ALUMINUM CRIMP CONNECTORS ON STRAND FILLED CONDUCTORS

THERMAL RUNAWAY ISSUE

2007 FALL ICC MEETING
Scottsdale, AZ
November 5, 2007

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Investigation performed within

COMPARATIVE LABORATORY EVALUATION OF JOINTS AND TERMINATIONS FOR MEDIUM VOLTAGE CABLES

Sponsored by

Electric Power Research Institute

in collaboration with

Center Point Energy (CNP), Houston, TX

SETS OF ACCESSORIES TESTED

15 KV Cold Shrink Joints	3
15 KV Pre-molded Joints	2
15 KV Cold Shrink Terminations	4
35 KV Cold Shrink Terminations	1

6 joints or 4 terminations per set
All terminations and 4 joint sets – crimp connectors
1 joint set – shear bolt connectors

DETAIL OF SAMPLES

- Crimp connectors: 2 to 3 inches in length
- Lug barrels: 0.94 to 3.37 inches in length and 0.6 to 0.85 inch in the outer diameter
- 15 and 35 kV TR-XLPE insulated cables,
  1/0 AWG Al conductor with strand filling compound
  type A-162A   BLH2OCK®
- Accessories were assembled mainly by manufacturer splicers, using different tools

CONNECTORS USED IN JOINTS

Joint	Connector	L	ID	OD
A	Al ferrule	2.000	0.390	0.644
C	Al ferrule	3.045	0.410	0.645
D	Al ferrule	2.150	0.390	0.640
E	Al shear bolt	3.930	-	1.220

TERMINATION LUGS

	Connector	L	ID	OD
A		1.80	0.39	0.64
C		3.37	0.39	0.85
E		1.10	0.40	0.60
F		0.94	0.41	0.64

All barrels are Aluminum

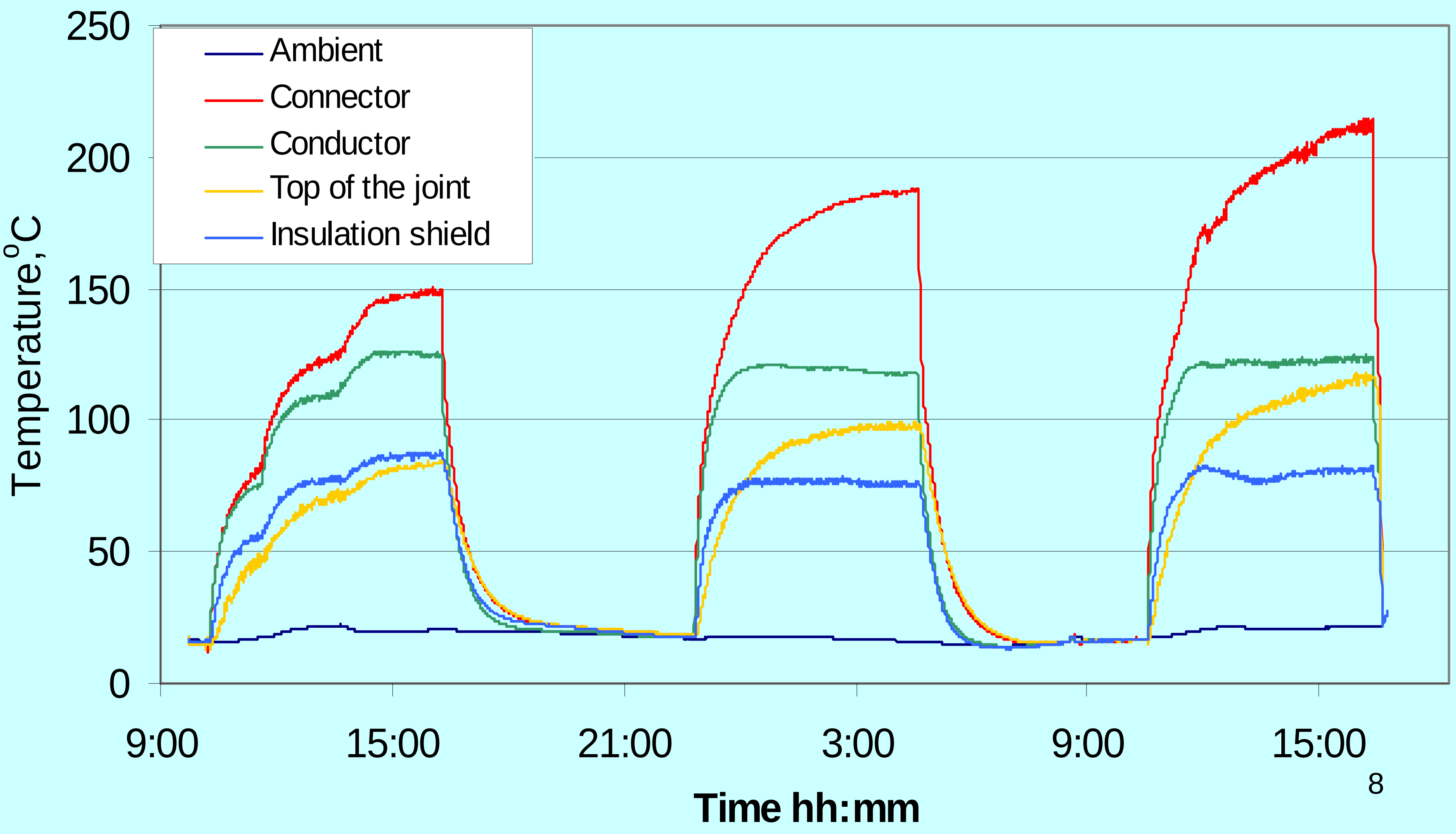
SCHEDULED TEST SEQUENCE

	Joints	Terminations
PD	√	√
AC withstand	√	√
DC withstand	√	√
Impulse withstand	√	
PD	√	√
Cyclic aging	√	√
PD		√
Impulse withstand		√
Pressure leak		√
PD	√	
AC withstand and breakdown	√	√

Manufacturer's "A“ pre-molded 15 kV joint

2nd Dummy assembled by manufacturer's splicer

Crimping tool: Anderson versa-crimp VC6-FT



Manufacturer's "C" pre-molded 15 kV joint

Joints assembled by manufacturer's splicers

Crimping tool: Burndy Y-35, die U25 ART

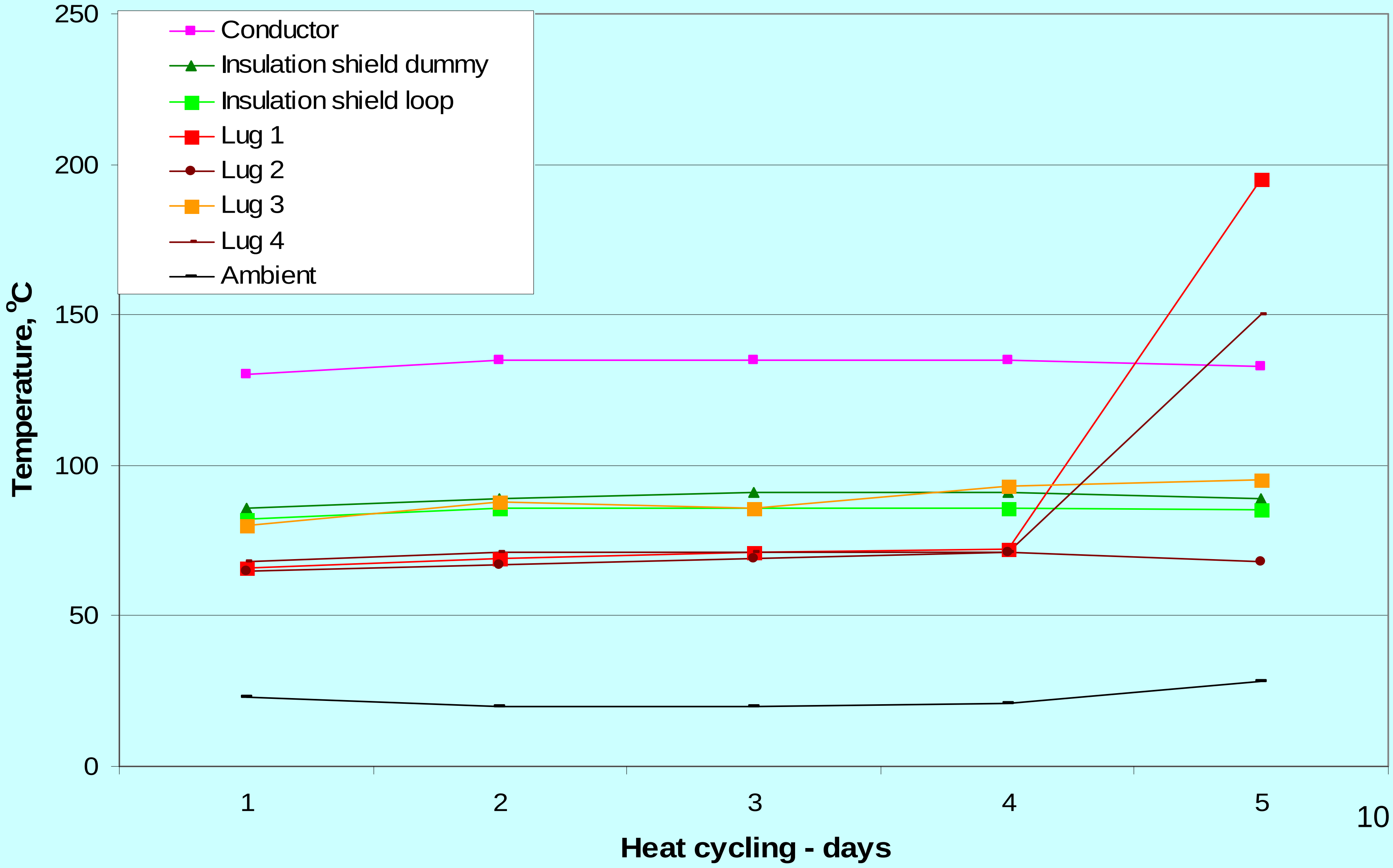
During the 1st day in the aging set-up:

- "dummy": T_{cond}=71 °C, T_{conn}=96 °C, after 1 hour under test
- one of the joints was found to be overheating and shrunk after 2 hours under test

15 KV TERMINATIONS, MANUFACTURER E

Assembled by manufacturer's splicer

Crimping tool: Burndy Y-35, die U25 ART



15 KV TERMINATION, MANUFACTURER F

One of the lugs run away at the first heat cycle.

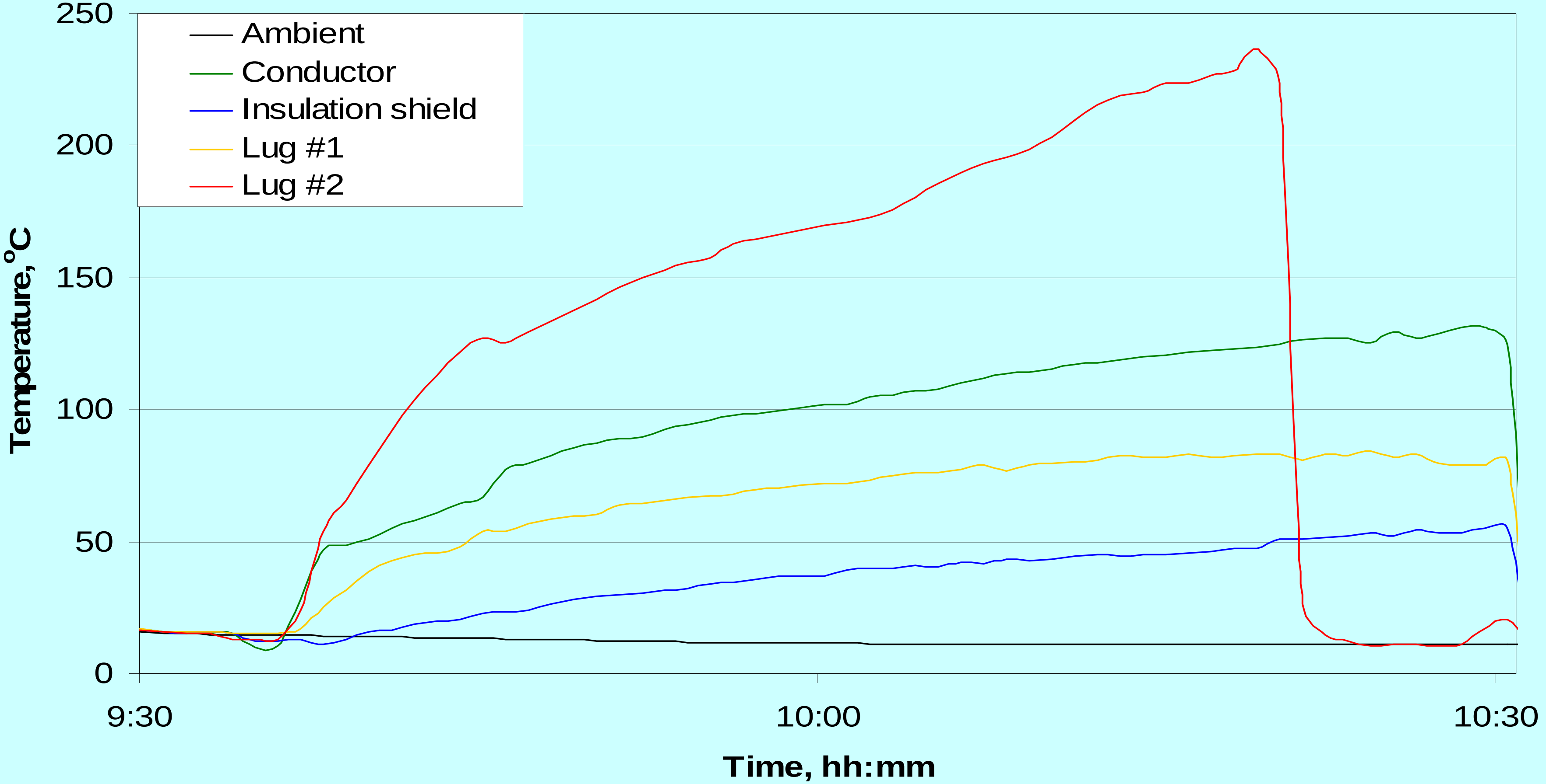
Upon replacing the termination with a spare one, the following temperatures were recorded on each of the four lugs when the conductor temperature was **95** °C:

126, 96, 120, 66 °C

35 KV TERMINATION, MANUFACTURER A

The only available termination that passed the test in 15 kV class

Higher heating current is required for 35 kV cable: 345 vs. 315 A, which constitutes approximately 20 % higher heat dissipation



SUMMARY OF RESULTS ON JOINTS

CRIMP CONNECTORS FAILED EITHER DURING TESTS ON DUMMY, HOT IMPULSE TESTS, OR HEAT CYCLING

THE ONLY SET OF JOINTS THAT PASSED THE ENTIRE TEST SEQUENCE WAS THE ONE WITH SHEAR BOLT CONNECTORS

RESULTS ON TERMINATIONS

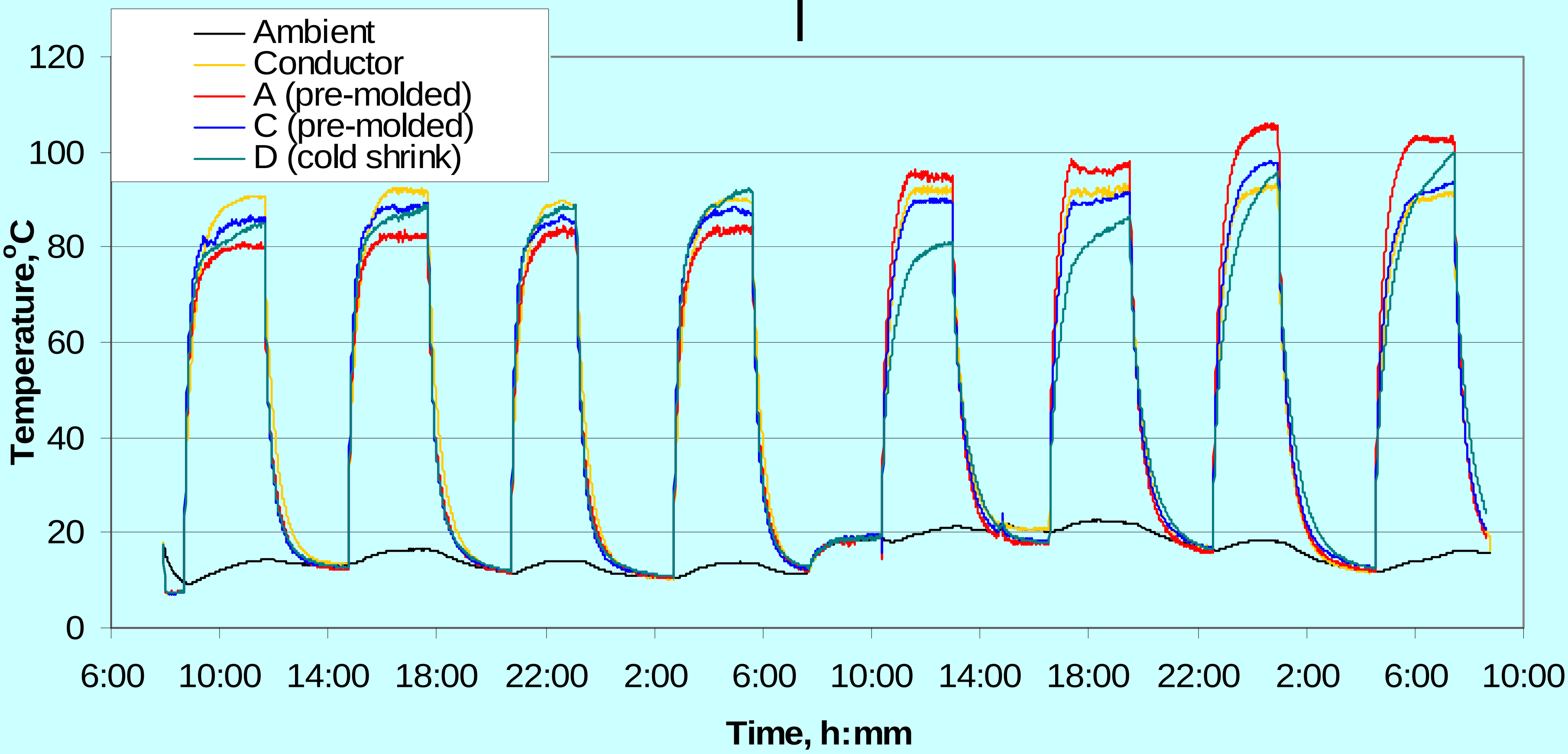
LUGS ON TWO SETS OF 15 KV TERMINATIONS FAILED EITHER DURING TESTS ON DUMMY, HOT IMPULSE TESTS, OR HEAT CYCLING

TWO SETS OF TERMINATIONS (WITH LARGER LUGS) PASSED THE ENTIRE TEST SEQUENCE

THE SAME TYPE OF TERMINATIONS, WITH IDENTICAL LUGS, THAT PASSED THE TESTS ON 15 KV CLASS FAILED ON 35 KV CLASS

INFLUENCE OF THE JOINT BODY ON CONNECTOR TEMPERATURE

Bare connectors ← | → Insulated connectors



JOINT BODY INFLUENCE

Change in the heat transfer mode due to application of the joint body caused:

- 15 ^{o}C reduction of the connector temperature in cold shrink joint
- 10 ^{o}C increase of the connector temperature in one of pre-molded joints

INFLUENCE OF THE FILLING COMPOUND

CONTACT RESISTANCE BETWEEN EACH INDIVIDUAL STRAND AND THE CONNECTOR WAS EVALUATED ON THE FOLLOWING COMBINATIONS:

- Non-filled conductor without antioxidant
- Non-filled conductor with antioxidant
- Strand filled conductor without antioxidant
- Strand filled conductor with antioxidant

SAMPLE DETAILS

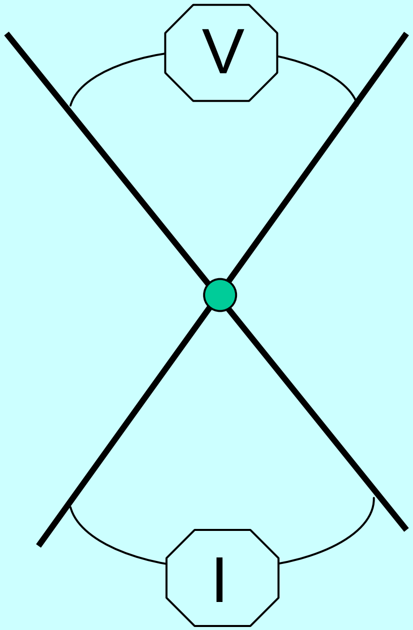
Connector – Al cylinder 1.6 inch long, 0.41 and 0.63 inch inner and outer diameters

Applied over continuous (not cut) conductor

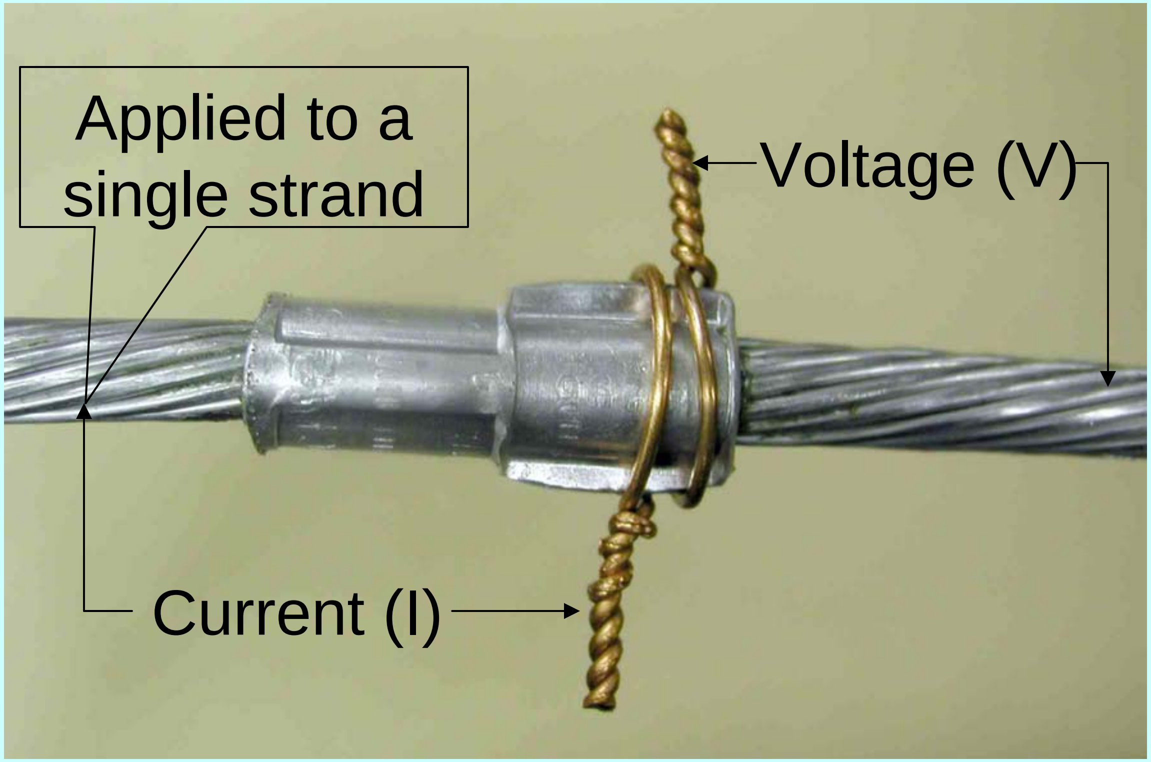
Two crimps, Burndy Y-35, die U25 ART, applied with 90^{o} circumferential shift

Strands separated on one side, at 2 inches from the connector end

MEASUREMENT OF CONTACT RESISTANCE BETWEEN INDIVIDUAL STRANDS



Measurement of contact resistance between crossed wires



Measurement current 16-18 A

TEST PROGRAM

1. Heating during 48 hours in air circulating oven at 130 ^oC and then measurement at room temperature
2. Measurement at 130 ^oC
3. Measurement at room temperature
4. Heat cycling to 130 ^oC in the oven, 50 cycles with 4-hour heating and 6-hour cooling, followed by measurement at room temperature
5. 15 A ac current circulation through the central strand during 16 hours, at 90 ^oC, followed by measurement at room temperature

Combinations without antioxidant showed deterioration during the initial test steps

CONTACT RESISTANCE, μΩ

reduced to 25 ^{o}C

connectors with antioxidant

Temp.	Contact	Outer (12 strands) Min	Outer (12 strands) Max	Outer (12 strands) Avg	Middle (6 strands) Min	Middle (6 strands) Max	Middle (6 strands) Avg	Center (1 strand)
Room	Non-filled	18	104	**33**	32	64	**45**	**49**
	Filled	13	33	**21**	19	74	**38**	**39**
130 ^{o}C	Non-filled	11	23	**16**	19	30	**25**	**29**
	Filled	27	50	**33**	40	85	**60**	**68**
Room	Non-filled	16	27	**21**	22	33	**25**	**29**
	Filled	38	120	**58**	63	125	**94**	**103**
Room, After 50 cycles	Non-filled	15	194	**52**	18	61	**35**	**33**
	Filled	33	199	**80**	41	149	**86**	**109**
After heat and current	Non-filled	15	70	**32**	20	104	**58**	**106**
	Filled	113	5690	**1670**	253	3820	**1270**	**2390**

CONTACT RESISTANCE RESULTS

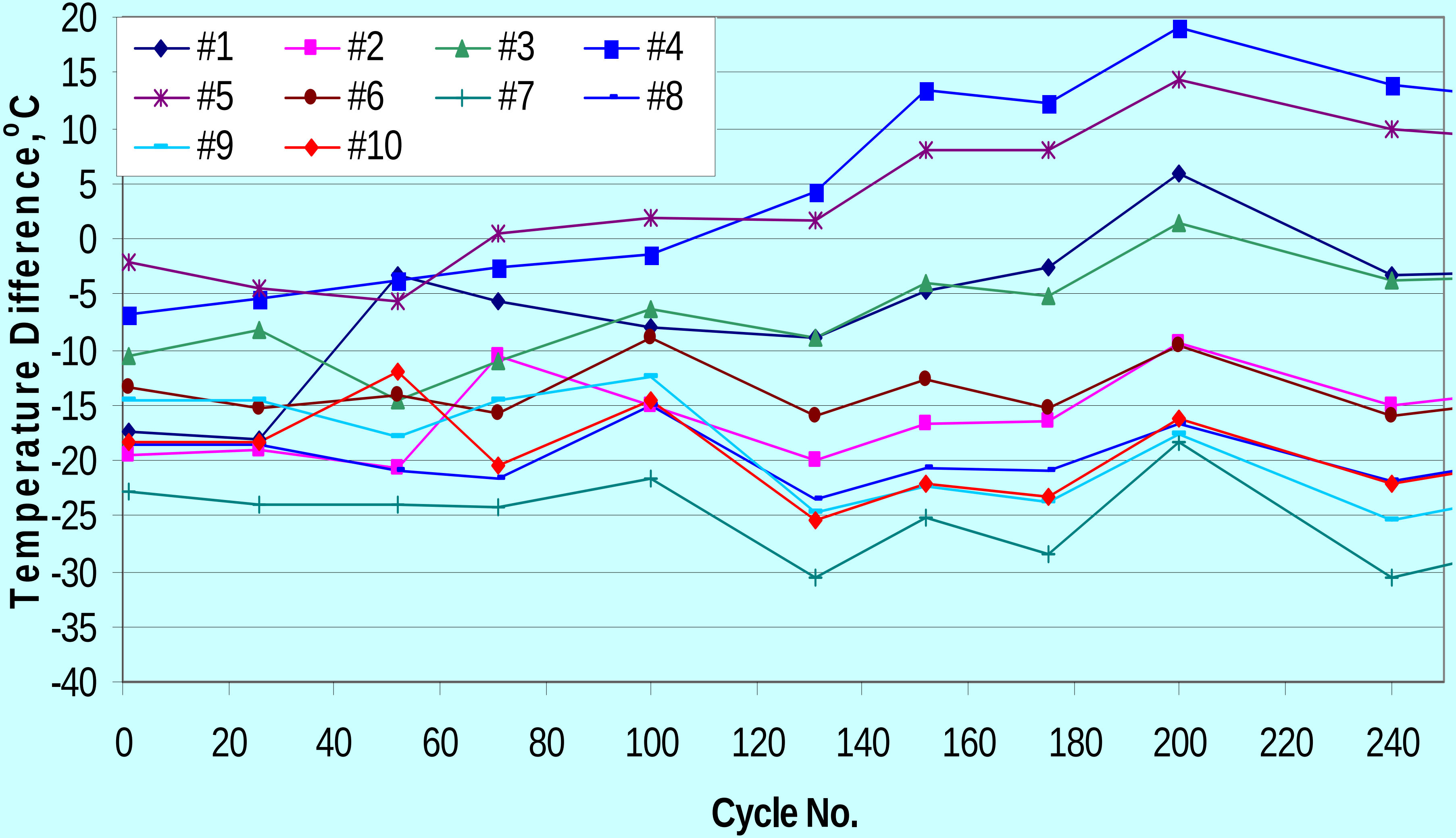
- Connector with antioxidant on non-filled conductor practically did not change its performance
- Contact resistance on the strand-filled conductor slightly increased (2-3 times) during measurements at high temperature (16-18 A applied for a few seconds) and significantly deteriorated (up to 20 times) during continuous current circulation at high temperature

750 KCMIL COMPACT CONDUCTOR

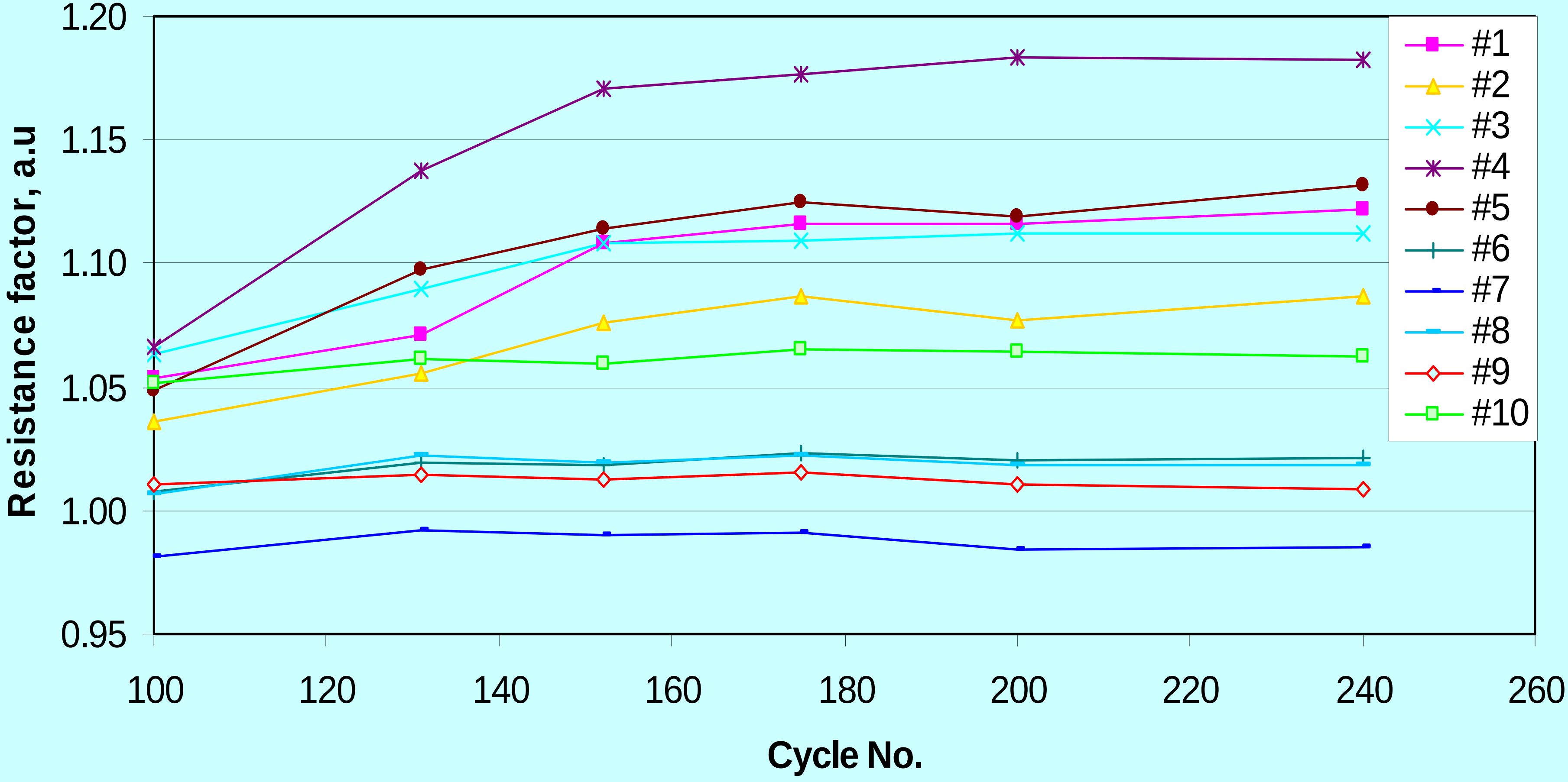
filling compound type A-162A BLH2OCK®

- Tests are underway on 2 connector types with circumferential and hexagonal crimps
- Test protocol – as per ANSI 119.4. Two hundred forty cycles are completed

CONNECTOR TEMPERATURE



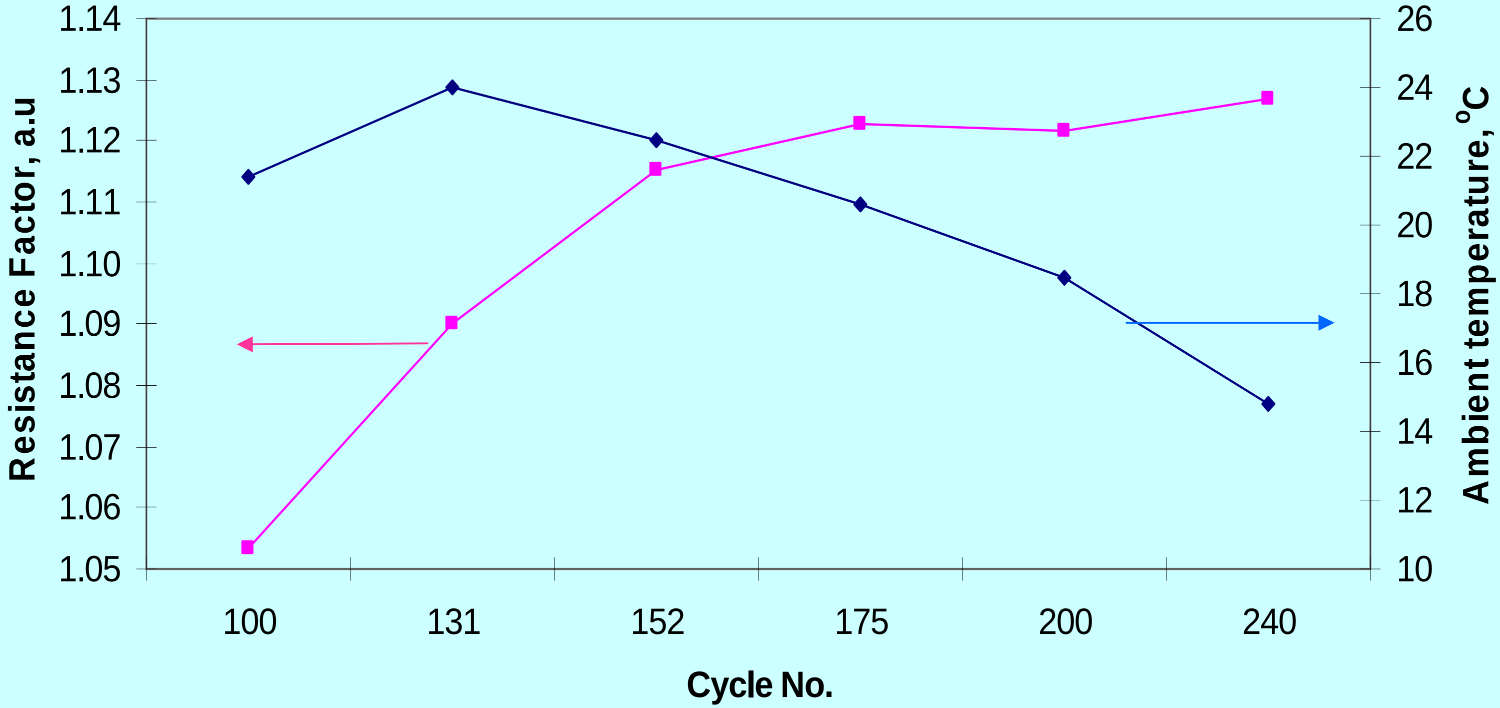
CONNECTOR RESISTANCE



CONNECTOR DETERIORATION VS. AMBIENT TEMPERATURE

ANSI 119.4 specifies temperature of the control conductor as 100 to 105 °C above ambient

Ambient temperature 15 to 35 °C



RESULTS ON 750 KCMIL CONDUCTOR

- Connectors with hexagonal crimps demonstrate good performance, while those with circumferential crimps show tendency to deterioration
- One of the reasons could be that connectors with circumferential crimps are designed for 750 kcmil compressed conductors, while being tested on 750 kcmil compact conductor
- Nothing similar to the catastrophic runaways observed on 1/0 AWG was noted on 750 kcmil conductor

WHAT IS THE DIFFERENCE BETWEEN 1/0 AWG AND 750 KCMIL CONNECTORS?

1/0 AWG	750 KCMIL
Different conductor manufacturers and different batches of strand filling compound	
Compressed (more strand filling compound)	Compact (less strand filling compound)
Current density across the conductor (A/in^2)	
3800	1660
Current density at the crimped surface (A/in^2)	
420	218

CONCLUSIONS

1. 1/0 AWG Al compression connectors used in joints and terminations exhibited overheating, no matter what crimping tool was used and who performed the assembly
2. Bare connectors and connectors inside accessories perform differently. There are also differences between 15 and 35 kV devices of the same type

CONCLUSIONS (continued)

3. Test results obtained on 1/0 AWG and 750 kcmil conductors are drastically different
4. Difference in the connector performance, when tested bare or insulated, on 15 or 35 kV cable, on 1/0 AWG or 750 kcmil conductor, could be due to different current densities
5. Strand filling compound appears to affect the connector performance. A combination of high temperature and current density appears to contribute to contact deterioration

GAPS IN STANDARDIZATION

1. Testing of connectors on non-filled conductors does not qualify same for application on strand filled conductors

2. It appears that connectability tests performed to qualify strand-filling compounds on a specific conductor (connector) size do not qualify same for other sizes

3. It is a common approach in domestic specifications that the range covered by qualification tests (sizes, design variations, etc.) is not defined

GAPS IN STANDARDIZATION (continued)

4. According to IEEE 404, connectors are qualified separately, joints are qualified with any connector size, Cu or Al, and all combinations of connectors and joints are considered qualified. IEEE 48 (terminations) does not address this issue at all.

GAPS IN STANDARDIZATION (continued)

5. It appears reasonable to require as part of the qualification of joints and terminations to demonstrate that the connector temperature does not exceed certain limit. A new specification for underground connectors needs to consider a higher test temperature (the same limit) and possibly higher heating current densities (typical for insulated conductors).

QUESTIONS

1. What conductor (connector) sizes are prone to connector overheating?
2. Is it necessary to evaluate all filling compounds and designs available on the market? Are special qualification procedures required?
3. How to deal with the problem? Can any of the existing crimping techniques solve the problem? Are new connector designs necessary? Is it necessary to remove the filling compound, and how?

QUESTIONS (continued)

4. How do industry specifications need to be modified to take care of the problem?
5. What could be a set of parameters to define the most critical designs to be tested during connector and strand filling compound qualification – conductor size and design, current density, area of the crimp, etc.?
6. Do existing cable systems require de-rating and to what extent?