	13.86	1.15	7853
0.8	13.87	1.15	7959
0.9	13.87	1.15	7942
1.0	13.91	1.15	8111
1.1	13.88	1.15	8146

Elapsed Time	Applied voltage		Current
(s)	(kV rms)	(pu Ur)	(mA peak)
0.1	12.95	1.07	738
1.0	13.03	1.08	797
2.0	13.04	1.08	783
3.0	13.05	1.08	819
4.1	13.02	1.08	763
5.0	13.02	1.08	764
6.1	13.03	1.08	794
7.0	13.04	1.08	799
8.1	13.03	1.08	779
9.2	13.05	1.08	840
10.2	13.04	1.08	858

Elapsed Time	Applied voltage		Current
(s)	(kV rms)	(pu Ur)	(mA peak)
0	12.19	1.01	88
21	12.19	1.01	86
45	12.19	1.01	81
66	12.19	1.01	86
83	12.19	1.01	87
92	12.18	1.01	91
103	12.17	1.01	92
114	12.18	1.01	96
122	12.19	1.01	96
129	12.20	1.01	105

Table 3. Measurements of power dissipation and current made during 30 min at U_c'

1 s elevated voltage			
Elapsed time	Applied voltage	Power dissipation	Current
(min)	(kV rms)	(W)	(mA peak)
0	10.07	32.9	8.3
0.5	10.06	29.3	7.3
1.0	10.08	27.8	7.0
2.0	10.07	26.3	6.6
5.5	10.03	23.3	6.0
10.0	10.04	22.3	5.5
21.0	10.05	20.5	5.4
30.0	10.03	19.3	5.1

10 s elevated voltage			
Elapsed time	Applied voltage	Power dissipation	Current
(min)	(kV rms)	(W)	(mA peak)
0	10.24	42.4	10.3
0.5	10.28	39.6	10.1
1.0	10.11	33.7	8.8
2.0	10.10	31.8	8.2
5.5	10.12	30.5	7.8
10.5	10.13	29.8	7.5
21.0	10.13	28.7	7.6
30.5	10.11	28.6	7.4

129 s elevated voltage			
Elapsed time	Applied voltage	Power dissipation	Current
(min)	(kV rms)	(W)	(mA peak)
0	9.83	27.7	6.8
0.5	9.83	27.1	7.0
1.0	9.84	26.4	6.7
2.0	9.84	25.6	6.7
5.5	9.79	23.0	6.1
10.5	9.81	21.6	5.6
21.0	9.82	19.4	5.2
31.0	9.83	18.1	4.8

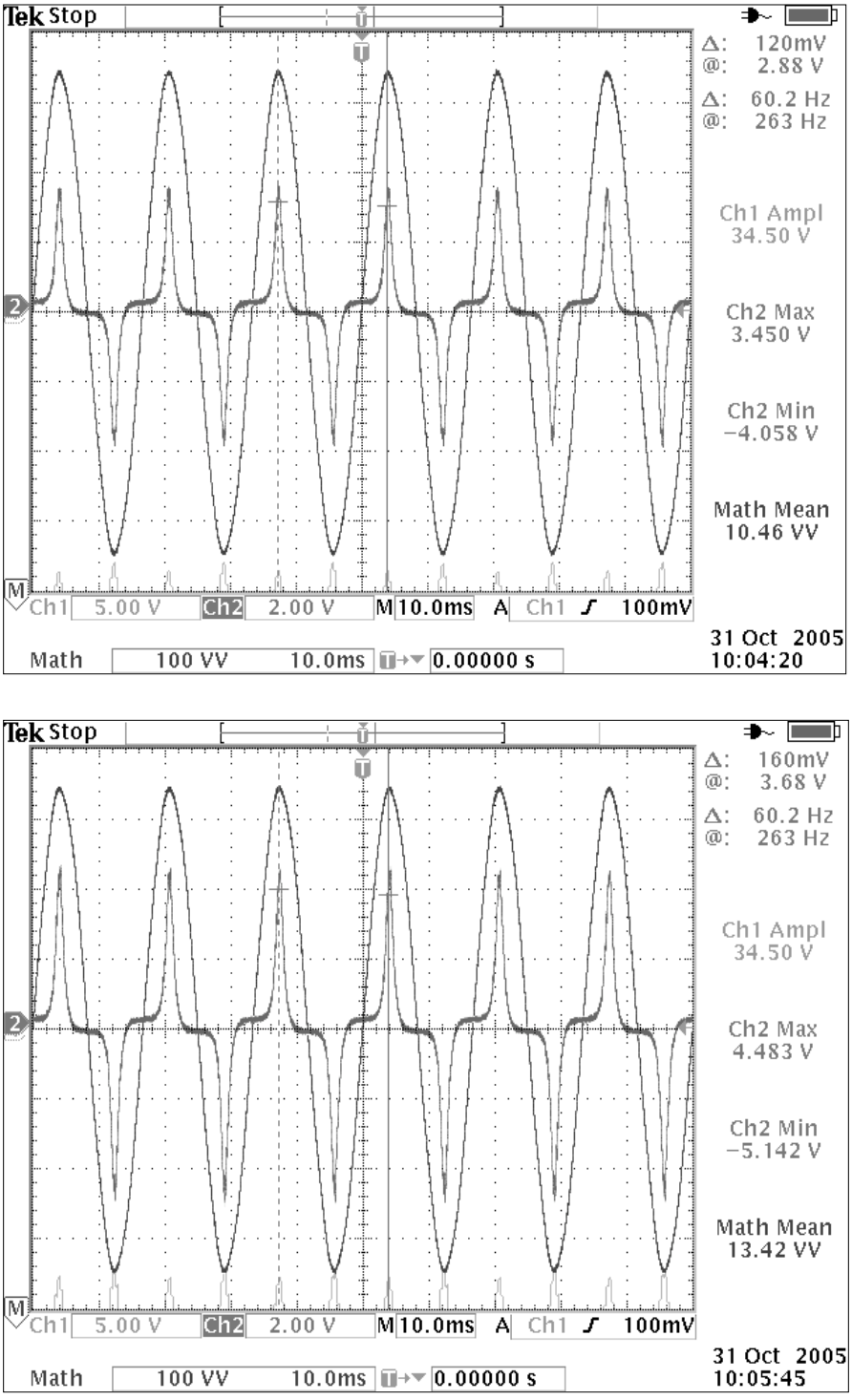


Figure 2. Oscillograms of voltage and current after 45 s and 129 s of application of elevated voltage for section 3

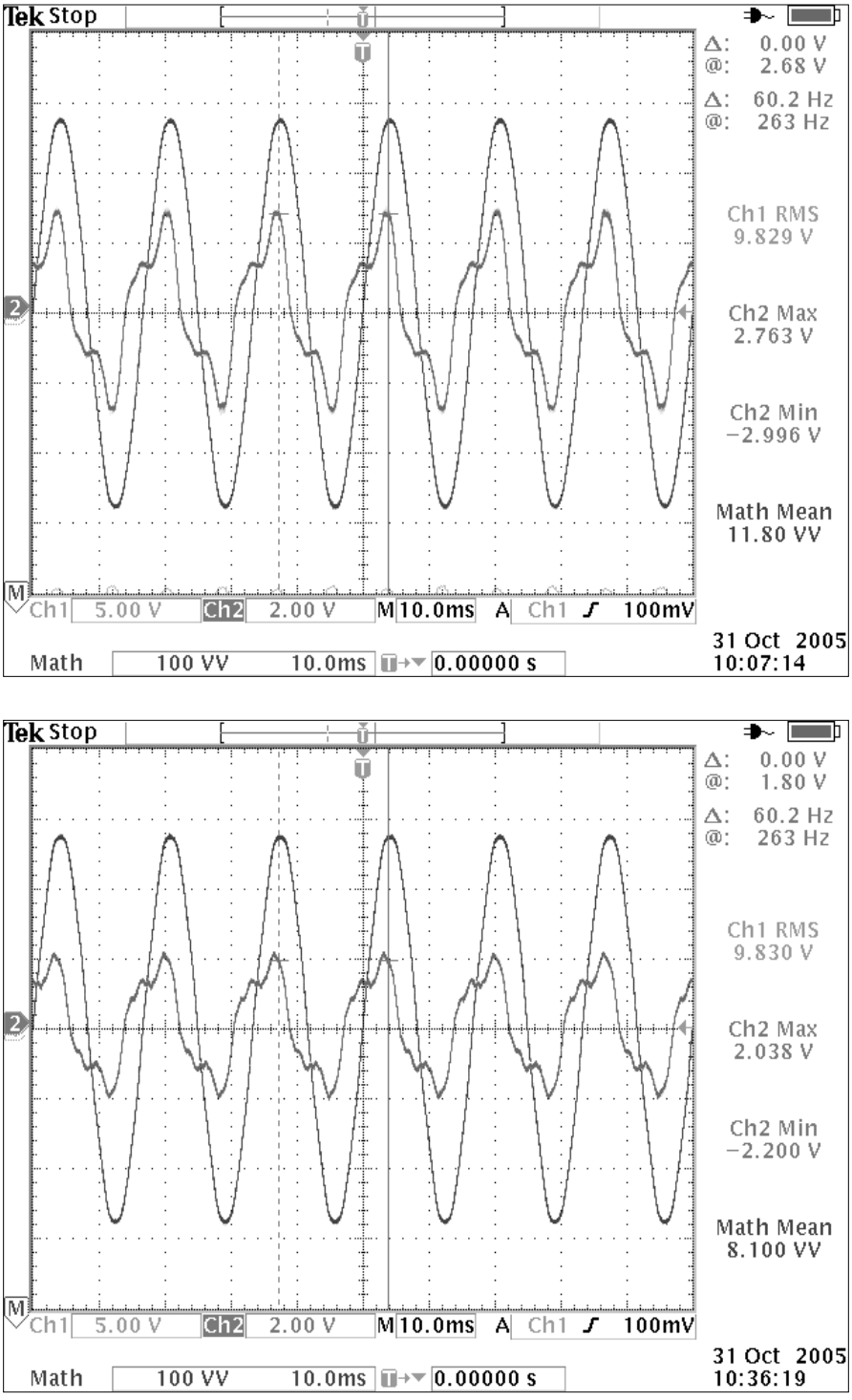


Figure 3. Oscillograms of voltage and current after 1 min and after 30 min of application of U_c' following 129 s application of elevated voltage

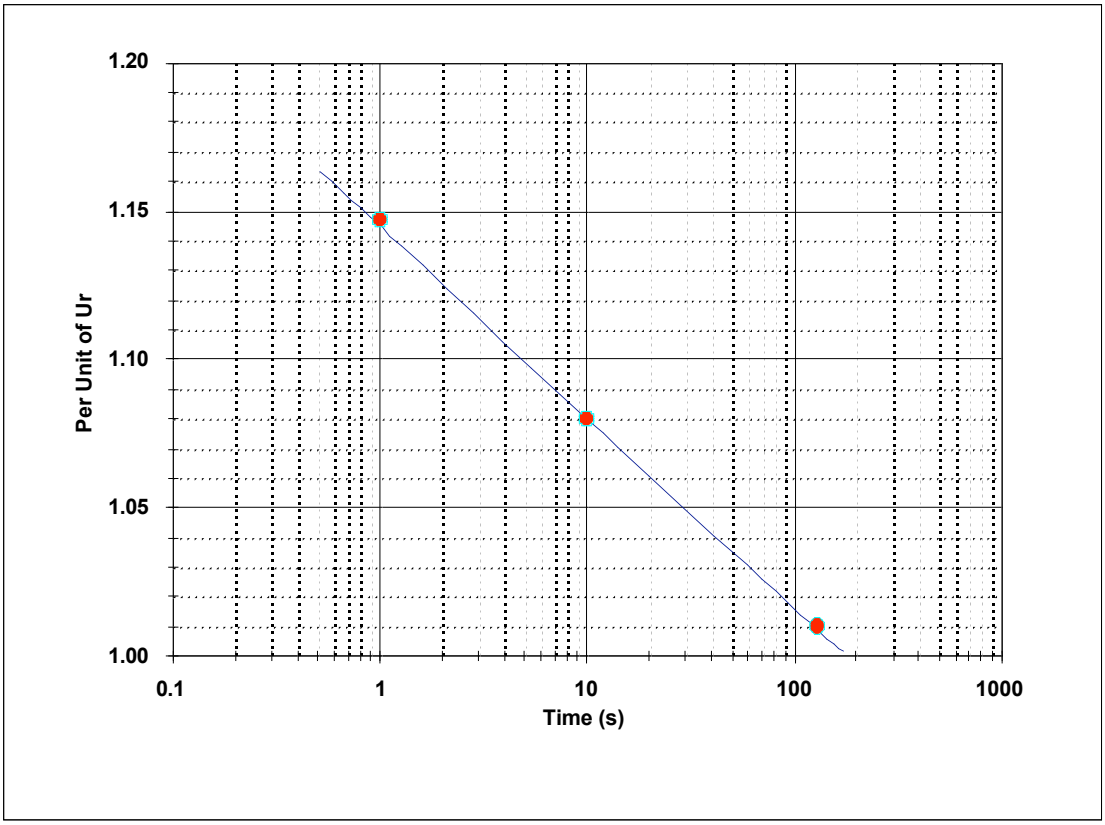


Figure 4. Power frequency voltage vs. time characteristic for PH4 series arresters, with test points for 1 s, 10 s and 129 s