1 psl.

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Test Report

2013 – 63

Type Test of a Mechanical Terminal Lug (Barrel) for rmv 95 mm^2 Aluminium Conductor

Customer: Behr Bircher Cellpack BBC Radeberg GmbH
Carl-Eschebach-Str. 11
01454 Radeberg

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

1 Purpose of Test

The electrical and mechanical properties of a mechanical terminal lug (class A) manufactured by Behr Bircher Cellpack BBC Radeberg GmbH were tested according IEC 61238-1 05/2003.

2 Miscellaneous Data

Test object:	6 terminal lugs Type: CSK 95-240/CP Drawing number: Z000381 dated 07.03.2013, Figures 2.1 - 2.2. The terminal lugs were mounted on aluminium conductors rmv 95 mm^2, outside diameter d = 11,8 mm, number of single wires n = 19.
	3 terminal lugs Type: CSK 95-240/CP Drawing number: Z000381 dated 07.03.2013, Figures 2.1 - 2.2. The terminal lugs were mounted on aluminium conductors rmv 95 mm^2, outside diameter d = 11,8 mm, number of single wires n = 19.
Delivery:	18.07.2013
Mounting:	18.07.2013
Assembler:	Dipl.-Ing. K.-U. Bentkowski
Place of test:	Lab 033 and Lab 21 at the Institute of Electric Energy Systems and High-Voltage Technology - University Karlsruhe Kaiserstraße 12 76128 Karlsruhe
	The mechanical test was performed at Materialprüfanstalt University Stuttgart Pfaffenwaldring 32 70569 Stuttgart
Test period:	31.07. - 06.11.2013
Atmospheric conditions:	Temperature: 18 - 25°C Air pressure: 980 - 1020 hPa Rel. humidity: 35 - 70 %

Representatives:	Representatives responsible for the test: Dr.-Ing. R. Badent Dr.-Ing. B. Hoferer	
Tests:	Pos 1.	Type test (electrical part) including thermal short circuit test (class A) according IEC 61238-1 05/2003.
	Pos 2.	Mechanical test (tensile test) according IEC 61238-1 05/2003.

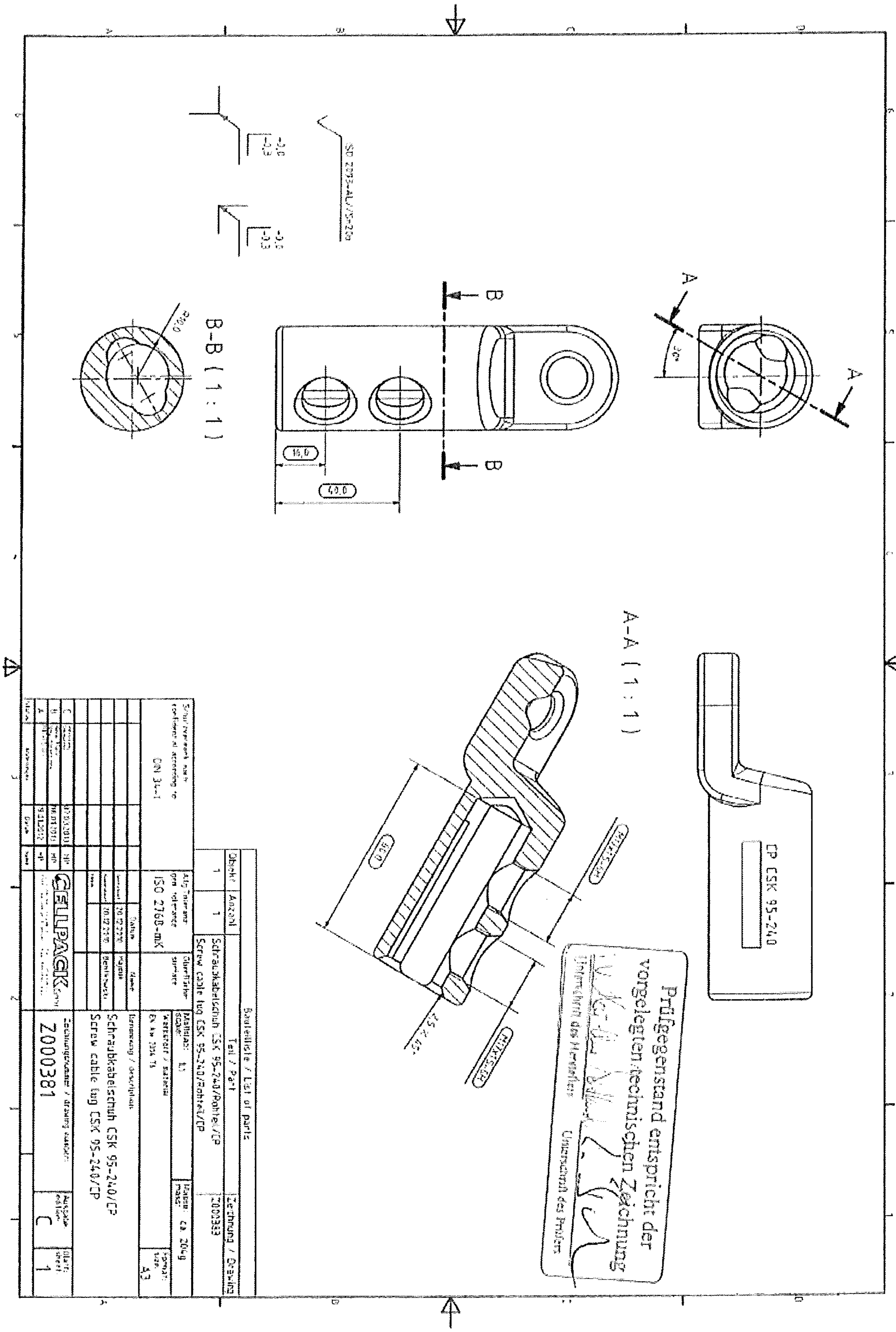

Figure 2.1: Terminal lug

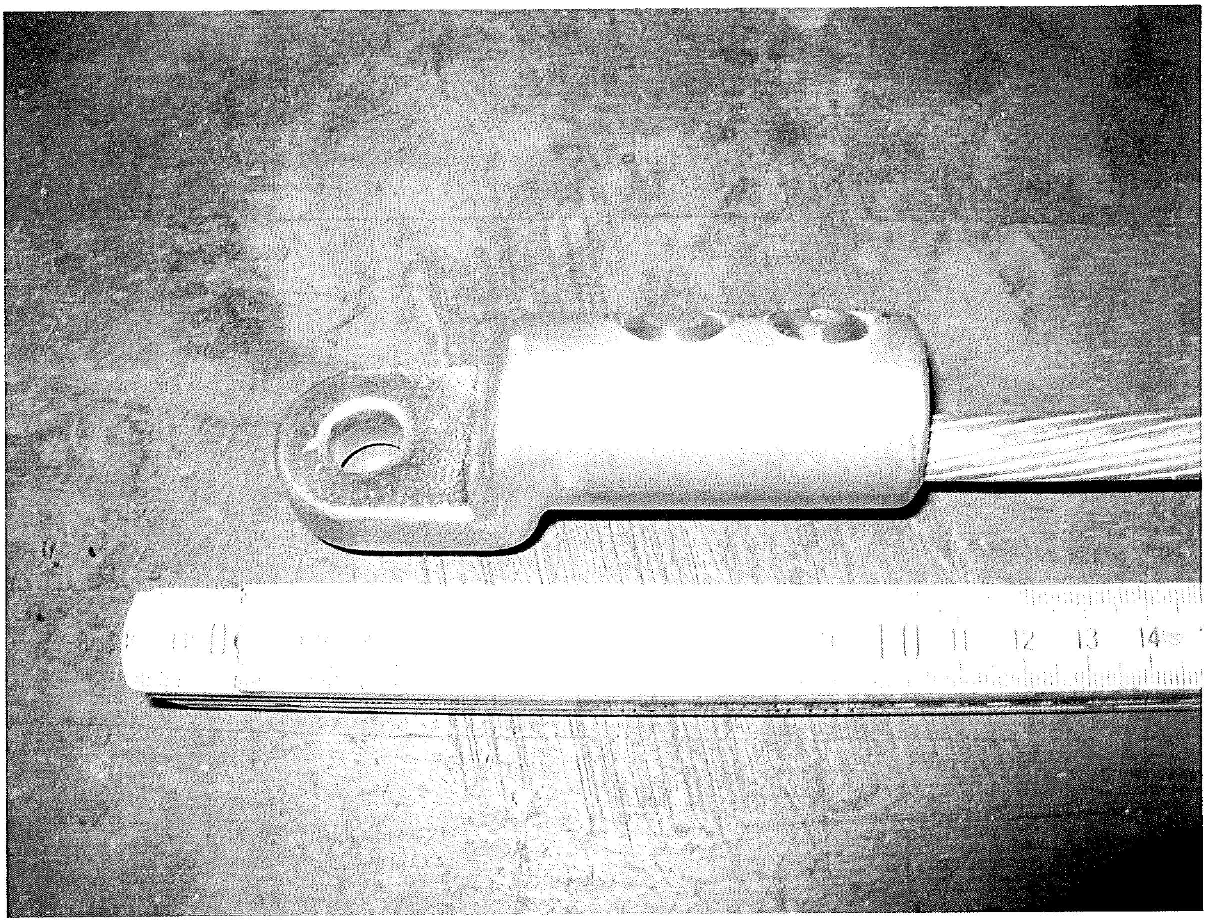

Figure 2.2: Mounted terminal lug

Chronology of the tests

18.07.2013	Mounting
31.07.2013	Measuring of the resistance factor k_0
01.08.2013	First and second heat cycle
01.08. - 11.08.2013	Heat cycles 3 - 200
12.08.2013	Measuring of the resistance factor k_2
13.08.2013	Thermal short circuit
15.08.2013	Measuring of the resistance factor k_3
15.08. - 06.11.2013	Heat cycles 201 to 1000 and measuring of the resistance factor after 250 cycles and thereafter every 75 cycles.
07.08.2013	Tensile test

3 Mounting

3.1 Electrical Test

The conductors were provided with welded equalizers. The mechanical terminal lugs were mounted in the high-voltage laboratory of the IEH by customer's technicians according to the company's specifications. In each mechanical terminal lug and each palm a thermocouple was placed in a previously prepared hole (diameter: 2,1 mm, depth: 5,0 mm); the position was designated by the customer. The test circuit for the thermal short-circuit was dismantleable. Terminal lugs were compressed on each wire, Figure 3.1.

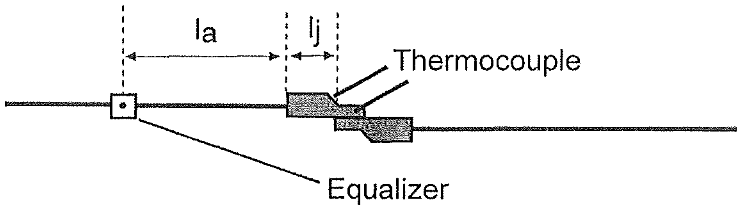

Figure 3.1: Arrangement

According to IEC 61238-1 05/2003 for conductor cross section q = 95 mm^2 the minimum lengths were as follows:

$$d_{min} = 780 \text{ mm}; \; l_a = 150 \text{ mm}.$$

For all test objects the length d was approximately 1000 mm and consequently larger than d_{min}.
Table 1 shows the lengths between the measuring point at the equalizer and each lug.

Test object	l_a/ mm	l_j/mm
1	158,0	73,0
2	158,0	73,0
3	158,0	73,0
4	158,0	73,0
5	158,0	73,0
6	158,0	73,0

Table 1: Geometry; length of the reference conductor l_r = 505 mm

3.2 Mechanical Test

The test objects were fitted as for the electrical test. According to IEC 61238-1 05/2003 for conductor cross section q = 95 mm^2 the minimum lengths between the test object and tensile test machine jaws shall be d_{min} = 500 mm. For all test objects the length d was approximately 600 mm and consequently larger than d_{min}.

4 Test Setups

4.1 Heat Cycle Test

The heat cycle test was carried out in lab 033 of the IEH. The test loop consists of six test objects and the reference conductor in series. Current inception was accomplished by a transformer (U_1 = 400 V; U_2 = 20 V) which used the test loop as secondary winding. The current was measured by a current transformer, ratio 1500/5, and a digital multimeter. The measurement uncertainty was ± 0,5 %.

During the cooling cycle ventilators were used to shorten the cycle time as much as possible. Temperature was measured by means of thermocouples NiCr-Ni, measuring uncertainty ± 2K.

4.1.1 First Heat Cycle

The object of the first heat cycle is to determine the reference conductor temperature to be used for the subsequent cycles. The current in the test loop was increased until reaching the temperatures indicated in Table 2.

Test object	temperature/°C
1	81
2	82
3	76
4	75
5	75
6	74

Table 2: Temperatures of the barrel, first heat cycle
Current: I = 380 A
Reference conductor temperature: Θ_R = 140°C
Temperature of median lug: Θ_{Median} = 76°C

4.1.2 Second Heat Cycle

In a second heat cycle the heat cycle duration was determined. The temperature-time heating profile determined in this way was used for all subsequent cycles. Figure 4.1 shows the temperature profile recorded during the second heat cycle. For heating a controller was used. At the beginning of the cycle the set-point of the temperature was increased up to Θ_R using a temperature-controlled ramp and then kept constant. To achieve this profile, current injection in the range of 0..450 A was necessary. Due to temperature regulation, there is no possibility to state precisely the current value during heating.

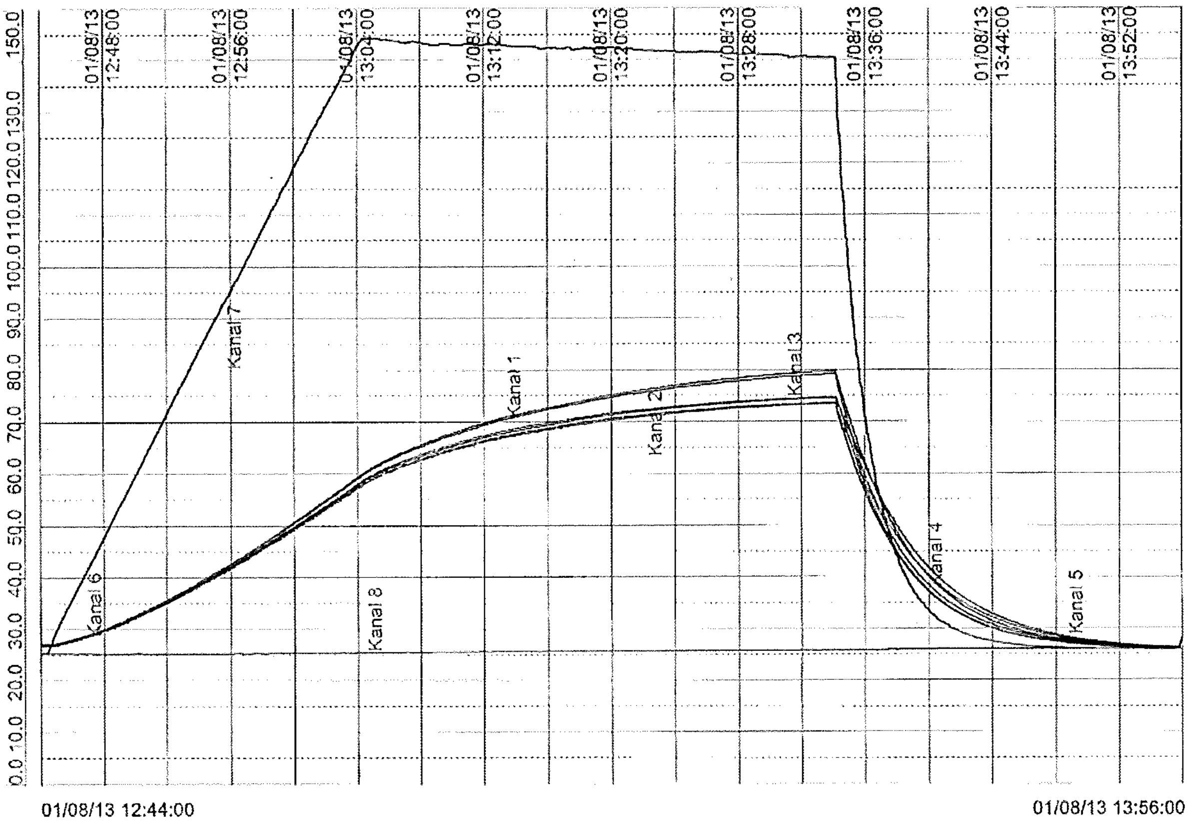

Figure 4.1: Heating profiles of the reference conductor and the terminal lugs
Current cycle: I_N = 0..450 A regulated; t_N = 50 min.
Cooling cycle: t_C = 20 min.
Temperature of the reference conductor: Θ_R = 140 °C
Temperature of median lug: Θ_{Median} = 75 °C

4.2 Resistance Measurements

For resistance measurement a DC - current I = 20 A is applied to the cold lugs. Defined measuring points were marked on the equalizers before assembly using a centre punch. The current was measured by means of a shunt (0,24 mΩ) and a digital multimeter. The voltage was recorded by a digital multimeter, the temperatures using thermocouples.

Measuring uncertainties: Current measurement: 0,5 %
Voltage measurement: 0,5 %
Temperature measurement: 2 K

4.3 Short Circuit Tests

Six short circuits were applied after 200 heat cycles. Since the test is intended to reproduce the thermal effects of high currents only, the test objects were mounted in a wooden frame in order to reduce the electro-dynamic forces.

Figure 4.3.1 illustrates the test setup. Via a vacuum circuit-breaker the 123 V - tapping of a 800 kVA - transformer is directly applied to the test object. The current is measured by means of a rogowski current transducer Type CWT600B (Sensitivity 0,05mV/A). The output signal of the current transformer is recorded by a digital storage oscilloscope (Tektronix 2430 A).

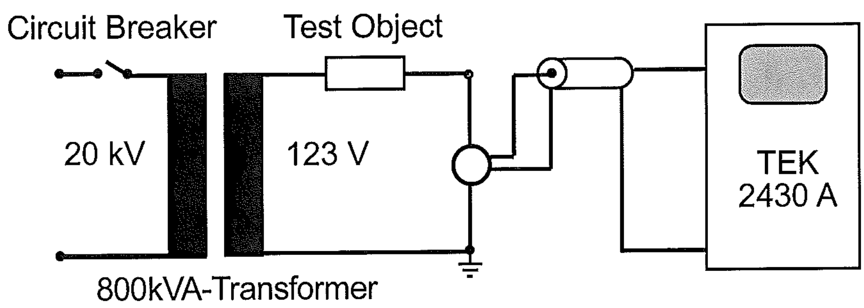

Figure 4.3.1: Test setup

Measuring uncertainties: Current transducer ± 1%
Oscilloscope: ± 2 %

According to IEC 61238-1 05/2003 the conductor must be heated adiabatically from ambient temperature up to 250°C - 270°C. The short - circuit current was calculated according to IEC 724. For the equivalent rms current, the limit load integral is

$$\int i^2 dt = k^2 q^2 ln \frac{\Theta_f + \beta}{\Theta_i + \beta}$$

Aluminium has the following characteristic values:

$$k = 148 \ A\sqrt{s}/mm^2$$
$$\beta = 228 \ °C$$

For $q = 95 \ mm^2$ a temperature of $\Theta_i = 20°C$ and a conductor end temperature of $\Theta_f = 250°C$, this yields to:

$$\int i^2 dt = 129{,}72 \cdot 10^6 \ A^2s$$

and to a thermal equivalent 1s short-circuit current of

$$I_{K(250°C)} = 11{,}39 \ kA.$$

Analogous, a conductor end temperature of $\Theta_f = 270°C$ yields to

$$I_{K(270°C)} = 11{,}74 \ kA.$$

To ensure a temperature between 250°C and 270°C, the current values must be in the range between 11,39 and 11,74 kA.

Figure 4.3.2 shows the oscillogramm of the thermal short circuit.

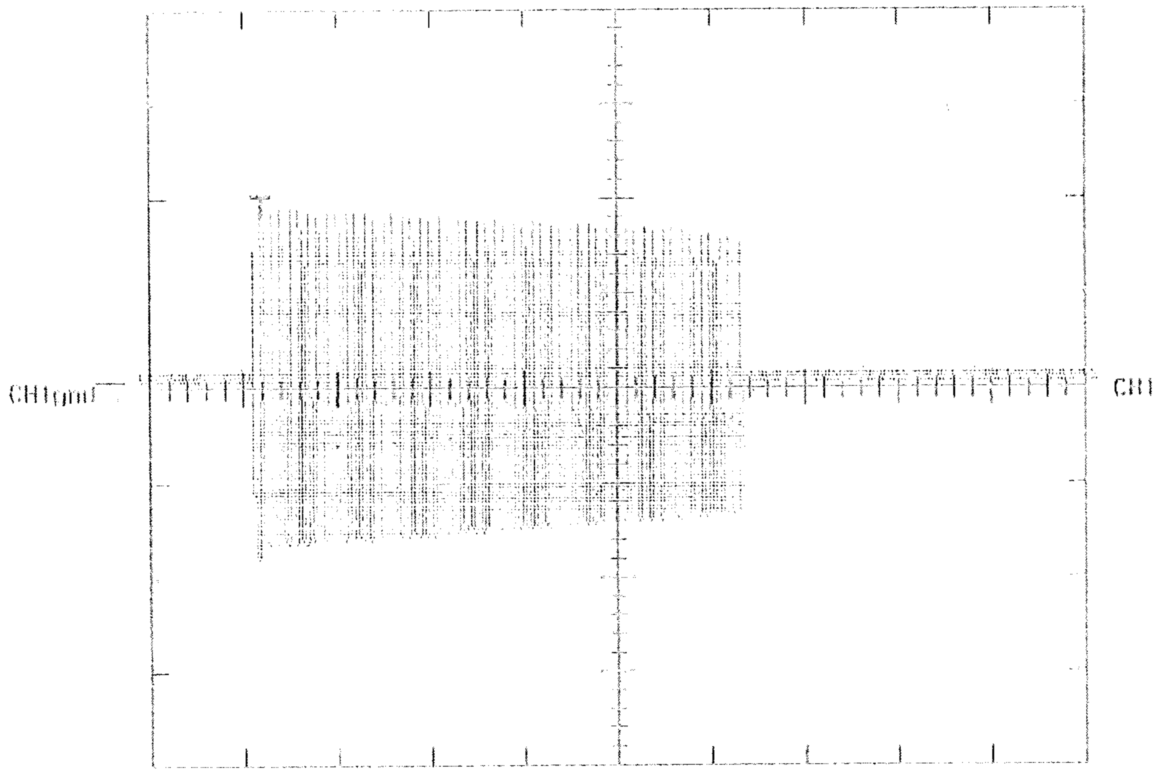

Figure 4.3.2: Horizontal: 200 ms/Div; vertical: 10 kA/Div

The current was I = 11,31 kA. This yields to a short circuit duration t = 1,04 s.

4.4 Tensile Test

The test was performed with servo-hydraulic test machine Serial - No. H2996-013-50520, with a nominal load of 40 kN. The test objects were mounted vertically by means of clamping tools. The force was measured by means of a load cell. According to IEC 61238-1 05/2003 the rate of application of the load shall not exceed 10 N per square millimetre of cross-sectional area and per second up to 3,8 kN for q = 95 mm^2 , which is the maintained for 1 min.

5 Results

5.1 Resistance Measurement after assembly

Immediately after assembly, the conductor resistance factor was determined. The measuring current was I = 20 A. Table 3 shows the resistance factors k_0 of the six mechanical terminal lugs.

lug	k_0
1	0,405
2	0,456
3	0,439
4	0,434
5	0,415
6	0,495

Table 3: Resistance factors k_0.

This yields to the following statistical values:

$$\overline{k_0} = 0{,}441$$
$$s_0 = 0{,}032$$
$$\delta = 0{,}121$$

Requirement for the initial scatter: $\delta < 0{,}30$.

5.2 Resistance Measurement prior to Short-circuit Test

In all conductors the resistance factor k was determined according to Chapter 4.2.

Test object	k	k/k_0	Θ_{max} /°C
1	0,447	1,105	79
2	0,511	1,120	80
3	0,474	1,078	74
4	0,470	1,083	76
5	0,450	1,084	74
6	0,547	1,104	73

Table 4: Resistance factors after 200 heat cycles
Temperature of the reference conductor: Θ_R = 140°C
Requirement: $k/k_0 < 2{,}0$
Required maximum temperature: $\Theta_{max} < \Theta_R$

5.3 Short-circuit Test

The test loop was dismantled and each test object was subjected to six thermal short circuit tests according to Chapter 4.3. After each short-circuit, the test objects were cooled to a temperature of 20°C.

I_K = 11,31 kA
t_K = 1,04 s
n = 6

5.4 Resistance Measurement after Short-circuit Test

For the subsequent heat cycles the test loop was assembled again. The determination of the resistance factor after the short-circuit test yields to table 5.

Test object	k	k/k_0	Θ_{max} /°C
1	0,476	1,177	75
2	0,547	1,199	75
3	0,506	1,152	77
4	0,509	1,172	75
5	0,498	1,199	79
6	0,577	1,165	77

Table 5: Resistance factors after short-circuit test
Temperature of the reference conductor: Θ_R = 140°C
Requirement: $k/k_0 < 2,0$
Required maximum temperature: $\Theta_{max} < \Theta_R$

5.5 Heat Cycles 201 - 1000

After the short-circuit test , 800 heat cycles were carried out. After 250 cycles and, thereafter every 75 cycles the resistance factor k of all lugs was determined. Table 6 shows the resistance factors k of the lugs as well as the mean values, the standard deviation and the scatter after the resistance measurements.

x	Cycle	Test object 1	Test object 2	Test object 3	Test object 4	Test object 5	Test object 6	Mean Value	s	δ
	0	0,405	0,456	0,439	0,434	0,415	0,495	0,44082	0,03229	0,12085
	200 VK	0,447	0,511	0,474	0,470	0,450	0,547	0,48317	0,03867	0,13206
	200 NK	0,476	0,547	0,506	0,509	0,498	0,577	0,51880	0,03655	0,11625
-5	250	0,475	0,554	0,501	0,506	0,491	0,569	0,51604	0,03722	0,11902
-4	325	0,477	0,561	0,494	0,499	0,490	0,564	0,51413	0,03823	0,12268
-3	400	0,492	0,581	0,517	0,510	0,507	0,585	0,53208	0,04050	0,12558
-2	475	0,496	0,578	0,512	0,513	0,509	0,582	0,53186	0,03807	0,11810
-1	550	0,490	0,575	0,513	0,523	0,520	0,584	0,53412	0,03728	0,11517
0	625	0,489	0,579	0,503	0,506	0,501	0,575	0,52537	0,04019	0,12622
1	700	0,496	0,576	0,512	0,502	0,499	0,577	0,52694	0,03863	0,12096
2	775	0,507	0,594	0,512	0,505	0,507	0,586	0,53513	0,04255	0,13121
3	850	0,508	0,601	0,521	0,520	0,507	0,589	0,54103	0,04257	0,12984
4	925	0,501	0,592	0,516	0,511	0,506	0,589	0,53573	0,04244	0,13072
5	1000	0,507	0,599	0,526	0,518	0,512	0,602	0,54409	0,04402	0,13348

Table 6: Resistance factors k

Figure 5.1 shows the graph of the resistance factors k of the terminal lugs.

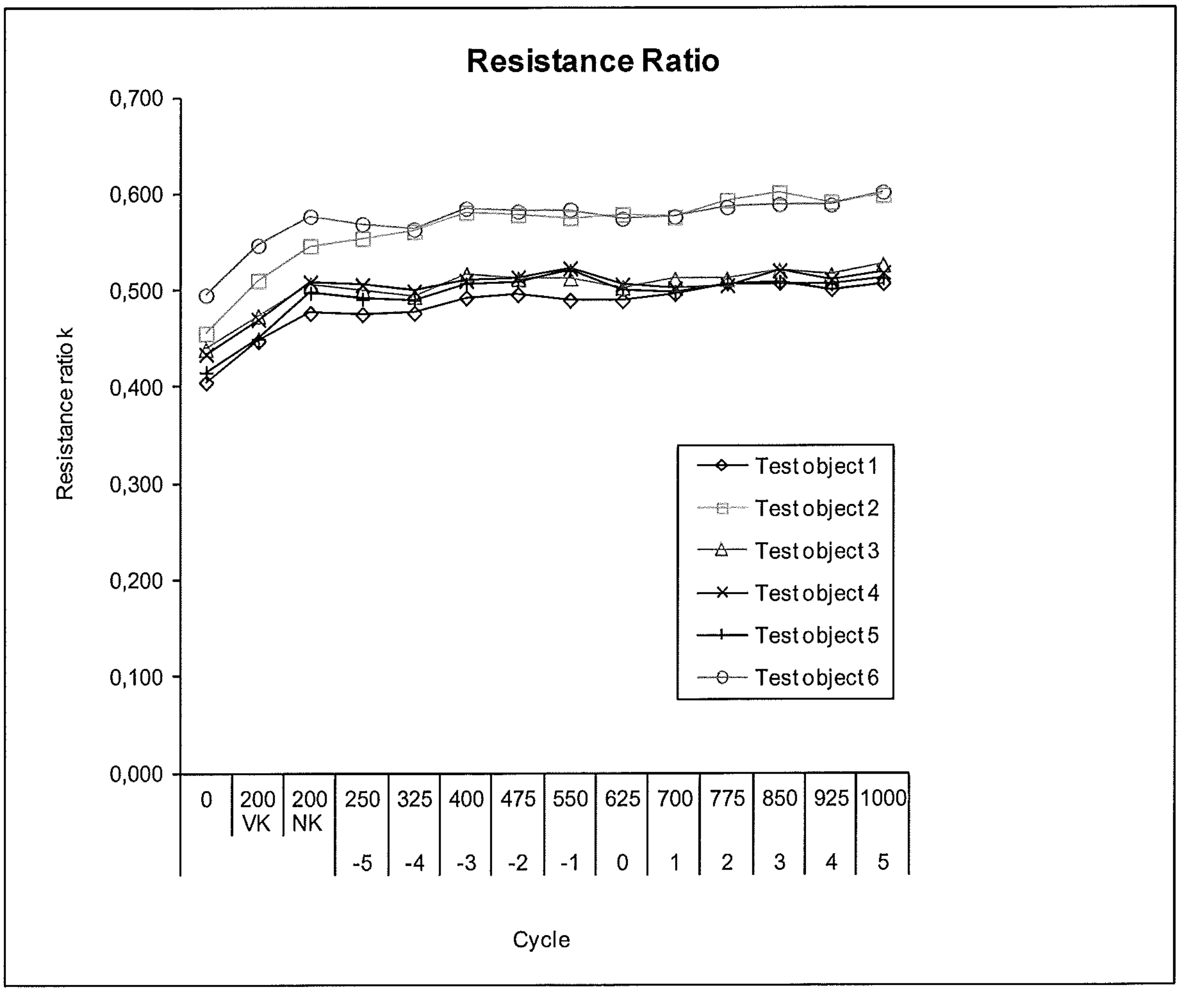

Figure 5.1: Resistance factors

Table 7 resp. Figure 5.2 show the maximum temperatures Θ_{max} of each terminal lug and the appropriate temperatures of the reference conductor during the 1000 heat cycles.

Temperature in °C	Test object 1	Test object 2	Test object 3	Test object 4	Test object 5	Test object 6
Temperature of terminal lug Θ_{max}	81	82	78	79	82	80
Θ_{ref}	140	140	140	140	140	140
$\Theta_{max}/\Theta_{ref} \leq 1$	0,579	0,586	0,557	0,564	0,586	0,571

Table 7: Maximum temperatures
Requirement: $\Theta_{max}/\Theta_{ref} < 1$

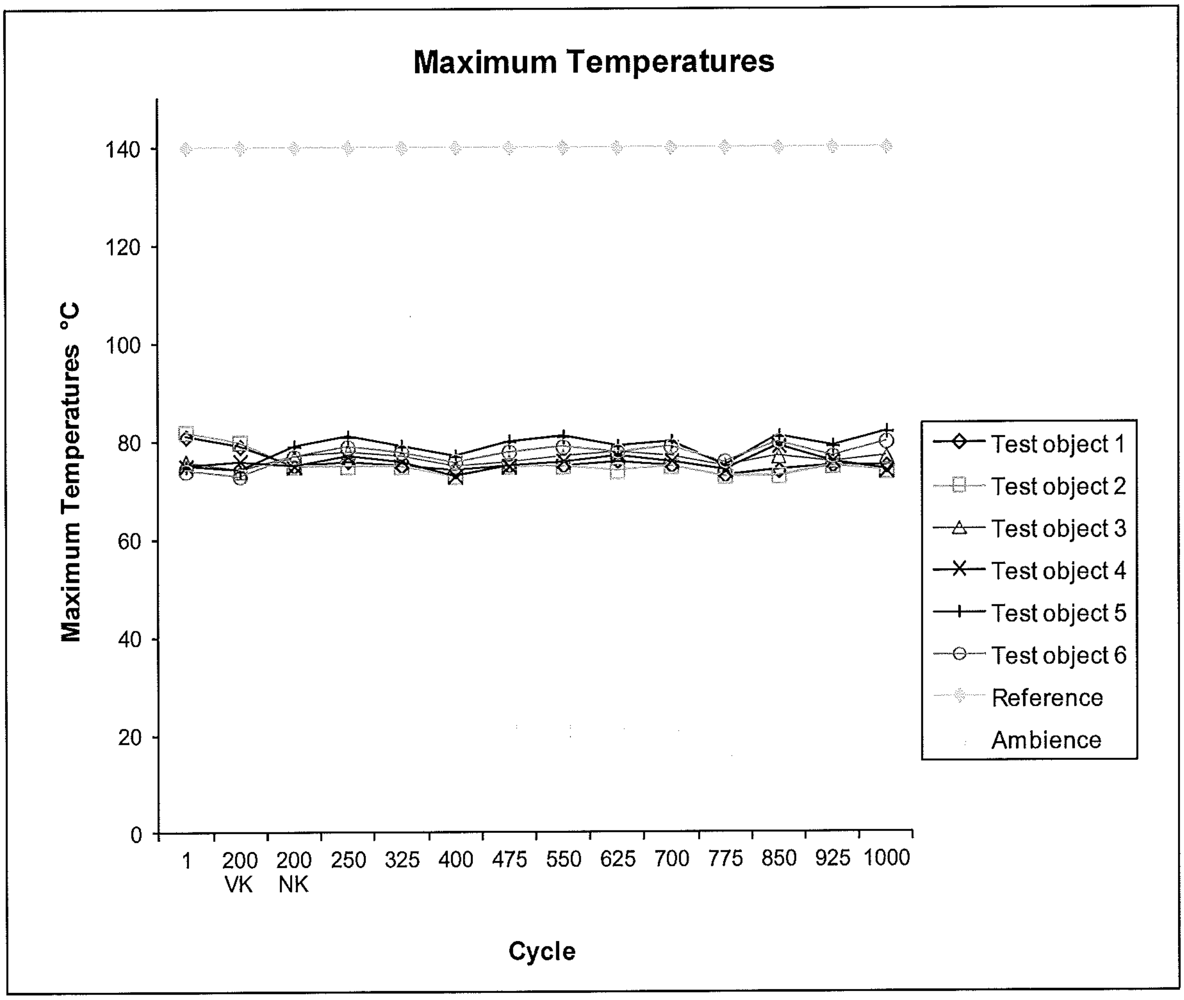

Figure 5.2: Maximum temperatures
Requirement: $\Theta_{max}/\Theta_{ref} < 1$

Table 8 shows the statistical evaluation of the resistance factors of the last 11 measurements, including the mean values of the resistance factors, the standard deviation s, the mean scatter β and the change in resistance factor D.

	Test object 1	Test object 2	Test object 3	Test object 4	Test object 5	Test object 6	Mean Value	s	β
Mean value	0,494	0,581	0,511	0,510	0,505	0,582	0,53059	0,03987	0,12400
b	0,00305	0,00394	0,00205	0,00092	0,00133	0,00251			
M	0,06166	0,06788	0,04002	0,01794	0,02631	0,04311			
S	0,02345	0,02525	0,02647	0,02993	0,03354	0,02414			
D	0,085	0,093	0,066	0,048	0,060	0,067			

Table 8: Statistical evaluation
Requirements: $\beta < 0{,}30$; $D < 0{,}15$

Table 9 shows the resistance factor ratio λ of the terminal lugs.

Cycle	Test object 1	Test object 2	Test object 3	Test object 4	Test object 5	Test object 6
0	1,000	1,000	1,000	1,000	1,000	1,000
200 VK	1,105	1,120	1,078	1,083	1,084	1,104
200 NK	1,177	1,199	1,152	1,172	1,199	1,165
250	1,174	1,216	1,139	1,165	1,183	1,149
325	1,177	1,231	1,124	1,150	1,180	1,138
400	1,216	1,275	1,176	1,175	1,221	1,181
475	1,224	1,269	1,165	1,183	1,227	1,175
550	1,210	1,262	1,166	1,204	1,253	1,179
625	1,208	1,270	1,145	1,165	1,206	1,159
700	1,226	1,264	1,165	1,156	1,201	1,164
775	1,253	1,302	1,164	1,163	1,222	1,183
850	1,255	1,319	1,185	1,198	1,222	1,189
925	1,238	1,298	1,174	1,177	1,219	1,188
1000	1,253	1,313	1,198	1,194	1,234	1,215

Table 9: Resistance factor ratio
Requirements: $\lambda < 2{,}0$

5.6 Tensile Test

The test was carried out as described in 4.

Initial load: $F = 0{,}1$ kN

Rate of application: 500 N/s

Maximum force: $F = 3{,}8$ kN, $t = 1$ min.

With each test object no slipping occurred during the last minute of the test.

6 Conclusion

The mechanical terminal lug (barrel) type CSK 95-240/CP (manufacturer Behr Bircher Cellpack BBC Radeberg GmbH) mounted on aluminium conductors rmv 95 mm^2 passed all tests described in clause 2 successfully. The test objects fulfilled the requirements of the type test according to IEC 61238-1 05/2003.

Karlsruhe, 15.11.2013