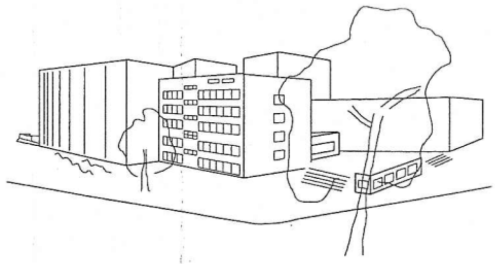
Bereich Hochspannungsprüftechnik

Institut für Elektroenergiesysteme und Hochspannungstechnik



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Test Report Nº 2009-125/1

Type Test
of a 145 kV- Cross Bonding Joint
Type SC 145-II

Client: 3 M Deutschland GmbH
Carl-Schurz-Str.1

41453 Neuss

Reporter: Dr.-Ing. R. Badent
Dr.-Ing. B. Hoferer

This report includes 25 numbered pages and is only valid with the original signature. Copying of extracts is subject to the written authorization of the test laboratory. The test results concern exclusively the tested objects.

1 Purpose of Test

One 145 kV cross bonding joint type SC 145-II was subjected to a type test according to IEC 60840 04/2004, " type test on accessories".

2 Miscellaneous Data

Test object:	*1 cold shrink crossbond joint with cold shrink rejacketing* U_m = 145 kV, Type SC 145-II, Figure 2.1 Type of the cable: single core XLPE cable with copper conductor 1x400RMV 76/132/145 kV, Figure 2.2 Cable length between accessories: 6 m	
Manufacturer:	3 M China Ltd Tian Lin Road Shanghai 200233 P.R.C.	
Place of test:	*Institute of Electric Energy Systems and High-Voltage Technology* – University of Karlsruhe, Kaiserstraße 12 – 76128 Karlsruhe	
Testing dates:	Delivery:	07.12.2009
	Mounting:	07.12. - 16.12.2009
	Test date:	14.01. - 12.03.2010
Atmospheric conditions:	Temperature:	19°C - 23°C
	Air pressure:	980 - 1020 mbar
	rel. humidity:	35% - 50%
Representatives	*Clients representative* Dipl.-Ing. J. Weichold *Representatives responsible for the tests* Dr.-Ing. R. Badent ; Dr.-Ing. B. Hoferer; Mr. O. Müller	

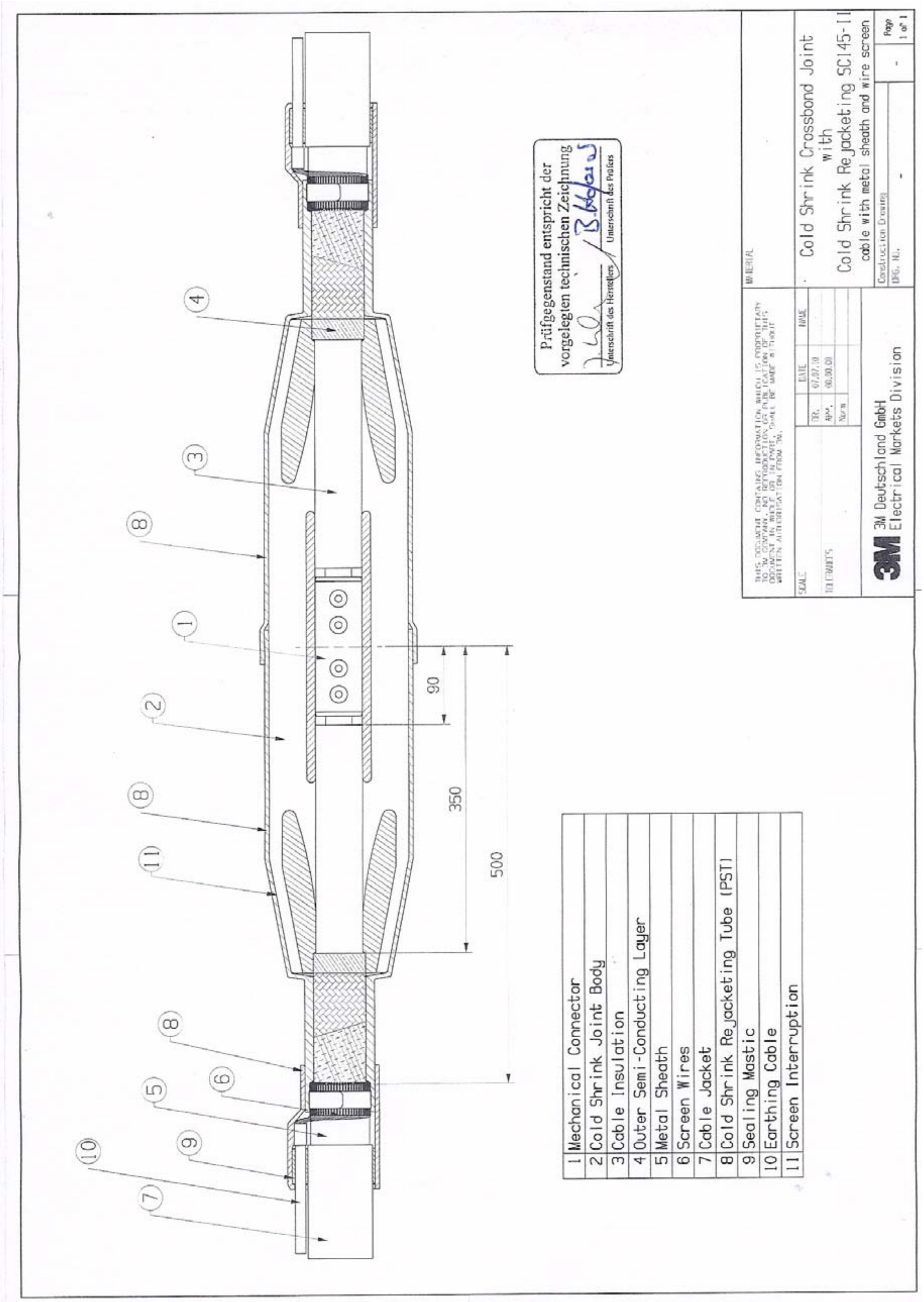

Figure 2.1: Cross bonding joint type SC 145-II

Prüfgegenstand entspricht der vorgelegten technischen Zeichnung
Unterschrift des Herstellers / Unterschrift des Prüfers

Identification of Test Cable

Rated voltage U_0/U (U_m):	76/132 (145) kV		
Construction:	☒ 1-core	☐ 3-core	
Conductors:	☐ Al	☒ Cu	
	☒ Stranded	☐ Solid	
	Cross-section:	400 mm²	
Insulation:	☒ XLPE	☐ PE	☐ EPR
Insulation screen:	☒ Bonded	☐ Strippable	☐ Graphite
Metallic screen:	☒ Wires	☐ Tape	☐ Extruded
	Cross-section:	205 mm²	
Armour:	☐ Wire	☐ Tape	
Metallic sheath/ Oversheath:	☒ Lead	☐ Al	☐ Laminated
	☐ PVC	☒ PE	
	☒ Conductive Layer		

Diameters:			
	Conductor	23,6	mm
	Insulation	54,8	mm
	Insulation screen	56,9	mm
	Oversheath	75,0	mm

Cable marking:

Figure 2.2: Cable data sheet

Tests: Test volume, chronological order and requirements conform to IEC 60840 04/2004 type test on accessories.

Pos. 1 Check on Insulation Thickness

Pos. 2 Partial Discharge Test
$\hat{u} / \sqrt{2}$ = 1,75 U_0 = 133 kV 10s thereafter ;
$\hat{u} / \sqrt{2}$ = 1,5 U_0 = 114 kV
no detectable discharge

Pos. 3 Heating cycle voltage test
Load cycle: 24 h
8h loading up to 95°C - 100 °C conductor temperature with at least 2h at 95°C-100°C
16h cooling
Test voltage: $\hat{u} / \sqrt{2}$ = 2,0 U_0 = 152 kV
Number of cycles: 20

Pos. 4 Partial Discharge Test
$\hat{u} / \sqrt{2}$ = 1,75 U_0 = 133 kV 10s thereafter ;
$\hat{u} / \sqrt{2}$ = 1,5 U_0 = 114 kV
no detectable discharge

Pos. 5 Partial Discharge Test at elevated temperature
8h loading up to 95°C - 100 °C conductor temperature with at least 2h at 95°C-100°C
$\hat{u} / \sqrt{2}$ = 1,75 U_0 = 133 kV 10s thereafter ;
$\hat{u} / \sqrt{2}$ = 1,5 U_0 = 114 kV
no detectable discharge

Pos. 6 Lightning impulse voltage test at elevated temperature
T = 95°C-100°C, at least 2h, $\hat{u}$ = 650 kV,
10 impulses each polarity

Pos. 7 AC-voltage withstand test during cooling period
$\hat{u} / \sqrt{2}$ = 2,5 U_0 = 190 kV, t = 15 min

Pos.8 Test of outer protection of buried joints

Pos. 8a Water immersion and heat cycling
Raising the water temperature up to 70-75°C with at least 5h at 70-75°C, thereafter cooling to within 10°C above ambient temperature.
Number of cycles: 20
according to IEC 60840, Annex H.3

Pos. 8b DC-voltage test in water of the sectionalizing joint insulation section
U = - 20 kV, 1 min
outer protection, conductor and screen of the concentric cross bonding cable
U = - 20 kV, 1 min
according to IEC 60840, Annex H.4.2.1

Pos. 8c Lightning impulse voltage test of the sectionalizing joint insulation section
û = 75 kV, 10 impulses each polarity
outer protection, conductor and screen of the concentric cross bonding cable
û = 37,5 kV, 10 impulses each polarity
according to IEC 60840, Annex H.4.2.2

Pos. 9 Accessory examination

3 Mounting

The cable preparation, assembling and mounting of the cable system was accomplished by technicians of 3 M Deutschland GmbH. The length of free cable between accessories was 6 m.

4 Test Setup

4.1 Check on Insulation Thickness

The insulation thickness was measured as described in IEC 60811-1-1, chapter 8.1. For measuring the insulation thickness a profile projector with a magnification of 10 was used which allowed a reading of 0.001 mm.

4.2 AC Voltage Withstand Test

The test voltage was generated by a 360-kVA transformer. The voltage was measured with a capacitive divider (C_H = 351 pF; ratio = 10.000:1) and a peak voltmeter reading $\hat{u} / \sqrt{2}$. The primary side of the AC-transformer was connected to a motor-generator set consisting of a variable frequency DC motor and a synchronous generator with variable excitation. The generator delivers voltages from 0 ... 500 V with currents up to 1000 A.

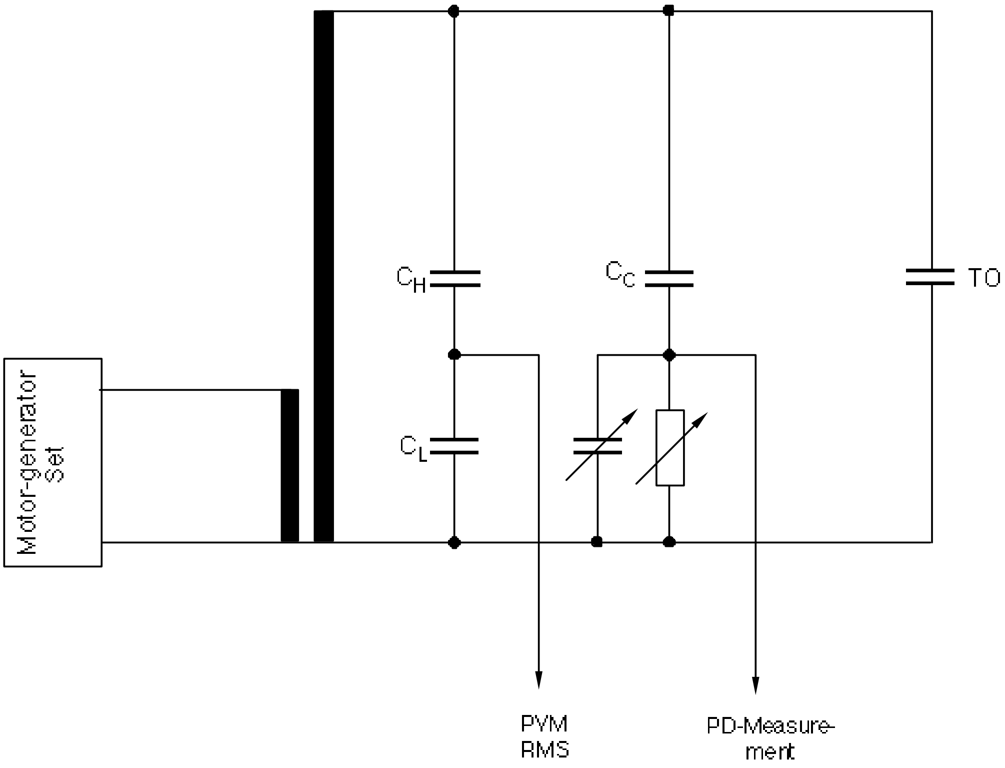

Figure 4.2: Test-setup for AC-voltage withstand test and PD measurement

AC-transformer:	500V/300kV; S_N = 360 kVA
Voltage measurement:	C_H = 351 pF; ratio 10.000:1 uncertainty 3 %
PD measurement:	C_C = 1000 pF; U_N = 800 kV_{rms} uncertainty 5 %

4.3 Partial-Discharge Test

The PD-measurement was performed with an analog bridge according to *Kreuger*, Figure 4.3. External PDs producing common mode signals at the detector are rejected by the differential amplifier. Internal PDs represent differential mode signals and are amplified. The background noise level at 114 kV_{rms} was 2.0 pC.

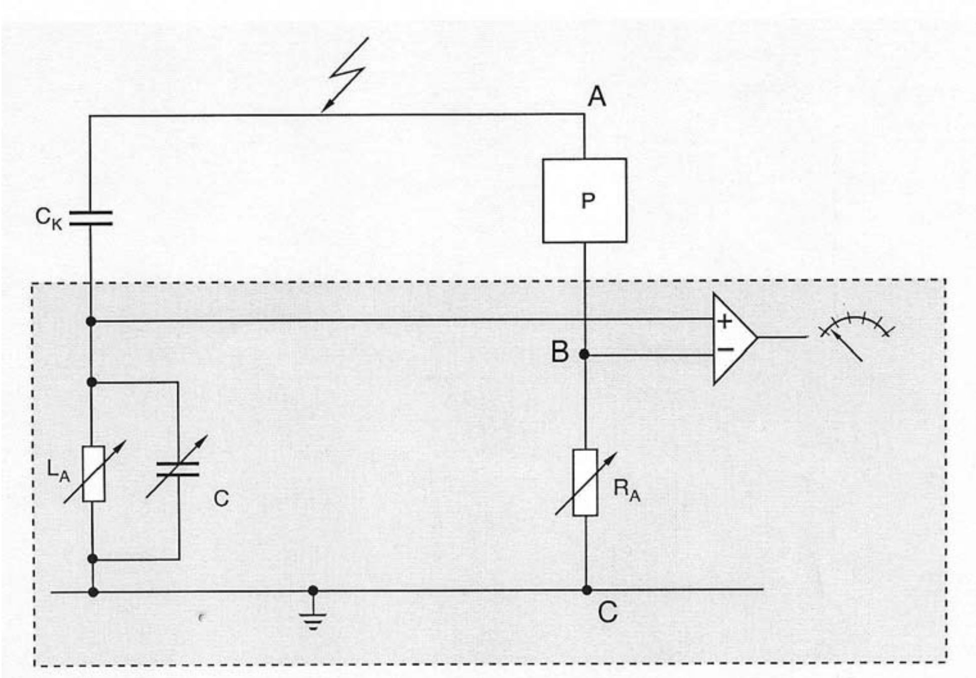

Figure 4.3: Scheme of PD test circuit
P : Test object
C_C: Coupling Capacitor

For balancing the bridge a calibrating impulse with q_A = 10.000 pC is applied between the terminals A (high-voltage) and C (ground) and the amplifier output is minimized. A pulse between the terminals A and C corresponds to an external PD. For the calibration a PD pulse, q_A = 5 pC, is applied between A and B. Subsequently, the amplifier output of the PD measuring unit is adapted to the applied pulse.

4.4 Cyclic Current Loading

According to IEC 60840 the test objects must be heated by a current which provides the permitted service temperature of the tested cable plus 5 K - 10 K, that means 95°C - 100°C, for XLPE-cable. The required heating current I was determined via a dummy cable. A 6 m sample of the cable used for the test, was provided with a 1 mm diameter drilling hole down to the center conductor. The temperature was measured with thermocouples NiCr-Ni. Two other thermocouples were installed on the conductor of the reference cable 0.5 m away from the middle and 1.0 m away from the middle. The difference between the three readings was less than 1°C. Furthermore two additional thermocouples NiCr-Ni were placed on the outer sheath of the cable, one on the dummy and one on the test loop. The maximum heating current was I = 1350 A, 8h. Current inception was accomplished by a transformer (U_1 = 400 V; U_2 = 20 V) which used the cable as secondary winding. The current was regulated by a control unit and measured by a current transformer, 3000:1, and a digital multimeter. The measurement uncertainty was 1%.

4.5 Lightning Impulse Voltage Test

For lightning impulse testing of the cable system 7 stages of a Marx generator (Haefely) with a maximum cumulative charging voltage of U = 1400 kV and a maximum impulse energy of E_{max} = 70 kWs were used. The crest value of the impulse voltage was measured by a damped capacitive divider and a subsequent impulse peak voltmeter (Haefely). The time to crest and the time to half value were evaluated from the oscillographs.

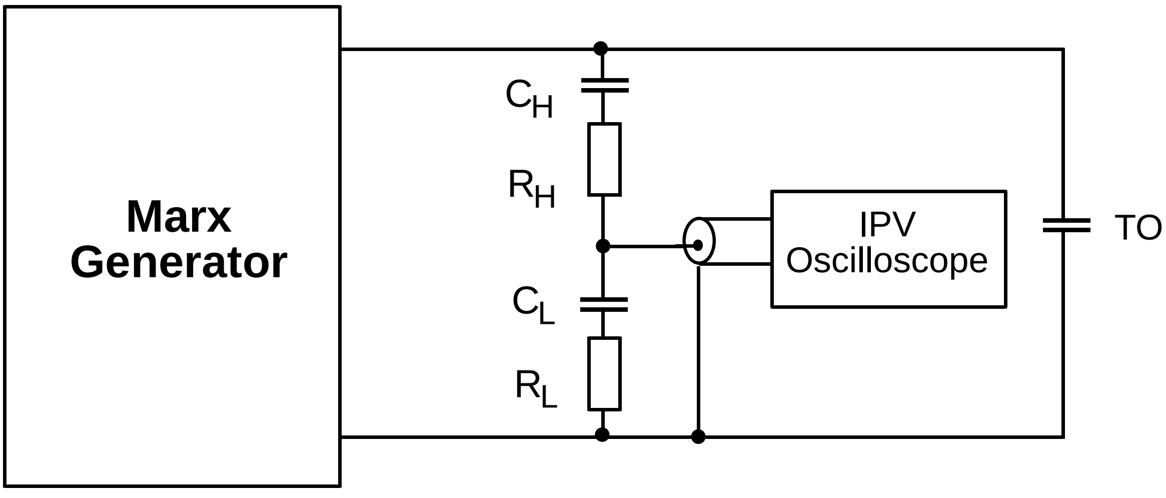

Figure 4.5.1: Scheme of switching impulse voltage test circuit
C_H: 1200 pF ; R_H = 70 Ω ; ratio: 3215;
IPV: impulse-peak-voltmeter (Haefely), measurement uncertainty 3%
Oscilloscope: Tektronix TDS 3044 B– measurement uncertainty 2%

The waveform parameters were determined at reduced charging voltage. Figure 4.5.2 shows the front time, Figure 4.5.3 the time to half value for positive polarity each. Figure 4.5.4 shows the front time, Figure 4.5.5 the time to half value for negative polarity each.

Positive impulse: : T_1 = 1.54 μs T_2 = 49.2 μs

Negative impulse: T_1 = 1.57 μs T_2 = 48.4 μs

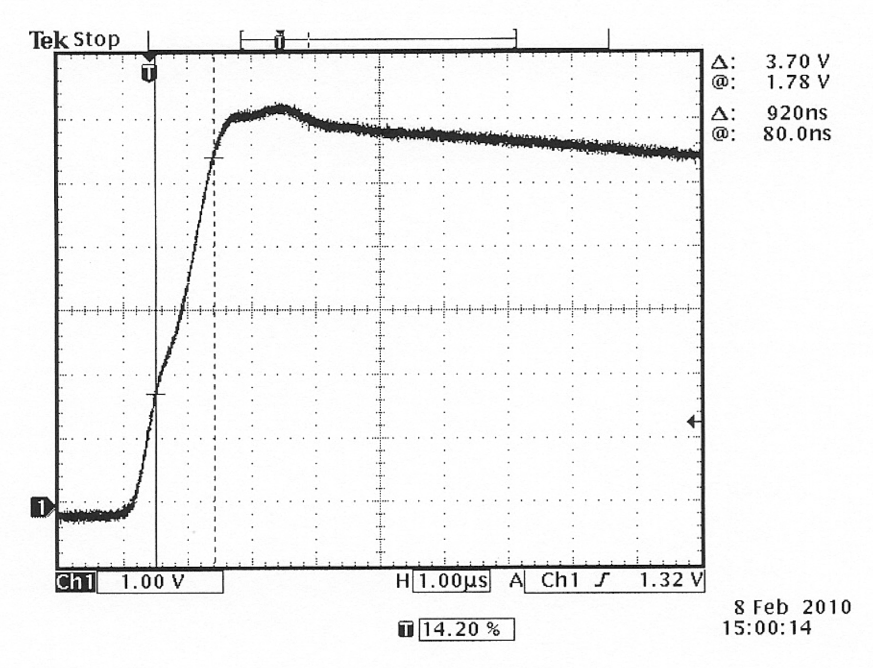

Figure 4.5.2: Front time, positive polarity
horiz.: 1 μs/Div; vert.: 1V/Div; probe 10:1; ratio 3215:1

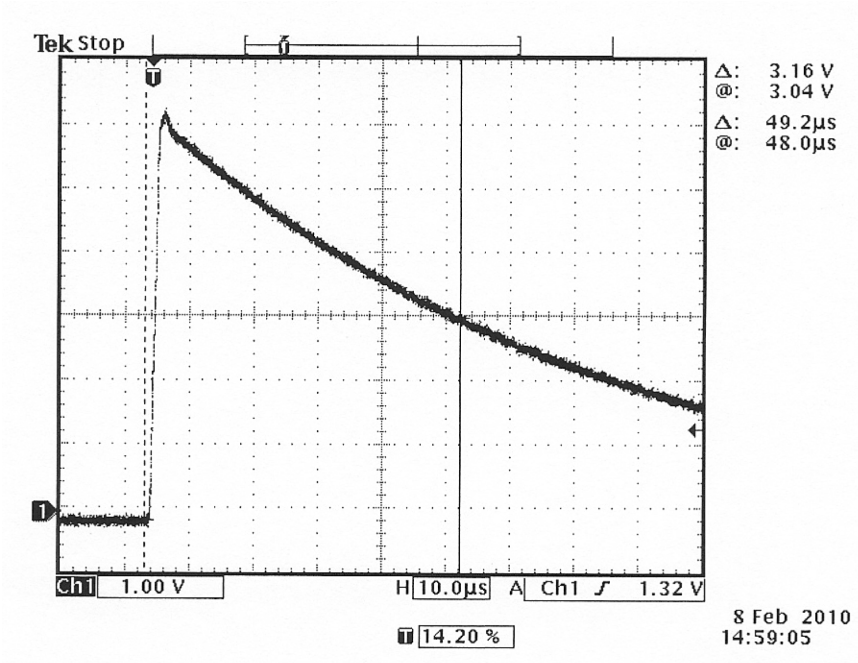

Figure 4.5.3: Time to half value, positive polarity
horiz.: 10 μs/Div; vert.: 1V/Div; probe 10:1; ratio 3215:1

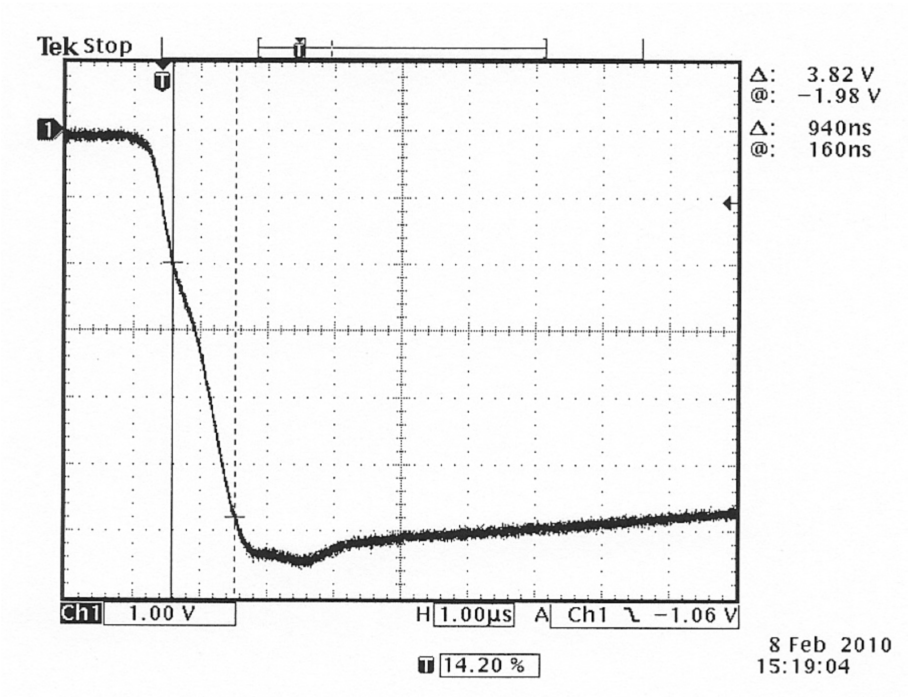

Figure 4.5.4: Front time, negative polarity
horiz.: 1 µs/Div; vert.: 1V/Div; probe 10:1; ratio 3215:1

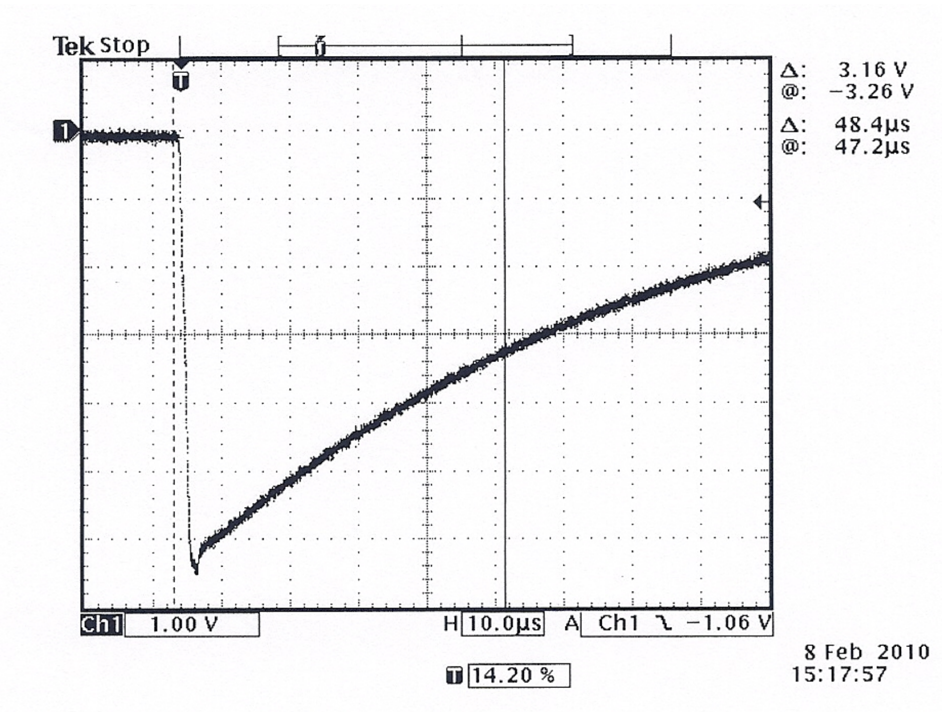

Figure 4.5.5: Time to half value, negative polarity
horiz.: 10 µs/Div; vert.: 1V/Div; probe 10:1; ratio 3215:1

For lightning impulse testing according IEC 60840 Annex H one stage of a Marx generator (Haefely) with a maximum charging voltage of V = 200 kV and a maximum impulse energy of E_{max} = 10 kWs was used.The crest value of the impulse voltage was measured by a damped capacitive divider and a subsequent impulse peak voltmeter (Haefely). The front time and the time to half value were evaluated from the oscillographs.

Concerning the insulation section the voltage was applied to screen 1. The other screen was grounded.
Concerning to the outer protection both screens were connected. The voltage was applied to the screens. The protective casing of the joint was wrapped with aluminium foil and grounded.

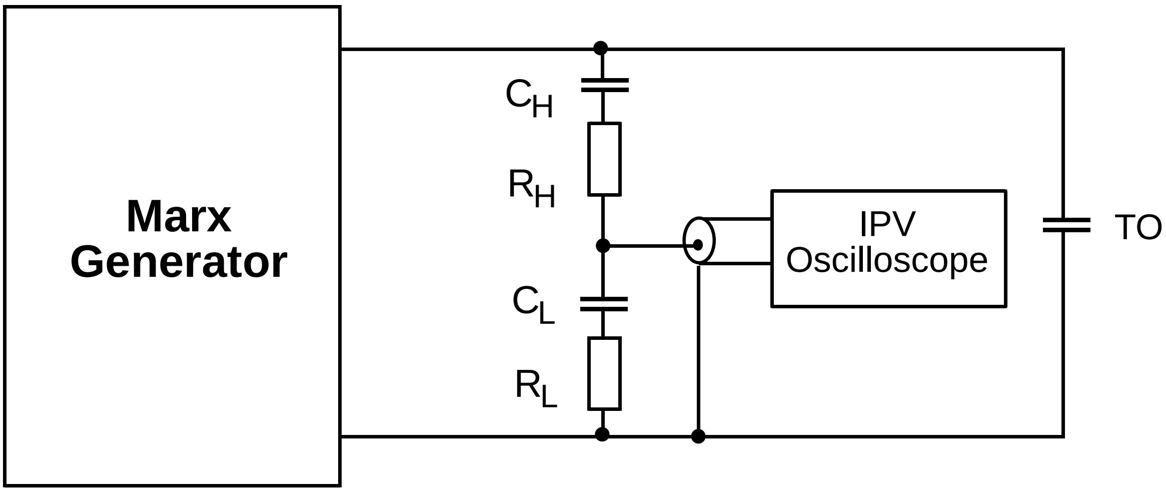

Figure 4.5.6: Scheme of lightning impulse voltage test circuit
C_H: 1200 pF ; R_H = 70 Ω ; ratio: 3215;
IPV: impulse-peak-voltmeter (Haefely) – measurement uncertainty 3%
Oscilloscope: Tektronix TDS 3044B – measurement uncertainty 2%

The waveform parameters were determined at reduced charging voltage. Figure 4.5.7 shows the front time, Figure 4.5.8 the time to half value for positive polarity each. Figure 4.5.9 shows the front time, Figure 4.5.10 the time to half value for negative polarity each.

Positive impulse : T_1 = 1.27 µs T_2 = 50.4 µs

Negative impulse: T_1 = 1.74 µs T_2 = 50.8 µs

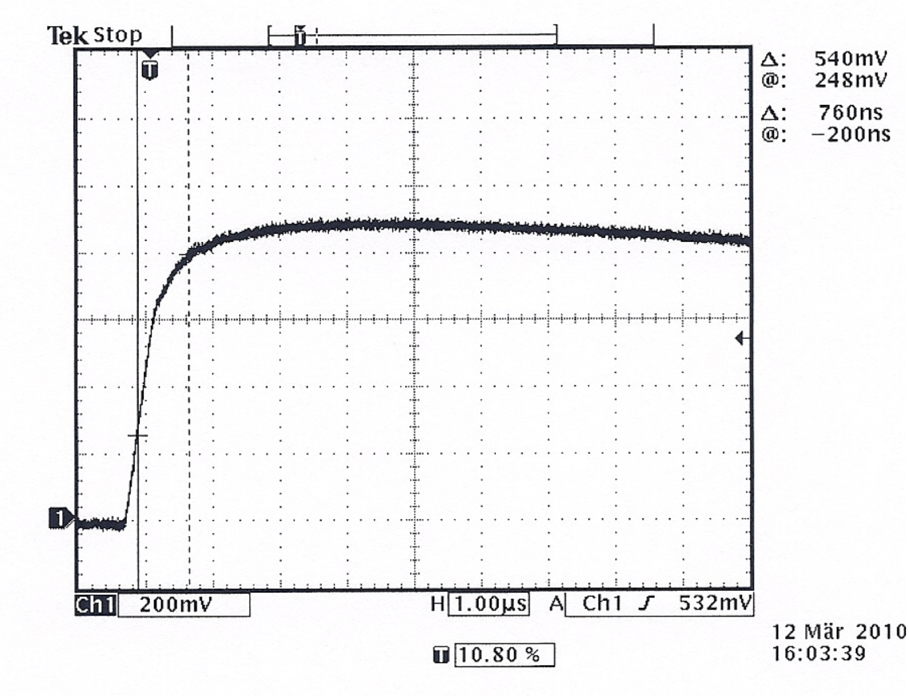

Figure 4.5.7: Front time, positive polarity
horiz.: 1 µs/Div; vert.: 200 mV/Div; probe 10:1; ratio 3215:1

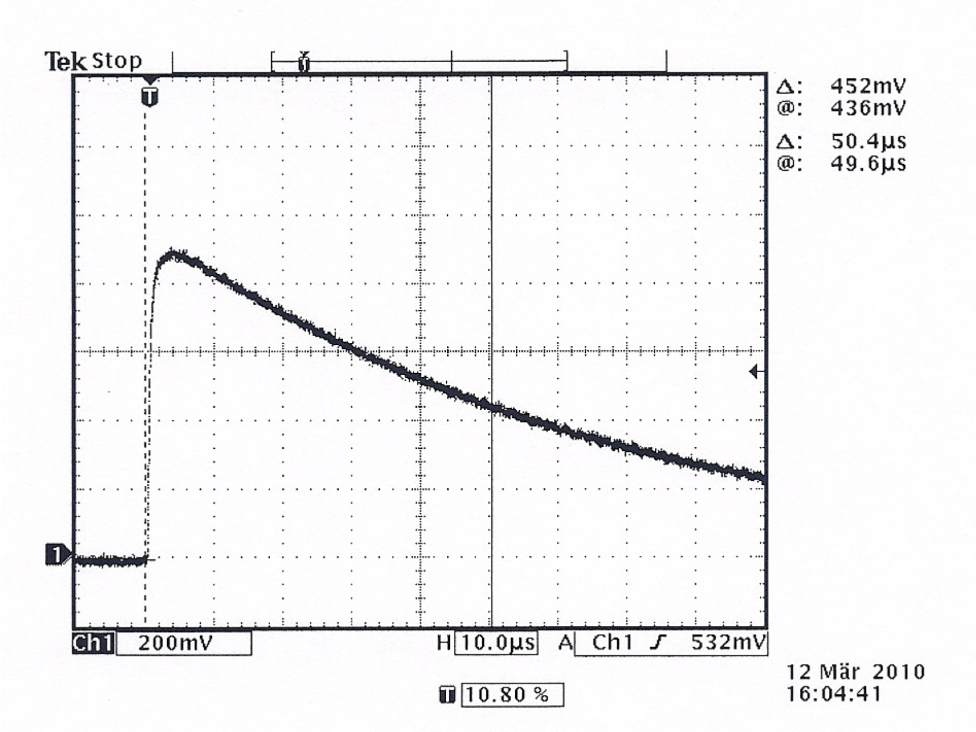

Figure 4.5.8: Time to half value, positive polarity
horiz.: 10 µs/Div; vert.: 200 mV/Div; probe 10:1; ratio 3215:1

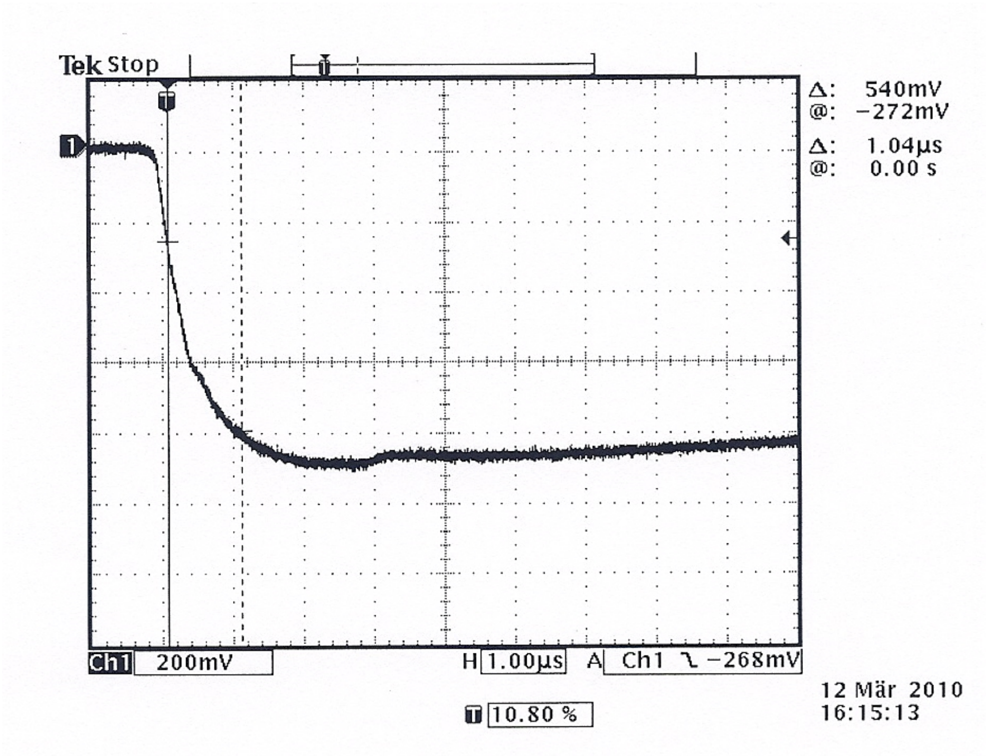

Figure 4.5.9: Front time, negative polarity
horiz.: 1 μs/Div; vert.: 200 mV/Div; probe 10:1; ratio 3215:1

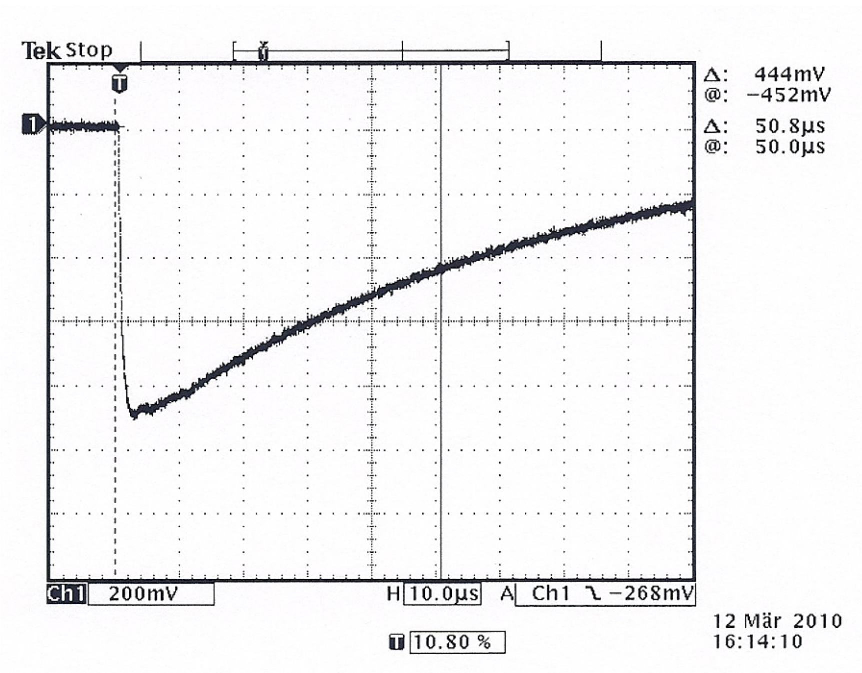

Figure 4.5.10: Time to half value, negative polarity
horiz.: 10 μs/Div; vert.: 200 mV/Div; probe 10:1; ratio 3215:1

4.6 Water Immersion and Heat Cycling

The test object was placed in a tank and filled with water. The water surface was 1000 mm above the test object.

Twenty heating/cooling cycles were applied by raising the water temperature to 70-75°C according to IEC 60840 Annex H. In each cycle, the water was raised to the specified temperature, maintained at that level for at least 5h and than cooled to within 10°C above ambient temperature by diluting water of lower temperature

The temperature was measured with a thermo couple NiCr-Ni, placed 50 mm above the test object. The measurement uncertainty was ± 2K.

4.7 DC Voltage Withstand Test

The DC-voltage was generated by a power supply unit. The voltage measurement was carried out with an ohmic-capacitive, ratio 2000:1. The measurement uncertainty was 1%. During the test the test object was placed in a tank and filled with water. The height of the water was 1000 mm above the test object. The conductivity of the water at 20°C was 63 mS/m.

5 Results

5.1 Check on Insulation Thickness

The test was carried out as described in 4.

Test date:	14.01.2010
Nominal value:	15.0 mm
Measured Values:	15.00 mm
	14.71 mm
	15.15 mm
	14.65 mm
	15.27 mm
	15.45 mm
Average Value:	15.04 mm
Result:	The average value exceeds the nominal value by 0.26%, so no correction was necessary

5.2 PD-Test

The test was carried out as described in 4.

Test date:	14.01.2010
Calibration pulse:	q_{cal} = 5 pC
Background noise level:	2.0 pC
Test voltage:	$\hat{u}/\sqrt{2}$ = 133 kV; t = 10 s, thereafter
	$\hat{u}/\sqrt{2}$ = 114 kV; with pd reading
PD:	no detectable discharges

The test was passed successfully

5.3 Heating cycle voltage test

The test was carried out as described in 4.

Test date:	15.01. – 04.02.2010
Test voltage:	$\hat{u}/\sqrt{2}$ = 152 kV
Heating current:	I =1200 . . .1350 A regulated, 8h
	I = 0A, 16 h
Cycle:	8 h heating; 16 h cooling
Number of cycles:	20

Neither breakdown nor flashover occurred.

The test was passed successfully

5.4 PD-Test

The test was carried out as described in 4.

Test date:	08.02.2010
Calibration pulse:	q_{cal} = 5 pC
Background noise level:	1.5 pC
Test voltage:	$\hat{u} / \sqrt{2}$ = 133 kV; t = 10 s, thereafter
	$\hat{u} / \sqrt{2}$ = 114 kV; with pd reading
PD:	no detectable discharges

The test was passed successfully

5.5 PD-Test at elevated temperature

The test was carried out as described in 4.

Test date:	08.02.2010
Calibration pulse:	q_{cal} = 5 pC
Background noise level:	1.5 pC
Heating current:	I = 1200 . . .1350 A regulated, 8 h
Temperature:	T = 96.1°C
Test voltage:	$\hat{u} / \sqrt{2}$ = 133 kV; t = 10 s, thereafter
	$\hat{u} / \sqrt{2}$ = 114 kV; with pd reading
PD:	no detectable discharges

The test was passed successfully

5.6 Lightning Impulse Voltage Withstand Test at elevated temperature

This test was carried out as described in 4.

Test date:	08.02.2010
Test voltage:	û = 650 kV
Heating current:	I = 1200 . . .1350 A regulated, 8 h
Temperature:	T = 96.3°C
Impulse:	1-5µs / 40-60 µs
Number of tests:	10 positive polarity, 10 negative polarity

Neither flashover nor breakdown occurred at the test objects during all lightning impulse voltage tests.

The test was passed successfully

Table 5.6.1 shows the test results with positive polarity, table 5.6.2 with negative polarity.

number	charging voltage / kV	û / kV	Figure	remark
1	30,0	200		front time,
2	30,0	200		time to half value
3	48,8	327		50%
4	67,9	456		70%
5	87,1	584		90%
6	96,9	650	5.6.1	1. 100%
7	96,9	650	5.6.1	2. 100%
8	96,9	650	5.6.1	3. 100%
9	96,9	649	5.6.1	4. 100%
10	96,9	650	5.6.1	5. 100%
11	96,9	650	5.6.2	6. 100%
12	96,9	648	5.6.2	7. 100%
13	96,9	651	5.6.2	8. 100%
14	96,9	650	5.6.2	9. 100%
15	96,9	649	5.6.2	10. 100%

Table 5.6.1: Lightning impulse voltage withstand test, positive polarity

number	charging voltage / kV	û / kV	Figure	remark
1	- 30,0	- 198		front time,
2	- 30,0	- 198		time to half value
3	- 48,8	- 323		50%
4	- 67,9	- 455		70%
5	- 96,9	- 584		90%
6	- 96,9	- 650	5.6.3	1. 100%
7	- 96,9	- 649	5.6.3	2. 100%
8	- 96,9	- 652	5.6.3	3. 100%
9	- 96,9	- 652	5.6.3	4. 100%
10	- 96,9	- 649	5.6.3	5. 100%
11	- 96,9	- 649	5.6.4	6. 100%
12	- 96,9	- 650	5.6.4	7. 100%
13	- 96,9	- 650	5.6.4	8. 100%
14	- 96,9	- 650	5.6.4	9. 100%
15	- 96,9	- 650	5.6.4	10. 100%

Table 5.6.2: Lightning impulse voltage withstand test, negative polarity

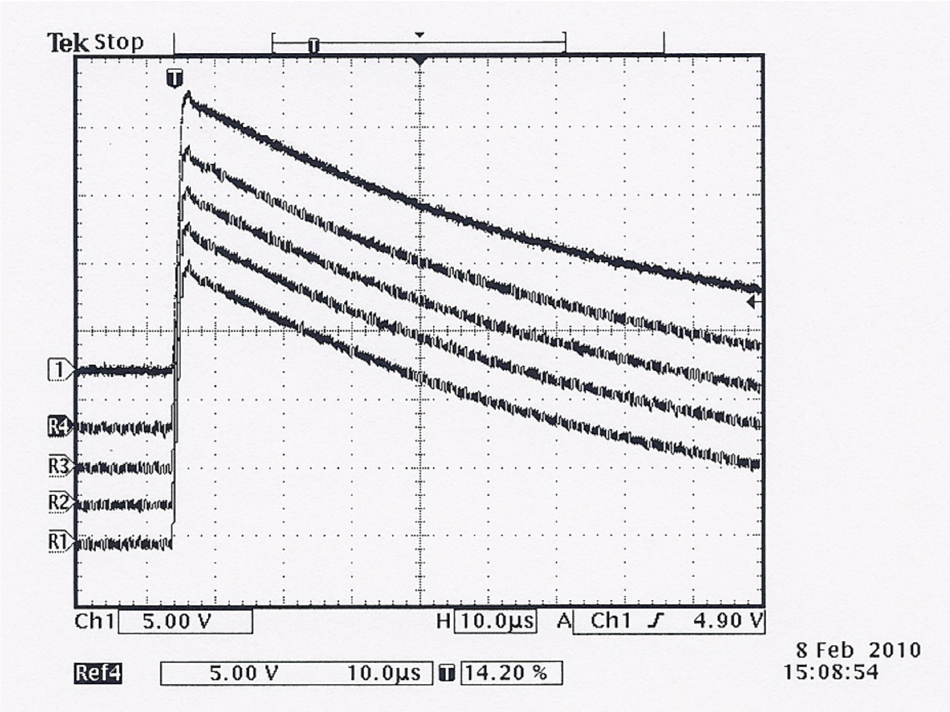

Figure 5.6.1: 100%-stress 1 - 5, positive polarity
Hor.: 10µs/Div; Vert.: 5V/Div; probe 10:1; ü = 3215

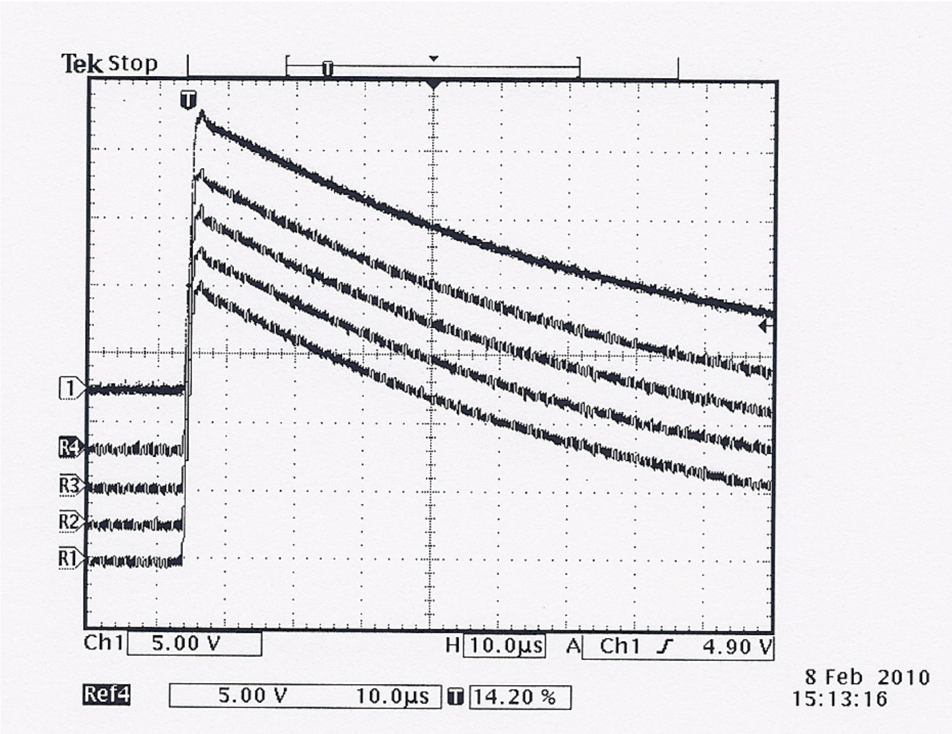

Figure 5.6.2: 100%-stress 6 - 10, positive polarity
Hor.: 10µs/Div; Vert.: 5V/Div; probe 10:1;ü = 3215

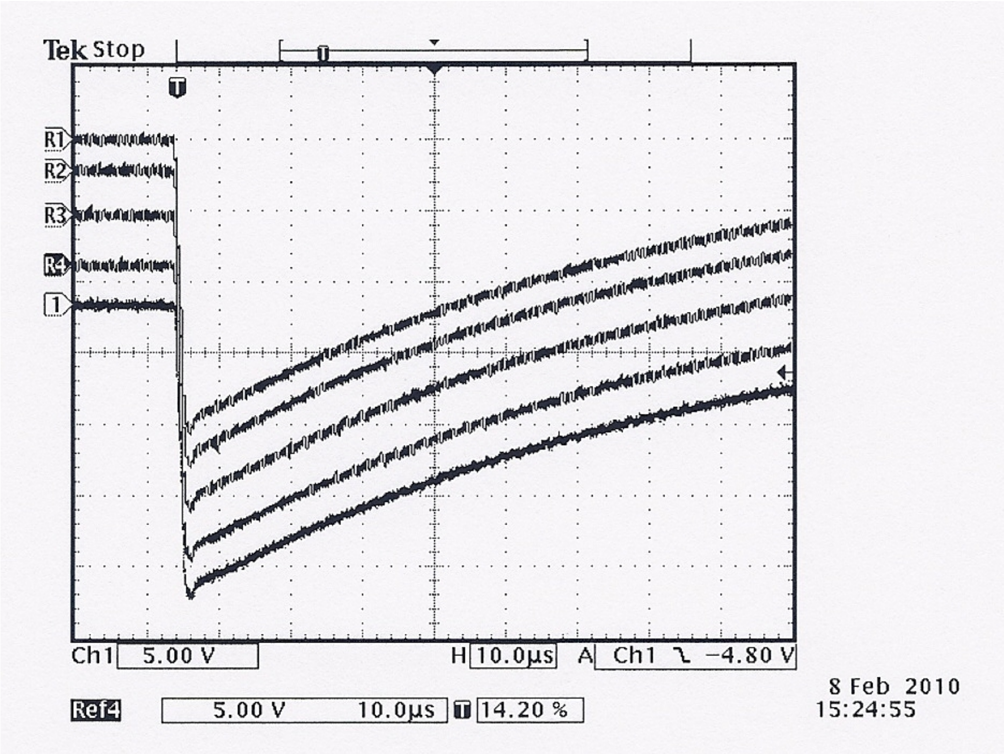

Figure 5.6.3: 100%-stress 1 - 5, negative polarity
Hor.: 10µs/Div; Vert.: 5V/Div; probe 10:1; ü = 3215

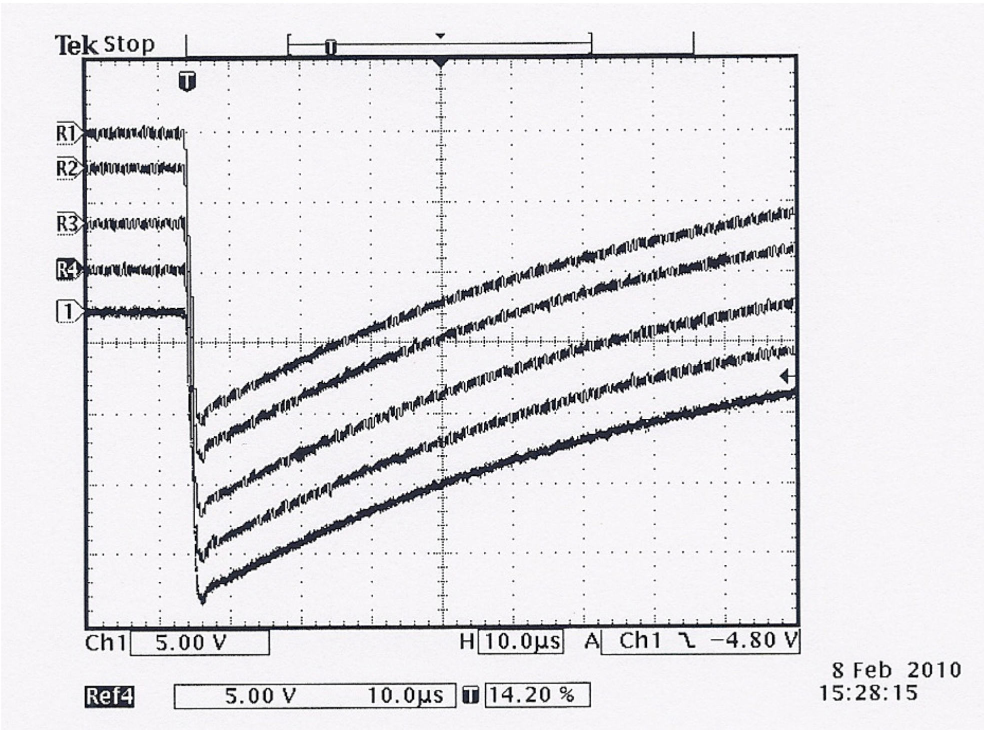

Figure 5.6.4: 100%-stress 6 - 10, negative polarity
Hor.: 10µs/Div; Vert.: 5V/Div; probe 10:1; ü = 3215

5.7 AC Voltage Withstand Test during cooling period

The test was carried out as described in 4.

Test date: 08.02.2010

Temperature: T = 45.0°C

Test voltage: $\hat{u} / \sqrt{2}$ = 190 kV; t = 15 min

Neither breakdown nor flashover occurred.

The test was passed successfully.

5.8 Test of outer Protection of Buried Joints

5.8.1 Water Immersion and Heat Cycling

The test was carried out as described in 4.

Test date: 15.02. – 05.03.2010

Temperature: 70-75°C, t = 5h

Number of cycles: 20

The test was passed successfully.

5.8.2 DC Voltage Test in Water

The test was carried out as described in 4.

Test date: 10.03.2010

Test object: insulation section

Test voltage: U = -20 kV; t = 1 min

Neither breakdown nor flashover occurred at the test object during DC voltage test.

The test was passed successfully.

Test object: outer protection, both screens - water

Test voltage: U = -20 kV; t = 1 min

Neither breakdown nor flashover occurred at the test object during DC voltage test.

The test was passed successfully.

5.8.3 Lightning Impulse Voltage Withstand Test

This test was carried out as described in 4.

Test date:	12.03.2010
Test object:	outer protection, both screens - casing
Test voltage:	û = 37,5 kV
Impulse:	1-5µs / 40-60 µs
Number of tests:	10 positive polarity, 10 negative polarity

Neither flashover nor breakdown occurred at the test objects during all lightning impulse voltage tests.

The test was passed successfully

Table 5.8.3.1 shows the test results with positive polarity, table 5.8.3.2 with negative polarity.

number	charging voltage / kV	û / kV	remark
1	18,0	17,6	front time,
2	18,0	16,6	time to half value
3	26,3	25,4	70%
4	34,4	33,4	90%
5	38,6	37,9	1. 100%
6	38,6	37,9	2. 100%
7	38,6	37,3	3. 100%
8	38,6	37,9	4. 100%
9	38,6	37,9	5. 100%
10	38,6	37,6	6. 100%
11	38,6	37,6	7. 100%
12	38,6	37,9	8. 100%
13	38,6	37,6	9. 100%
14	38,6	37,6	10. 100%

Table 5.8.3.1: Lightning impulse voltage withstand test, positive polarity

number	charging voltage / kV	û / kV	remark
1	- 18,0	- 17,0	front time,
2	- 18,0	- 17,5	time to half value
3	- 26,3	- 25,4	70%
4	- 34,4	- 33,4	90%
5	- 38,6	- 37,6	1. 100%
6	- 38,6	- 37,6	2. 100%
7	- 38,6	- 37,3	3. 100%
8	- 38,6	- 37,3	4. 100%
9	- 38,6	- 37,6	5. 100%
10	- 38,6	- 37,3	6. 100%
11	- 38,6	- 37,6	7. 100%
12	- 38,6	- 37,6	8. 100%
13	- 38,6	- 37,6	9. 100%
14	- 38,6	- 37,6	10. 100%

Table 5.8.3.2: Lightning impulse voltage withstand test, negative polarity

Test object:	insulation section
Test voltage:	û = 75 kV
Impulse:	1-5µs / 40-60 µs
Number of tests:	10 positive polarity, 10 negative polarity

Neither flashover nor breakdown occurred at the test objects during all lightning impulse voltage tests.

The test was passed successfully

Table 5.8.3.3 shows the test results with positive polarity, table 5.8.3.4 with negative polarity.

number	charging voltage / kV	û / kV	remark
1	30,0	28,7	front time,
2	30,0	28,5	time to half value
3	55,3	53,7	70%
4	69,5	67,5	90%
5	77,2	75,8	1. 100%
6	77,2	75,2	2. 100%
7	77,2	75,8	3. 100%
8	77,2	75,2	4. 100%
9	77,2	75,2	5. 100%
10	77,2	75,2	6. 100%
11	77,2	75,2	7. 100%
12	77,2	75,2	8. 100%
13	77,2	75,2	9. 100%
14	77,2	75,2	10. 100%

Table 5.8.3.3: Lightning impulse voltage withstand test, positive polarity

number	charging voltage / kV	û / kV	remark
1	- 30,0	- 28,8	front time,
2	- 30,0	- 28,5	time to half value
3	- 55,3	- 52,7	70%
4	- 69,5	- 67,5	90%
5	- 77,2	- 75,2	1. 100%
6	- 77,2	- 75,2	2. 100%
7	- 77,2	- 75,2	3. 100%
8	- 77,2	- 75,2	4. 100%
9	- 77,2	- 74,6	5. 100%
10	- 77,2	- 75,2	6. 100%
11	- 77,2	- 75,8	7. 100%
12	- 77,2	- 75,2	8. 100%
13	- 77,2	- 75,8	9. 100%
14	- 77,2	- 75,2	10. 100%

Table 5.8.3.4: Lightning impulse voltage withstand test, negative polarity

5.9 Accessory Examination

On completion of the electrical tests the accessory was examined. There was no evidence of electrical activity.

The test was passed successfully.

6 Conclusion

The cross bonding joint type SC 145-II U_m = 145 kV, manufacturer 3M Deutschland GmbH, passed all tests described in Chapter 2 successfully. The test object fulfilled the requirements according IEC 60840 04/2004, "type test on accessories".

Karlsruhe, 13.08.2010

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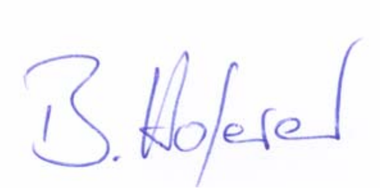

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