MEĐUNARODNO REGIONALNO SAVETOVANJE O ELEKTRODISTRIBUTIVNIM MREŽAMA

REGIONAL CONFERENCE AND EXHIBITION ON ELECTRICITY DISTRIBUTION

Crna Gora, Herceg Novi, 5 - 8. oktobar 2004. / *Montenegro, Herceg Novi, October 5 - 8, 2004*

* *

HEAT CYCLE TESTS OF MASSIVE ALUMINIUM CONNECTORS TYPE AM FOR ELECTRIC POWER PLANTS PURSUANT TO STANDARD IEC 61284

L. Sikimić, High Technic School - Požarevac, Serbia&Montenegro
B. Vlaović, NHBG ŽIKS – HARD, Beograd, Serbia&Montenegro

1. INTRODUCTION

This paper describes heat cycle tests of the massive aluminium joints type AM, which are intended for HV electric power plants. It was in detail described the procedure of the type heat cycle tests of the massive aluminium joints type AM, which had been performed in LV laboratory of Electric Power Institute - IRCE in Serbian Sarajevo.
The aim of the type heat cycle tests is insuring the long-term electrical perfomace of current-carrying joints. In service the joints have to satisfy the following requests:

- the electrical resistance of the joint will remain stable
- the temperature of the joint will not exceed the temperature of the conductor to which it is attached
- losses of corona and radio interference voltage will be minimal

The carried out analysis of the nacional standards that treat heat cycle tests of current-carrying joints was showed that standard IEC 61284 is the severest. The type heat cycle tests of the massive aluminium joints has been performed in LV laboratory of Electric Power Institute - IRCE in Serbian Sarajevo. Electric Power Institute – IRCE agreed with manufacturer of the joints (NHBG ŽIKS – HARD) to test the joints in compliance with standard IEC 61284.
A large number of the diferent type of the joints is successfuly certified. This paper presents the results of the massive aluminium joints type AM, catalogue numbers AM00 30 30 and AM14 30 50.
The massive aluminium joints type AM are produced from low percentage aluminium alloy (*Al* over 94%). They are intended for connecting (strong current connections) of aluminium an Al-steel conductors mutually and with electrical power equipment with aluminium connectors or connectors adapted for aluminium. They are especially convenient for conecting several conductors in bundle at small distances (about 50 *mm*) as well as for quick interventions in the field, because hydraulic presses for compression are not needed. The massive aluminium joints type AM of manufacturer NHBG ŽIKS – HARD is presented in *Fig. 1*.

Figure 1 *– The massive aluminium joints type AM of manufacturer NHBG ŽIKS – HARD*

2. THE TYPE HEAT CYCLE TESTS

In accordance with *13.5.3.2* of IEC-61284 each the joint is successfuly certified the type tests if it satsfied the following criteria:

- The initial resistance of the joints shall not differ by more than 30% from the mean of the initial resistance of each of the four joints assembled for test,
- The temperature of the joints, measured every 0,1 *N* cycles when the test current is flowing, shall not exceed that of the reference conductor,
- The average resistance of the joint over the last 0,5 *N* cycles shall not exceed the initial resistance of the joint by more than 50%,
- A graph of resistance every against number of cycles shall demonstrate with a reasonable probability that the rise in resistance over the last 0,5 *N* cycles is not more than 15% of the average resistance over the same period (Annex E)
- The joint resistance measured after the short-time overcurrent pulse test shall not exceed the resistance value measured before the short-time overcurrent pulse test by more than 50%

3. PROCEDURE OF THE HEAT CYCLE TESTS

Before start of the testing it had been carried out the visual and the dimensional control of samples of the joints in order to verify shapes, dimensions and surfaces of the joints with the original drawing of the tested joints.
The test arrangements is carried out in accordance with 13.4 of IEC-61284. The test assembly includes eight the joints that is shown in *Fig. 2*. Four the joints are AM00 30 30 and four joints are AM14 30 50. The joints are mutually connected by Al-steel conductors 490/65 mm^2. The length of the reference conductor shall be no less than100 times its diameter, up to a maximum of 4 *m* long. The length of the reference conductor is *3,6 m.*
In order to achieve appropriate contact pressure, the screws are tightening with corresponding force, i.e torque. Permissible torque for characteristic screws is given in catalogue of the joints.
The heat cycle test consist of *N* electrical load cycles. The number *N* of cycles is chosen from Table 1.

TABLE 1 *– CONDITIONS FOR HEAT CYCLE TEST*

Number of the heating cycles *N*	Temperature rise of the reference conductor T_f $[^0C]$	Number of pulses of overcurrent N_{sc}
1000	70	3
500	100	3
100	130	8

PRETRAŽIVANJE / SEARCH
ŠTAMPANJE / PRINT
IZLAZ / EXIT

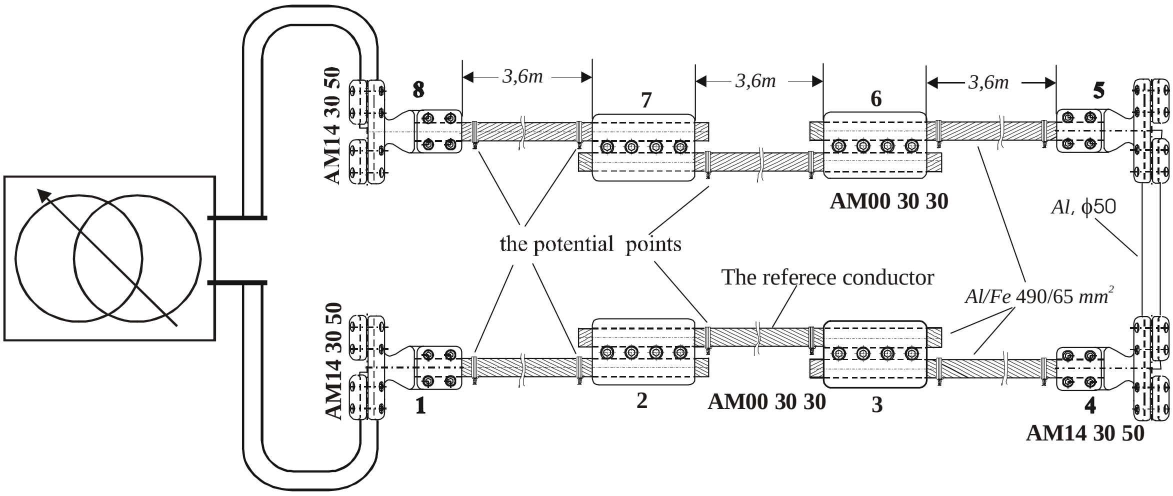

***Figure 2** – Schema of the test assembly for heat cycle test for the joints type AM*

The test assembly can be tested by different number *N* of the heating cycles, from *N*=100 to *N*=1000. If the number *N* of cycles is lower, the temperature of the reference conductor is higher. In order to cut a time of type tests, the joints is tested with *N=100*. Each cycle includes a heating period where the test assembly is loaded by the test current I_{isp}, followed by a subsequent cooling period when the current is switched off. The test current I_{isp} is an alternating current and its value I_{isp}=1350 A.

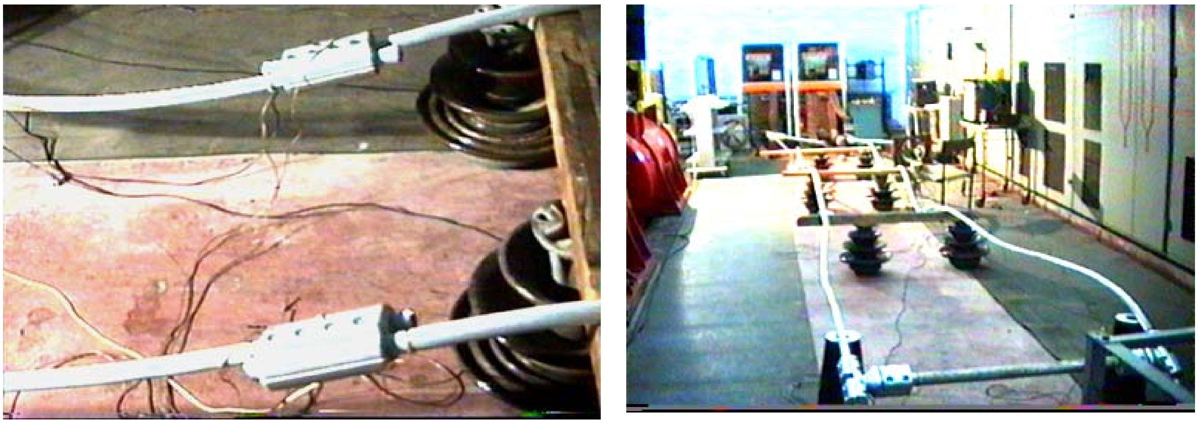

***Figure 3** – The joints AM00 30 30 and the test assembly for heat cycle test in LV laboratory of Electric Power Institute - IRCE*

The temperatures of the joints and reference conductors, including ambient, are measured by thermocouples. The thermocouples are inserted in a small hole drilled into the joints. On the reference conductor the thermocouple is positioned at the mid-point and securely located in a small hole drilled into conductor.

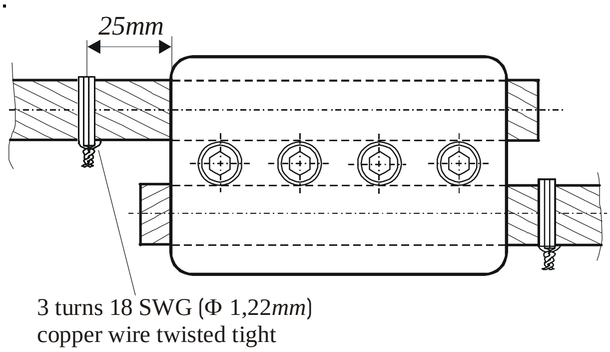

***Figure 4** – An example of a practical potential point for the joint AM00 30 30*

The resistance of each test joint and reference conductor is measured between the potential points installed in accordance with 13.4.3 of IEC-61284. Potential points for resistance measurements are installed on the conductor at a distance of 25 *mm* from ends of all test joints (*Fig. 4*). For stranded conductors an example of a practical potential point consists of turns of tinned copper wire (*Fig. 4*).
The resistance measurements is made with direct current having a magnitude not higher than 10% of the alternating test current. Instrument used for resistance measurements has accurate to within 1%.
The test is carried out in reasonably draught-free conditions at an ambient temperature 20 ^{o}C.
When the test assembly is loaded by the test current, the value and duration of the test current shall be as to raise the reference conductor temperature to value of T_f^{+5} above ambient and maintain this temperature for 30 *min*. At the end of the heating period the tested current is interrupted and the reference conductor allowed to cool to within 5 ^{o}C above ambient. This sequence of operation is repeated so that 0,1 *N* cycles of heating and cooling are applied.
During the last five cycles of the 0,1 *N* cycles the conductor temperature and temperature of each joint is measured during the last 15 *min* of the 30 *min* period. The test assembly then is allowed to cool to ambient and the resistance of each joint is measured. Heat cycling then is continued with measurement of temperature and resistance at the end of each 0,1 *N* cycles until 0,5 *N* cycles have been completed.
Eight short-time overcurrent pulses is applied after 50 heat cycles. The duration of the pulse is about 5 s. The value of short-time overcurrent has a magnitude sufficient to raise the reference conductor temperature to value of 180 ^{o}C above ambient. The test assembly is allowed to cool to ambient between pulses. The resistance of each joint under test is measured and recorded before and after the short-time overcurrent pulse test.
A further 0,5 *N* cycles then is followed with resistance measurement taken every 0,05 *N* cycles and temperature measurement every 0,1 *N* cycles.
The temperature measurement of each joint is shown in *Fig. 5* and *Fig. 6*. The resistance measurement of each joint is shown in *Fig. 7* and *Fig. 8*.

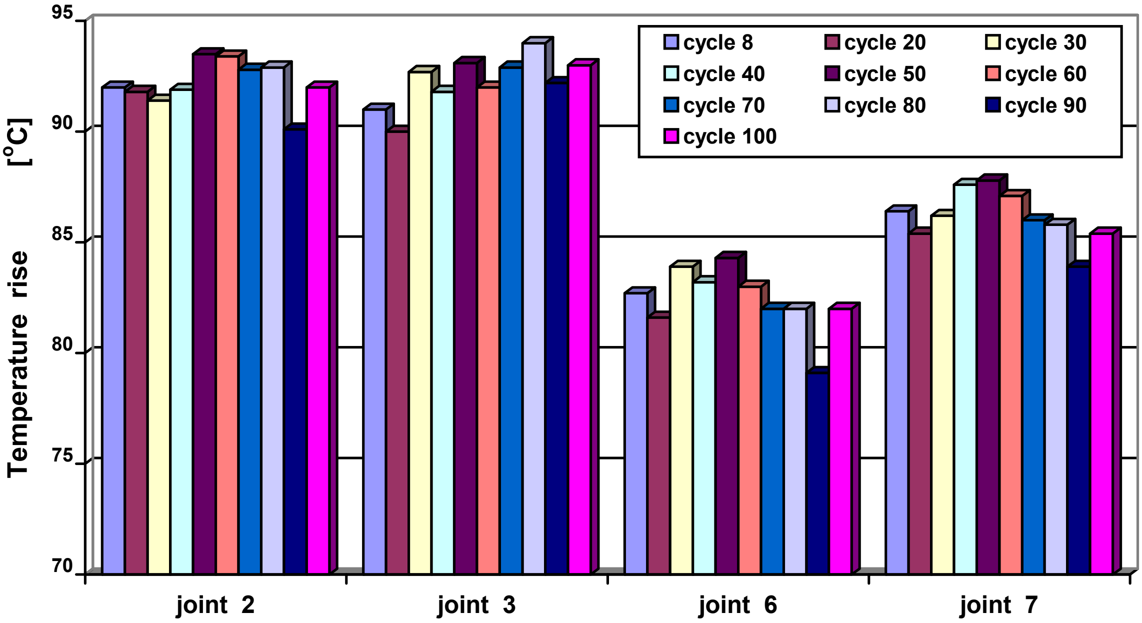

Figure 5 *– Temperature of the joint AM00 30 30 during heat cycle test*

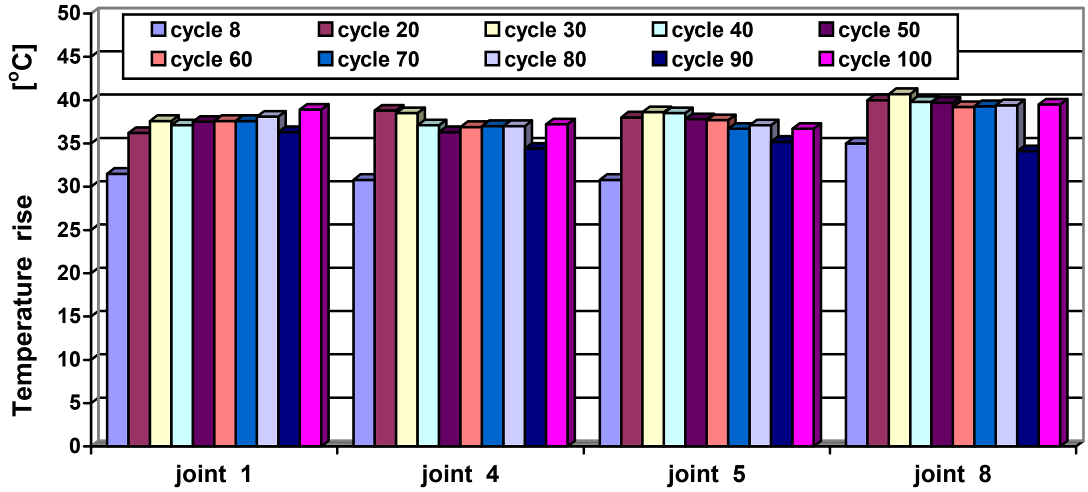

***Figure 6** – Temperature of the joint AM14 30 50 during heat cycle test*

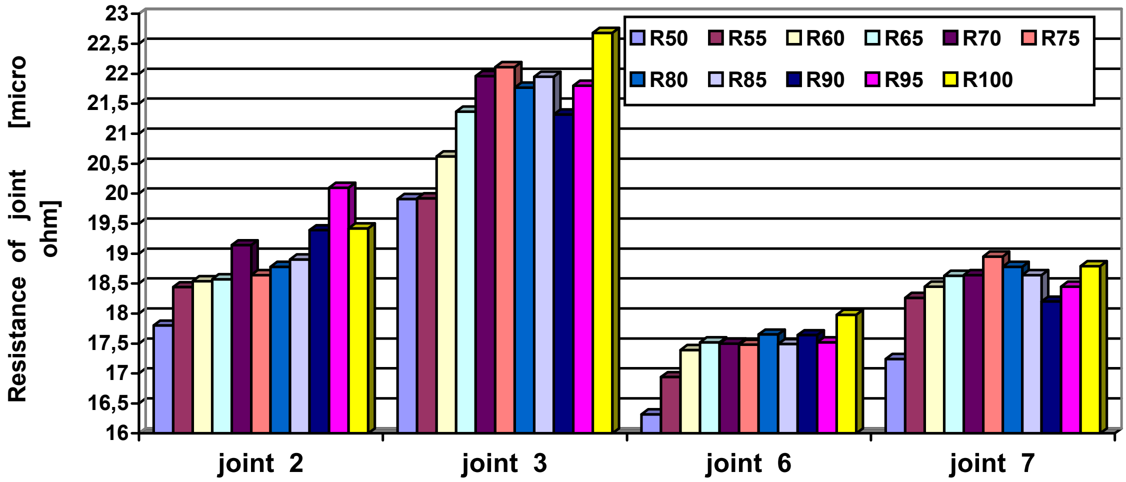

***Figure.7**– Resistance of the joint AM00 30 30 during heat cycle test*

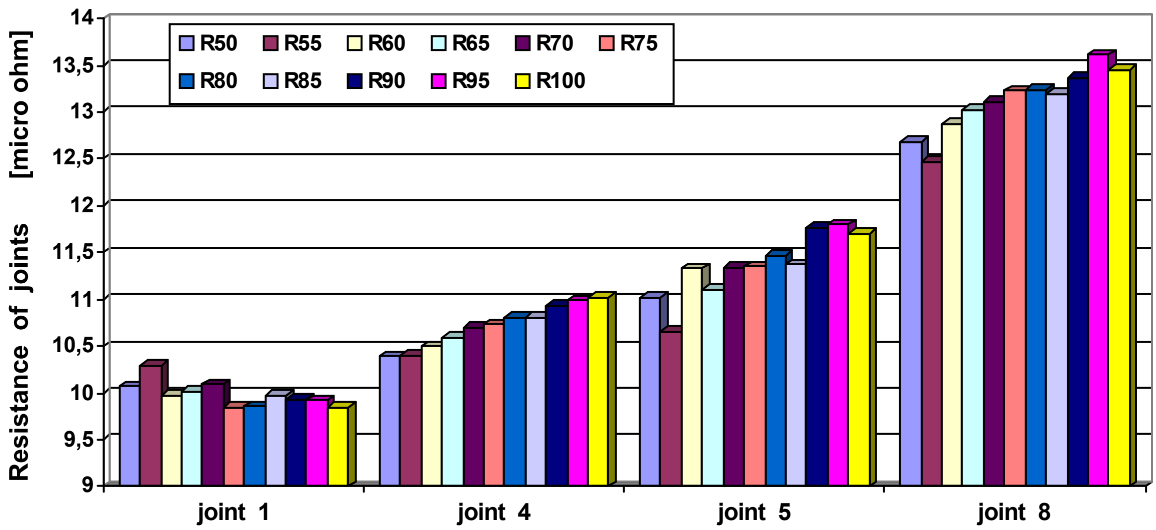

***Figure 8** – Resistance of the joint AM14 30 50 during heat cycle test*

4. ANALYSIS OF RESULTS OF HEAT CYCLE TEST

The initial resistances of each of joints is marked as $R_0(i)$. The mean value of the initial resistances of each of four joints assembled for test which are measured before heat cycle test:

$$R_{sr\,AM00} = \frac{\sum_{i=1}^{4} R_0(i)}{4} = 15{,}4[\mu\Omega]; \qquad R_{sr\,AM14} = \frac{\sum_{i=1}^{4} R_0(i)}{4} == 10{,}2[\mu\Omega]$$

The deviation of the initial resistances of each of four joints assembled for test from the mean resistance R_{sr} is:

$$R_{dev}(i) = \frac{R_{sr} - R_0(i)}{R_{sr}} \cdot 100 \quad [\%]$$

Values of the initial resistances of each joint and the mean resistance are presented in TABLE 2. These results show that the initial resistances of each of joints is not differ by more 30 % from the mean value of the initial resistances of each of four joints assembled for test. It is in accordance with *13.5.3.2* of *IEC 61284.*

TABLE 2 **-** VALUES OF THE INITIAL RESISTANCES OF EACH JOINT AND THE MEAN RESISTANCE FOR AM00 30 30 AND AM14 30 50

Resistance / *Sample*		R_0 $[\mu\Omega]$	R_{sr} $[\mu\Omega]$	R_{dev} $[\%]$	$R_{dev} \leq 30\%$
AM0030 30	2	15,88	15,4	3	satisfied
	3	16,52	15,4	7	satisfied
	6	13,04	15,4	18	satisfied
	7	16,17	15,4	5	satisfied
AM14 30 50	1	9,29	10,2	9	satisfied
	4	10,16	10,2	1	satisfied
	5	10,63	10,2	4	satisfied
	8	10,83	10,2	6	satisfied

By analysis of values of the temperature of each joints assembled for test and the temperature of the reference conductor (*Fig. 5* and *Fig. 6*), it is obviously the temperature of each joints, measured every 0,1 *N* cycles is substantially lower than the temperature of reference conductor. It is in accordance with *13.5.3.2* of *IEC 61284.* Resistance measurement of joints over the last 0,5 *N* cycles (R_{sruz}) are presented in *TABLE 3*.

TEBLE 3 – VALUES OF THE RESISTANCES OF EACH JOINT OVER THE LAST 0,5 *N* CYCLES

Cycles	*50*	*55*	*60*	*65*	*70*	*75*	*80*	*85*	*90*	*95*	*100*
Resistance	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	R_{10}	R_{11}
Sample	$[\mu\Omega]$	$[\mu\Omega]$	$[\mu\Omega]$	$[\mu\Omega]$	$[\mu\Omega]$	$[\mu\Omega]$	$[\mu\Omega]$	$[\mu\Omega]$	$[\mu\Omega]$	$[\mu\Omega]$	$[\mu\Omega]$
2	17.80	18.44	18.54	18.57	19.14	18.64	18.78	18.90	19.39	20.1	19.42
3	19.91	19.92	20.62	21.37	21.96	22.11	21.77	21.95	21.32	21.8	22.68
6	16.32	16.94	17.39	17.52	17.50	17.48	17.65	17.49	17.64	17.52	17.98
7	17.24	18.26	18.45	18.63	18.64	18.95	18.78	18.64	18.2	18.45	18.79
1	10,06	10,03	9,98	10,0	10,08	9,84	9,86	9,98	9,93	9,92	9,84
4	10,39	10,40	10,49	10,59	10,69	10,73	10,79	10,79	10,93	10,99	11,02
5	11,02	10,65	11,32	11,10	11,33	11,35	11,46	11,37	11,76	11,79	11,70
8	12,68	12,46	12,86	13,02	13,10	13,22	13,23	13,2	13,36	13,60	13,45

The mean resistance of the joint between 0,5 *N* and *N* load cycles is defined as:

$$R_{sruz} = \frac{R_1 + R_2 + R_3 + R_4 + R_5 + R_6 + R_7 + R_8 + R_9 + R_{10} + R_{11}}{11}$$

The deviation of the initial resistances of each of four joints (R_o) assembled for test from the average resistance of the joint over the last 0,5 *N* cycles (R_{sruz}) is:

$$\Delta R_{50\%} = \frac{R_{sruz} - R_0}{R_{sruz}} \cdot 100 \qquad [\%]$$

The mean resistance over the last 0,5 *N* cycles (R_{sruz}) are presented in *TABLE 4*. It is obviously the average resistance over the last 0,5 *N* cycles was not exceed the initial resistances of the joints by more than 50 %. It is in accordance with *13.5.3.2* of *IEC 61284.*

TEBLE 4 –THE AVERAGE RESISTANCE OVER THE LAST 0,5 *N* LOAD CYCLES

Sample	R_0 [$\mu\Omega$]	R_{sruz} [$\mu\Omega$]	$\Delta R_{50\%}$ %	*CONCLUSION*
2	15,88	**18.88**	**16**	satisfied
3	16,52	**21.31**	**23**	satisfied
6	13,04	**17.40**	**25**	satisfied
7	16,17	**18.45**	**12**	satisfied
1	9,29	**9,95**	**7**	satisfied
4	10,15	**10,71**	**5**	satisfied
5	10,62	**11,35**	**6**	satisfied
8	10,83	**13,1**	**17**	satisfied

A graph of resistance every against number of cycles shall demonstrate with a reasonable probability that the rise in resistance over the last 0,5 *N* cycles is not more than 15% of the mean resistance over the same period (Annex E). The calculation of the change of resistance between 0,5 *N* and *N* load cycles, using as a basis the line of best fit (obtained by method of least squares) for the data. A Slope of line of best fit of resistance measurements is defined as:

$$B = \frac{-5R_1 - 4R_2 - 3R_3 - 2R_4 - R_5 + R_7 + 2R_8 + 3R_9 + 4R_{10} + 5R_{11}}{11}$$

The change of resistance is expressed as a fraction of the mean resistance readings from 0,5 *N* to *N* load cycles inclusive, and is designated *M*:

$$M = \frac{10 \cdot B}{R_{sruz}}$$

If $M > 0{,}15$, the sample of joints is rejected. If $M \le 0{,}15$, we have to extend change of resistance calculation to take account of the scatter of resistance readings around the line of best fit. This is expressed as a fraction of the mean of resistance readings from 0,5 *N* and *N* load cycles and is designated *S*:

$$S = \frac{2.07}{R_{sruz}} \cdot \sqrt{\frac{A_1^2 + A_2^2 + A_3^2 + A_4^2 + A_5^2 + A_6^2 + A_7^2 + A_8^2 + A_9^2 + A_{10}^2 + A_{11}^2}{9}}$$

where:

$A_1 = R_1 - R_{sr} + 5B;$ $A_2 = R_2 - R_{sr} + 4B;$ $A_7 = R_7 - R_{sr} - B;$ $A_8 = R_8 - R_{sr} - 2B;$

$A_3 = R_3 - R_{sr} + 3B;$ $A_4 = R_4 - R_{sr} + 2B;$ $A_9 = R_9 - R_{sr} - 3B;$ $A_{10} = R_4 - R_{sr} - 4B;$

$A_5 = R_5 - R_{sr} + B;$ $A_6 = R_6 - R_{sr};$ $A_{11} = R_{11} - R_{sr} - 5B;$

Than, we have to calculate a quantity: $D = M + S$. *D* is the change of resistance between 0,5 *N* and *N* load cycles, calculated as a fraction of the mean resistance in this interval, with 95 % confidence based on the assumption that distribution of the resistance values about the line of best fit is normal.

The acceptance criterion is that *D* is not exceed 0,15. *B, S, M,* and *D* are presented in *TABLE 5.*

TEBLE 5 – VALUES OF PARAMETARS B, M, S, D OF EACH JOINT OVER THE LAST 0,5 N CYCLES (Annex E) FOR AM00 30 30 и AM14 30

Sample		R_{sr}	$\Delta R_{50\%}$	***B***	***M***	***S***	***D=M + S***	*CONCLUSION*
		$[\mu\Omega]$	%	%	%	%	%	
AM00 30 30	*2*	18.88	**16**	0.1599	0.0846	0.0353	**0.120**	≤ 0.15 (satisfied)
	3	21.31	**23**	0.1767	0.0829	0.0651	**0.148**	≤ 0.15 (satisfied)
	6	17.40	**25**	0.1042	0.0598	0.0332	**0.093**	≤ 0.15 (satisfied)
	7	18.45	**12**	0.072	0.0390	0.0461	**0.085**	≤ 0.15 (satisfied)
AM14 30 50	*1*	9,95	**7**	-0,0176	-0,0177	0,01357	**-0,004**	≤ 0.15 (satisfied)
	4	10,71	**5**	0,0666	0,06226	0,00098	**0,072**	≤ 0.15 (satisfied)
	5	11,35	**6**	0,0909	0,0801	0,03127	**0,111**	≤ 0.15 (satisfied)
	8	13,1	**17**	0,0946	0,07221	0,01983	**0,092**	≤ 0.15 (satisfied)

Eight short-time overcurrent pulses is applied after 50 heat cycles. The duration of the pulse is 1,56 s. The value of short-time overcurrent had a magnitude 44,8 kA_{eff} sufficient to raise the reference conductor temperature to value of 180 ^{o}C above ambient. The test assembly is allowed to cool to ambient between pulses. The resistance of each joint under test is measured and recorded before and after the short-time overcurrent pulse test. The joint resistances measured after the short-time overcurrent pulse test were not exceed the resistances measured before the short-time overcurrent pulse test by more than 11%. The permissible deviation is 50 %. It is in accordance with *13.5.3.2* of *IEC 61284.*

5. CONCLUSION

The carried out analysis shows that the massive aluminium joints type AM whose catalogue numbers AM00 30 30 and AM14 30 50, produced by NHBG ZIKS – HARD, satisfy completely type heat cycle test according to standard IEC 61284.
The very important thing for Electric Power of Serbia and Montenegro is that a quality manufacturer of the joints for HV electric power plants, that were exclusively imported only a few years ago, appeared at the domestic market. Successful type tests of several different types of the joints (type AM, type AK, type B, ...), were taken last year. The results of type tests of AM joints are presented in this paper.

6. LITERATURE

1. **IEC 61284** Overhead lines – Requirements and tests for fittings
2. Test Reports of Electric Power Institute IRCE - S. Sarajevo
3. Catalogue of the manufacturer of the joints (NHBG ZIKS - HARD)

HEAT CYCLE TESTS OF MASSIVE ALUMINIUM CONNECTORS TYPE AM FOR ELECTRIC POWER PLANTS PURSUANT TO STANDARD IEC 61284

SUMMARY

This paper describes heat cycle tests of the massive aluminium joints type AM, which are intended for HV electric power plants. It was in detail described the procedure of the type heat cycle tests of the massive aluminium joints type AM, which had been performed in LV laboratory of Electric Power Institute - IRCE in Serbian Sarajevo.

The carried out analysis of the nacional standards that treat heat cycle tests of current-carrying joints was showed that standard IEC 61284 is the severest. Electric Power Institute – IRCE agreed with manufacturer of the joints (NHBG ŽIKS – HARD) to test the joints in compliance with standard IEC 61284.

The carried out analysis shows that the massive aluminium joints type AM whose catalogue numbers AM00 30 30 and AM14 30 50, produced by NHBG ZIKS – HARD, satisfy completely type heat cycle test according to standard IEC 61284.

The very important thing for Electric Power of Serbia and Montenegro is that a quality manufacturer of the joints for HV electric power plants, that were exclusively imported only a few years ago, appeared at the domestic market.