

Agenda: Off Circuit Tapchangers

- Introductions
- Membership
- Old Minutes
- **Mission-Develop Functional Life Test and Report for De-energized Tap-changers**
- **Reports from Reinhausen, Central Moloney, Quality Switch/Cooper, and others on test results**
- Documents
 - Existing C57.131 Requirements for Load Tapchangers
 - Draft Document IEC 60214
 - P.J.H. Proposed Life Test**
 - PJH Proposed Report**
- Discussion
- Future Work
- Adjourn

Agenda: Off Circuit Tapchangers

Meeting Minutes from Porto, Portugal from 10/7/08

TF TAP CHANGERS FOR DE-ENERGIZED OPERATION

MEETING MINUTES

Hilton Miami Downtown, Miami, Florida – April 21, 2009
Chairman: Phil Hopkinson
Secretary: Scott Choinski

The Task Force on Life Tests, De-energized Tap Changers was called to order at 9:30 AM on April 21, 2009. There were 42 attendees, 16 members, and 28 guests with 8 requesting membership. Reviewed the Agenda for the meeting, and the Minutes from the October 7, 2008, meeting in Porto, Portugal, were approved.

1. Described conditions for alternative test for higher current and lower oil temperatures.
2. Challenged group to duplicate the model contained in spreadsheet titled "Kraemer Analysis"
3. Need to specify other parameters that give complete definition to the test.
4. The Task Force test was balloted at the C57.131 meeting on Monday and passed narrowly (13 for and 10 against) such that there is support to add the test to a future version of C57.131. A straw vote was held by the Task Force on the same issue and showed a much more favorable position with 19 in favor, 8 opposed.
5. Cooper Power has conducted testing that supports the findings of stability/non-stability @ 130°C
3. New Business

There was no new business.

Working Group for Off-Circuit Tapchangers 310/7/2009 by Philip J. Hopkinson

Mission:

Develop Functional Life Test and Report for De-energized tapchangers that recognizes transformer applications

Reference Documents:

C57.12.00 - General Requirements for Liquid Filled Transformers

C57.12.01 - General Requirements for Dry-Type Transformers

C57.91 - Guide for Loading Mineral Oil Immerse Transformers

C57.96 - Guide for Loading Dry-Type Distribution and Power Transformers

Working Group for Off-Circuit Tapchangers 410/7/2009 by Philip J. Hopkinson

Accomplished:

- Mission objective
- Tentative paper
- General conditions for test
 - **30 Cycles of test**
 - **On for 8 hrs in 130 C oil at 2XN current**
 - **Off for 16 hrs at normal ambient**
 - **Pass if Resistance change <25% and stability reached**
- C57.131 to be resting spot for Task Force documentation

Missing

- Verify acceleration factor of 1000:1
- Repeatable tests at lower oil temperature and higher current
- Complete description of test details

General requirements for Off-Circuit Tapchangers

Off-circuit tap-changers specified in this standard are for use with liquid filled and air insulated transformers and shall only be operated with the transformer de-energized.**

Since these tap-changers are always used as integral parts of transformers, the current ratings must coordinate with the expectations on the transformer. Transformer loading guides allow up to 2 times rated current for up to ½ hr. daily, dependent on ambient temperature and loss of life considerations. This is consistent with Section 9.2.1 of IEEE Loading Guide C57.91-1995. In addition, cold-load pickup of up to 3 times load is permissible as well as inrush current.

The thermal environment for off-circuit tap-changers is normally in or near the top-oil for liquid-filled transformers. Hence the tap-changer must be designed to operate satisfactorily in this environment. For liquid-filled transformers, the sustained rated liquid temperature shall be assumed to be as follows:

$$T_{oil} = T_{tor} + T_{amb}$$

- Where
- T_{oil} is the oil temperature for the tap-changer
 - T_{tor} is the top oil rise of the transformer
 - The rated rise occurs at rated steady-state load
 - The maximum rise occurs at the highest allowable overload
 - T_{amb} is the outside ambient for the transformer

Insulation System	T _{tor}		T _{amb}		T _{oil}	
	Rated	Max	Rated	Max	Rated	Max
55 C	45	60	20	40	65	100
65 C	55	70	20	40	75	110

Dry Type Tap-changers

Dry type tap-changers can be considered to be of three different styles:

- a. Suitable for mounting above the core-clamp and exposed to air that is heated by the transformer windings
- b. Suitable for mounting within the transformer cabinet but not above the transformer core and windings
- c. Suitable only for mounting in a separate enclosure and not exposed to air that is heated by the windings or core.

Tap-changer air temperatures for the three cases are as follows:

Style	Outside Amb		Rise/Amb		Net Air Temp	
	Rated	Max	Rated	Max	Rated	Rise
a. On Core Clamp	30	40	130	150	160	190
b. In trans. Cabinet	30	40	50	70	80	110
c. Separate Cabinet	30	40	20	30	50	70

Life Considerations

Life expectancy is commonly addressed in terms of thermal life. Transformer thermal life is assumed to be 20 years. In IEEE's Liquid-filled transformer loading guide (IEEE 57.91-1995), uses 180,000 hours at rated load and ambient as the thermal index. Thermal life is a parameter that is both dependent on temperature and material composition. Both insulation and contact deterioration by oxidation have been found to obey the 10°C rule. Under the rule, each 10°C above or below the reference temperature causes life to change by 2 to 1.

Nameplate/Specified Ratings

Tap-changers shall be rated in terms of the following criteria and other requirements irrespective of the type of construction:

Table 5A-Rated current characteristics of off-circuit tap-changers

Maximum Continuous Rated Current Amps	Maximum Double Current for 1/2 hr. /Day	Max Symmetric Through-fault Current (amps)	Max Crest Fault Current (amps)
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Table 5B-Rated voltage characteristics of off-circuit tap-changers

System Highest Voltage	BIL Line- Gnd	Max BIL Tap-Tap	Max BIL Between 2 Tap Positions
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Quality Switch Silver-Silver Rotating Contact Tapchanger Ratings New IEC/IEEE Format

Switch No.	Voltages, (000)				Current Ratings, Amps			
	Highest System Volts	Max. System BIL	Max. BIL Tap-Tap	Max. BIL Tap-2 Taps	Max. Continuous	Max. 2x Rated ½ hr./day	Max. Symm Thru-Fault Current	Max. Crest Fault Current
Single Ring								
70-543-01	25	125	150	132	200	400	5000	7500
70-543-02	35	200	150	132	200	400	5000	7500
70-543-04	45	250	150	132	200	400	5000	7500
Triple Ring								
70-545-02	35	150	150	132	500	1000	14,000	20,000

New ratings allow users to match transformer application

Tapchanger Suitability for Synthetic Insulating Liquids

Synthetic insulating liquids may behave quite differently than mineral oil. Some of the more pronounced differences that have been observed are oxidation-stability, lubricity, heat transfer, dielectric integrity, flammability, and viscosity. Tap-changer ratings for use in synthetic insulating fluids must be established by the manufacturer.

Stability in Natural Ester Fluid

Natural ester fluid has proven to be stable in testing to date for a wide variety on contact pairs. It is still recommended that manufacturers test any proposed combinations of fluids and contact pairs to develop stability considerations before establishing switch ratings.

Routine and Type Test Requirements

Test	Routine	Type
a. Contact Resistance	X	
b. Contact spring pressure	X	
c. Dielectric Integrity	X	
d. Functional Life		X
e. Short Circuit		X
f. Mechanical endurance		X
g. Operating torque (manual)		X
h. Gland seal (Vacuum)	X	

Temperature Rise of Contacts

Tests shall be performed to verify that the temperature rise above the medium surrounding each type of contact, which carries current continuously in service, does not exceed the values given in table 6. This test shall be performed when the contacts have reached a steady temperature when carrying the through-currents in accordance with table 6, with tap-changer ambient in accordance with the rated values in section 7.1. The test is performed by measurements with thermocouples or other devices capable of measuring bulk temperature, and ambient liquid or air. The bulk rise is the difference between the bulk temperature and the temperature of the tap-changer environment (liquid or air).

It is important to note that the temperature rises in table 6 are limit values. The manufacturer must recognize that stable materials must be used so that aging does not result in thermal runaway. Time shall not result in higher temperature rises at the table 6 currents.

Table 6- Contact temperature-rise for off-circuit tap-changers

Style	Rated Current	2X Rated Current
Liquid	10	30
Dry	25	75

Functional Life Tests

A functional life test shall be performed as a Type Test to demonstrate the adequacy of the contact design to achieve long stable thermal life. The test consists of thermal cycling at accelerated current and temperature, with daily cool-down cycles. The original test depends on an acceleration factor of 1000:1. A successful test is completed if contact resistance remains within 25% of the original value and stability is achieved.

The test is conducted by passing twice rated current through the contacts for 8 hours per cycle at ambient temperatures of 130°C

A total of 30 cycles (days) of the 8-hour on 16 hour off 2XN current are required to complete the functional life test.

2 Criteria of success:

1. Resistance change <25%
2. Stability reached

Functional Life Tests

What about the 2 Criteria of success?:

1. Resistance change $<25\%$
2. Stability reached

1. Test claims to be a 1000:1 Acceleration of normal use
2. No known field failures from tapchangers that pass test.
3. If test truly represents 30 years then:
 - **Resistance change $>25\%$ may be OK**
 - **Some oxidation may be OK**

Functional Life Tests-Issues

Issues for test

1. **Validity of acceleration factor**
2. **Sample that should be a real tapchanger.**
3. **Sample Preparation.**
4. **Connections to tapchanger for current, voltage and temperature**
5. **Oil volume for the test**
6. **Oil temperature**
7. **Current in multiples of rating**
8. **Data collection**

2 Criteria of success:

1. Resistance change $<25\%$
2. Stability reached

Functional Life Tests-Issues

Issue 1: **Test Validity**

10 C rule a factor

1. **RMS Equivalent Load normally 50%**
2. **Average ambient of 20 C**
3. **Normal tapchanger sees average temperature of 20C + 25C oil +2C Tapchanger = 47 C**
4. **For 1000 Times acceleration: $2^X = 1000$**
5. **$X \sim 10 = (T_{test} - T_{avg}) / 10$**
6. **$T_{test} = 100 + 50 = 150 C$**
7. **T_{test} is indeed 151C and is OK.**

2 Criteria of success:

1. Resistance change <25%
2. Stability reached

Suppose we wanted to define life as equivalent to Cellulose life

Functional Life Tests-Issues

Issue 1: Test Validity

1. IEEE C57.12.00 defines life as 180,000 at 110 C
 2. $180,000 \text{ hours} / 8,760 \text{ hrs/year} = 20.5 \text{ years at } 110 \text{ C}$
 3. 110 C = sum of 3 parameters
 - Avg ambient of 30 C
 - Avg wdg rise/ambient of 65 C
 - HS increment over avg wdg 15C
 1. But normal avg wdg/avg oil 12C
 2. Avg oil/amb 53C
 3. Avg tapchanger contact/oil 8C
 4. Super temperature/avg 2C
 5. Tapchanger ambient 30C
- 93 C
6. Tapchanger contacts see 93 C when winding sees 110 C
 7. Years required at 93 C 20.5 or 180,000 hours
 8. Days for 20.5 years = $20.5 * 365 = 7500$ at 93 C

Suppose we wanted to define life as equal to oil-Cellulose

Functional Life Tests-Issues

Issue 1: Test Validity- - What time and temperature to have equal life as oil-cellulose (110 C for 180,000 hrs)?

1. For 93 C, 180,000 hours (20.5 years) 7500 days
2. 10 C rule applies to contact aging.
3. For 103 C 3750 days
4. For 113 C 1875 days
5. For 123 C 938 days
6. For 133 C 469 days
7. For 143 C 234 days
8. For 153 C 117 days 30 days now
9. For 163 C 58 days
10. For 173 C 29 days

Conclusion: Test to date not equivalent to insulation life

Functional Life Tests-Issues

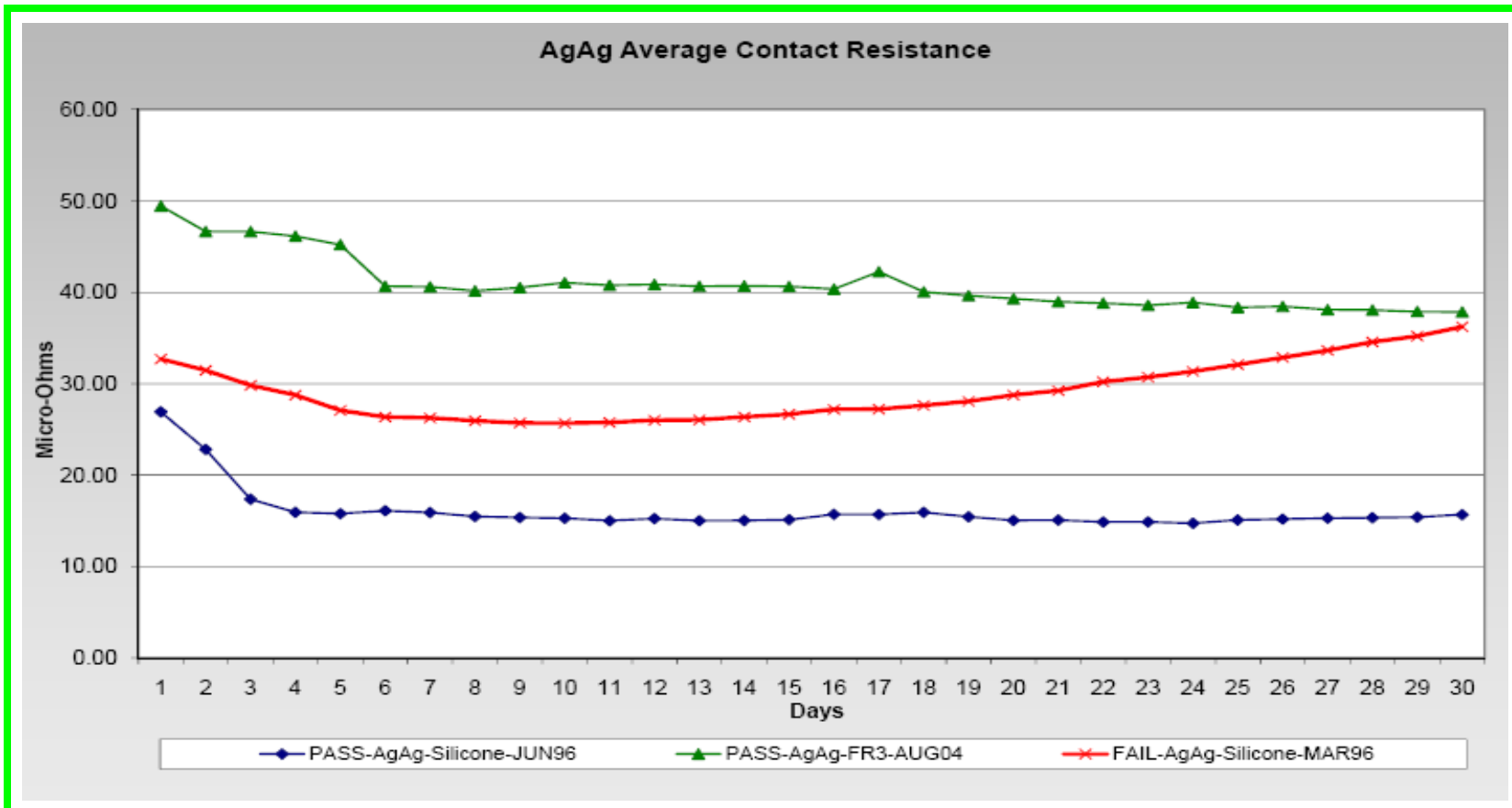
Issue 1: **Test Validity**

- 1. Test valid for typical use as no field failures reported.**
- 2. More time or higher temperature needed to test equivalent life as oil-cellulose.**
- 3. Conservative approach has proven successful to**
 - <25% resistance increase**
 - Stability.**
- 4. Extended time or higher temperature could allow more resistance change than 25% and be OK.**

Conclusions:

- Conservatism good**
- Present test works.**
- New criteria needed if test lengthened**

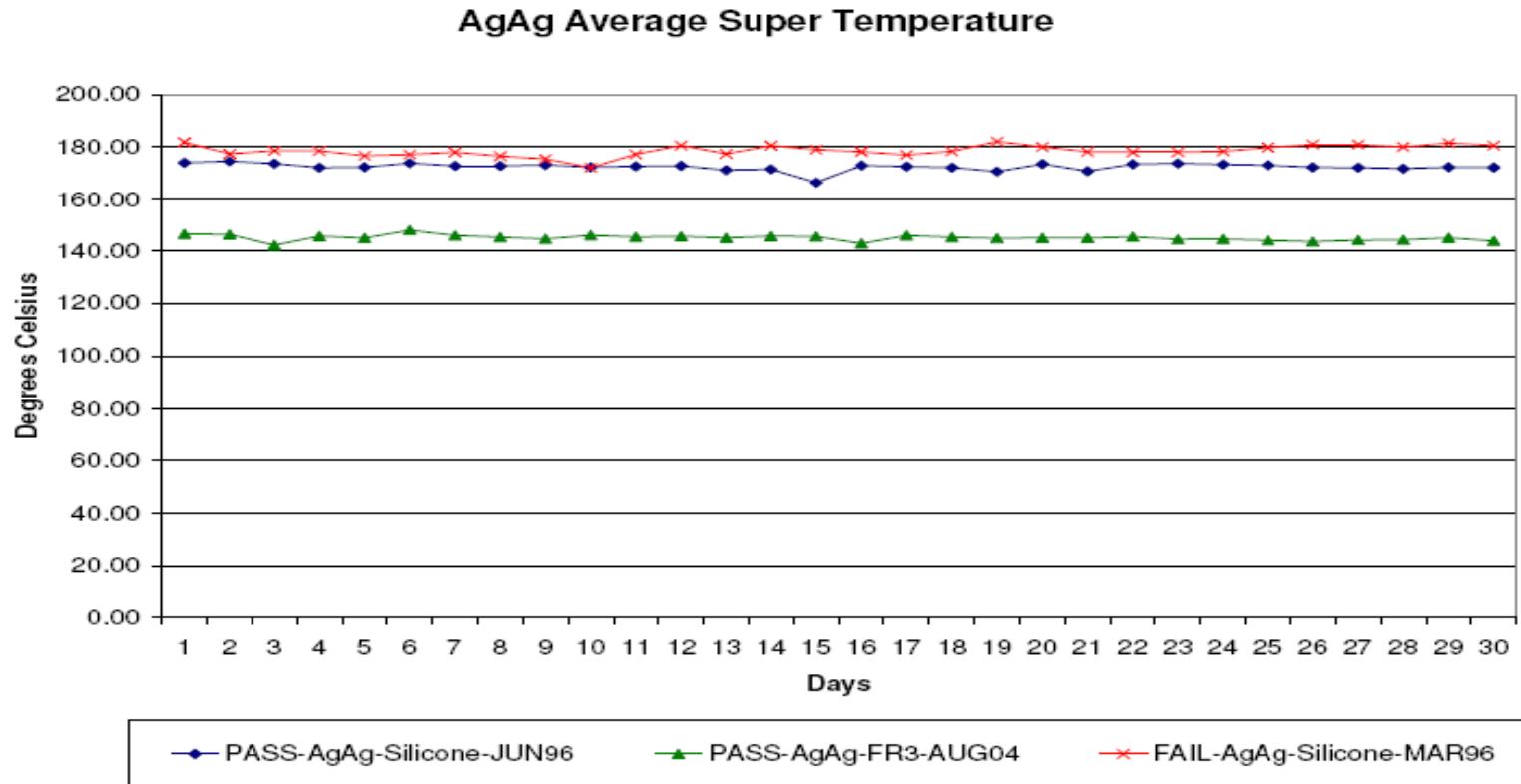
Functional Life Tests-Issues



Observations:

- Ag-Ag Silicone March 1996 is not apparently stable and probably failed
- Ag-Ag Silicone August 2004 clearly passed
- Ag-Ag FR3 August 2004 passed

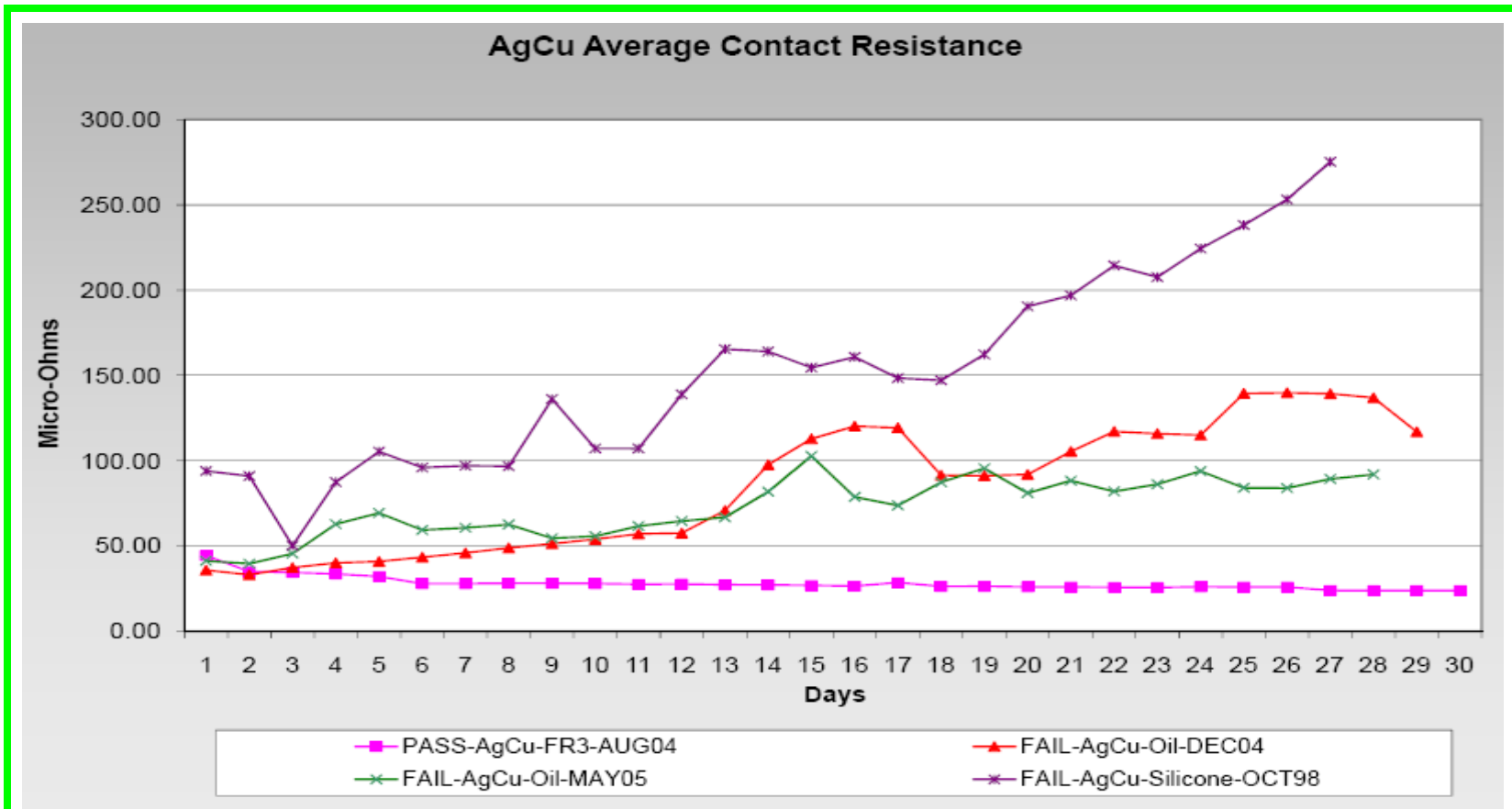
Functional Life Tests-Issues



Observations: Normally super temperature reflects stability or lack thereof

- Ag-Ag Silicone March 1996 is not apparently stable and may be OK
- Ag-Ag Silicone August 2004 clearly passed
- Ag-Ag FR3 August 2004 passed with flying colors

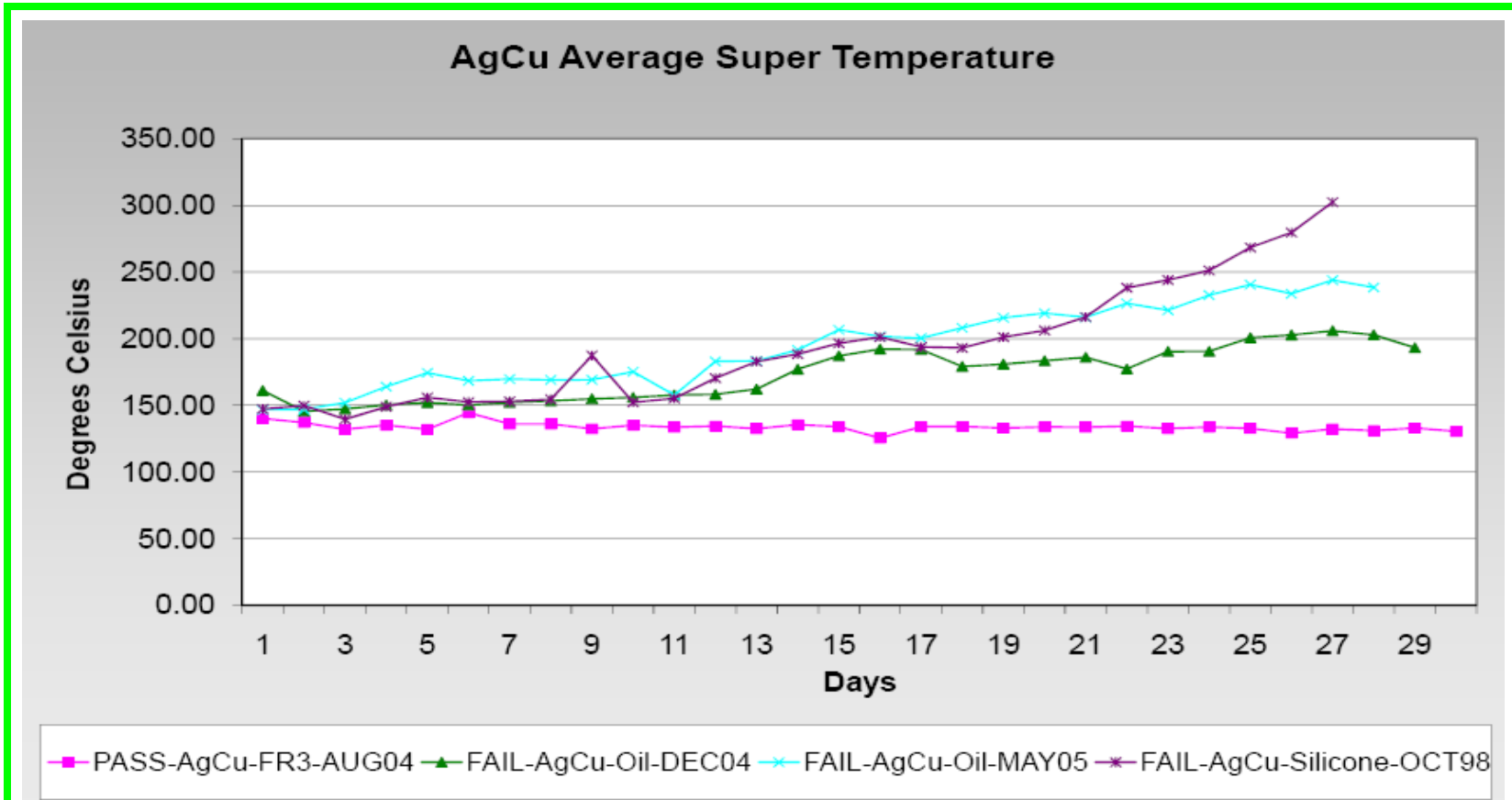
Functional Life Tests-Issues



Observations:

- Ag-Cu Silicone October 1998 clearly failed
- Ag-Cu Oil also failed
- Ag-Cu FR3 August 2004 passed

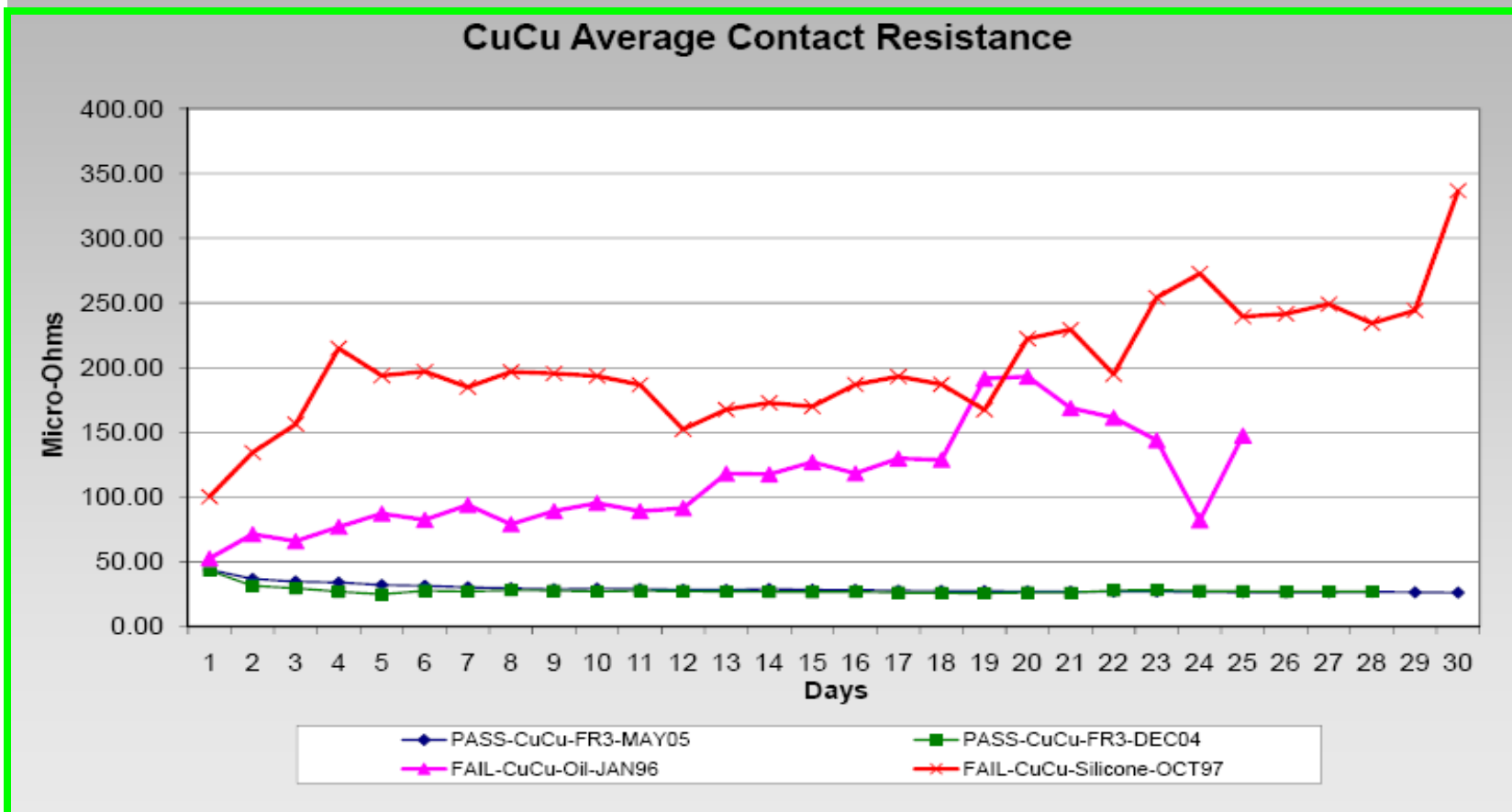
Functional Life Tests-Issues



Observations: Super Temperature indicates

- Ag-Cu Silicone October 1998 clearly failed
- Ag-Cu Oil also failed
- Ag-Cu FR3 August 2004 passed with clear stability.

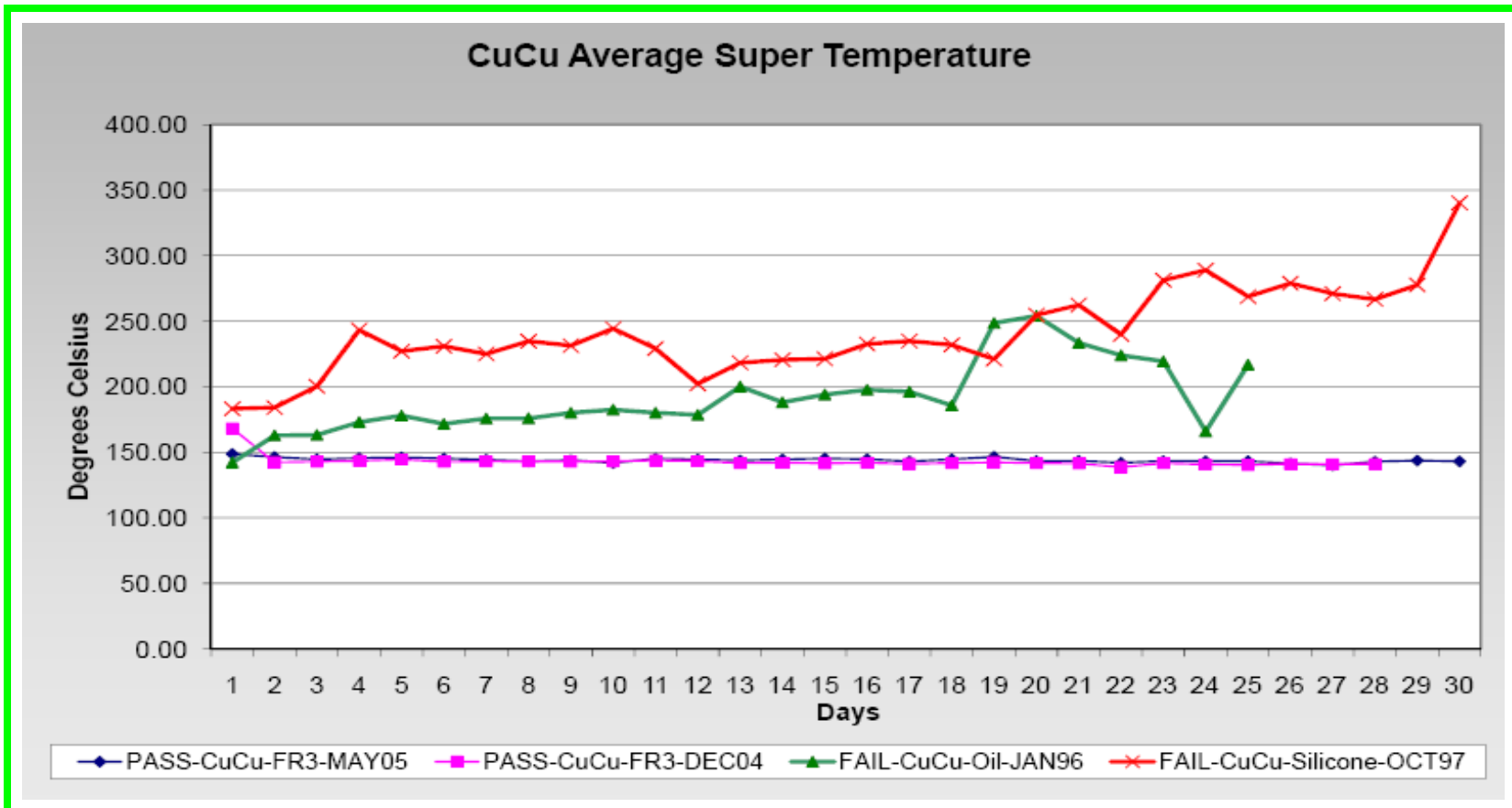
Functional Life Tests-Issues



Observations:

- Cu-Cu Silicone clearly failed
- Cu-Cu Mineral oil also failed
- Cu-Cu FR3 clearly passed

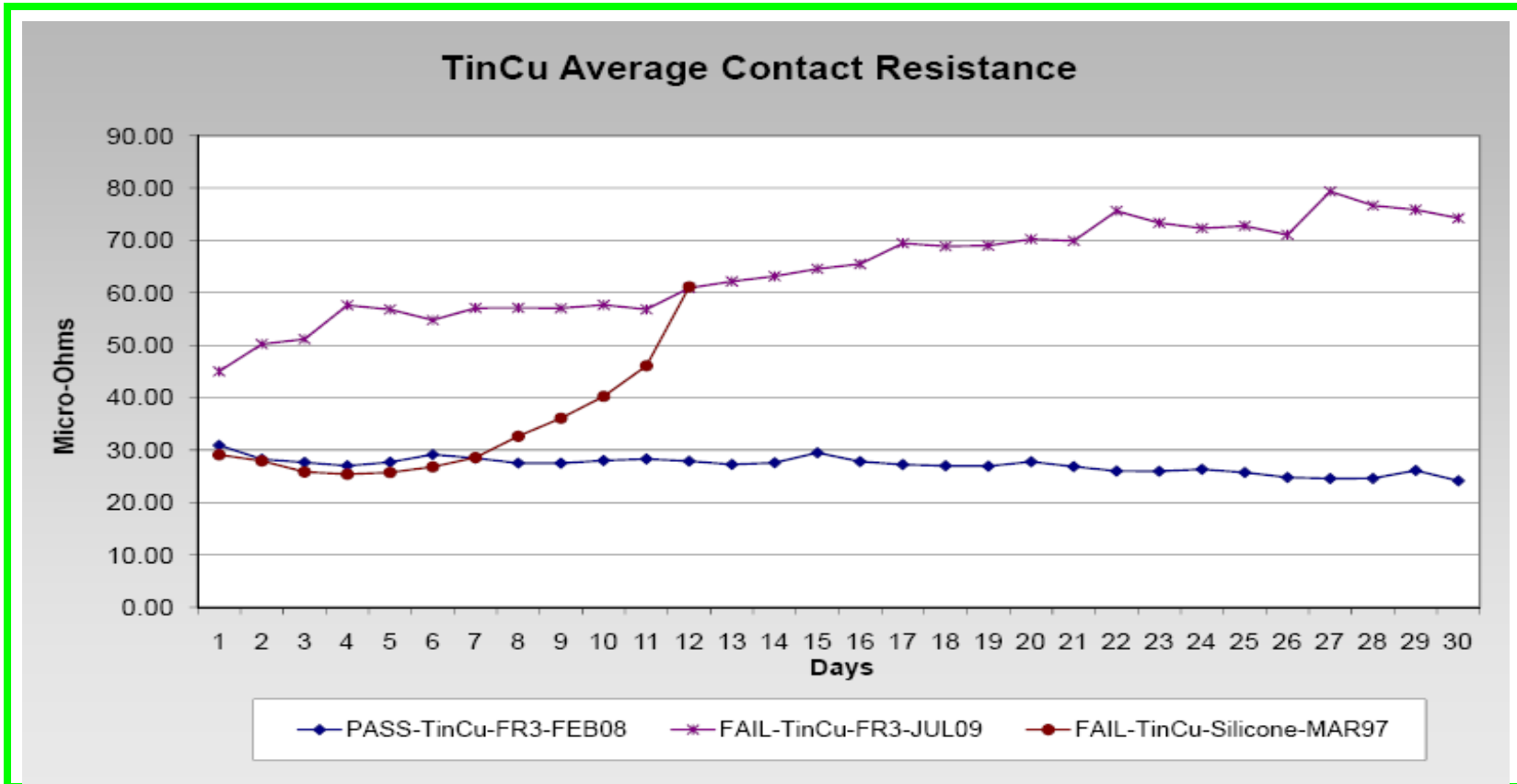
Functional Life Tests-Issues



Observations: Stability is only seen with one of the contact sets

- Cu-Cu Silicone clearly failed
- Cu-Cu Mineral oil also failed
- Cu-Cu FR3 clearly passed

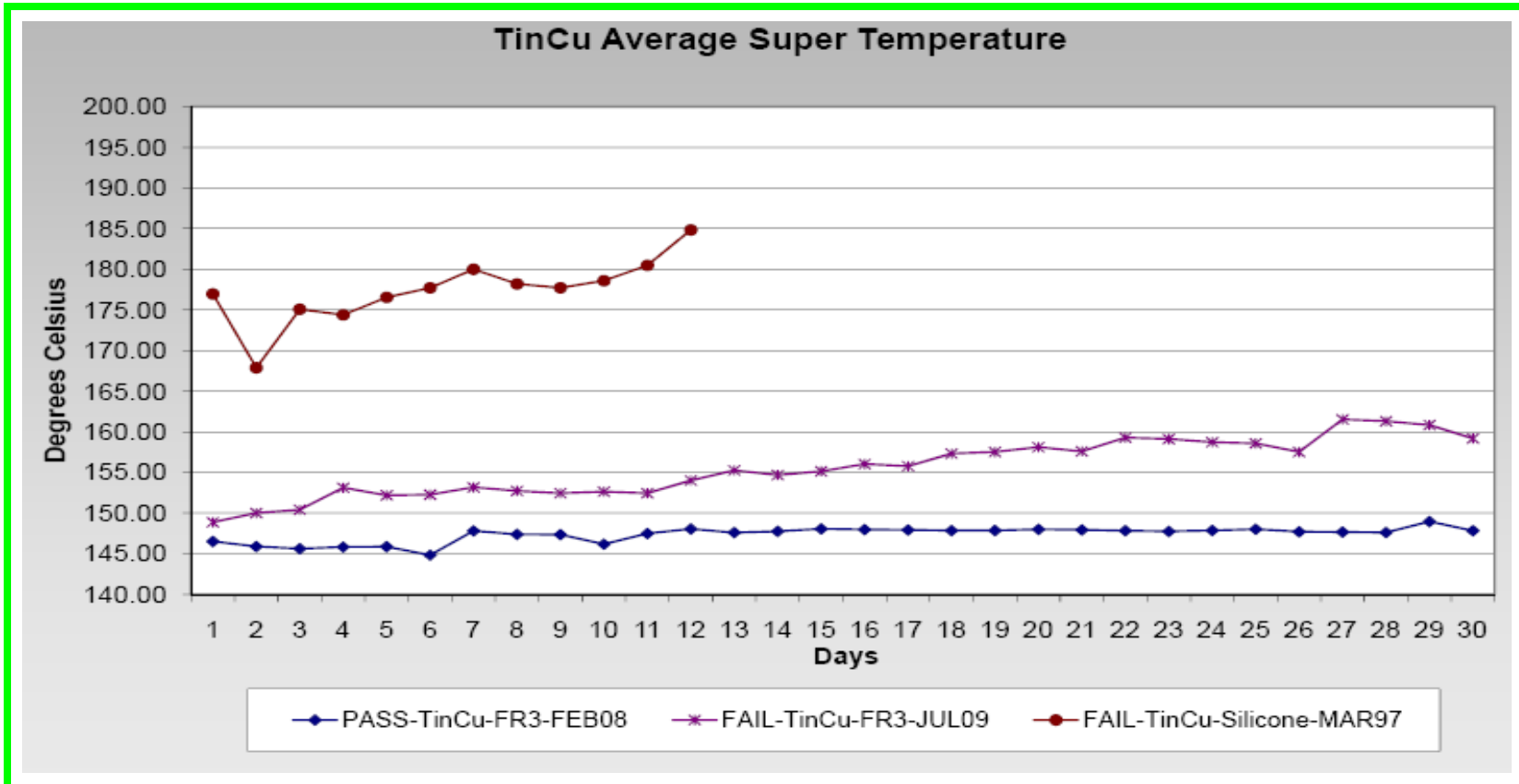
Functional Life Tests-Issues



Observations:

- Tin-CU Silicone clearly failed
- Tin-CU FR3 Feb 2008 passed
- Tin-CU FR3 July 2009 appears to have failed

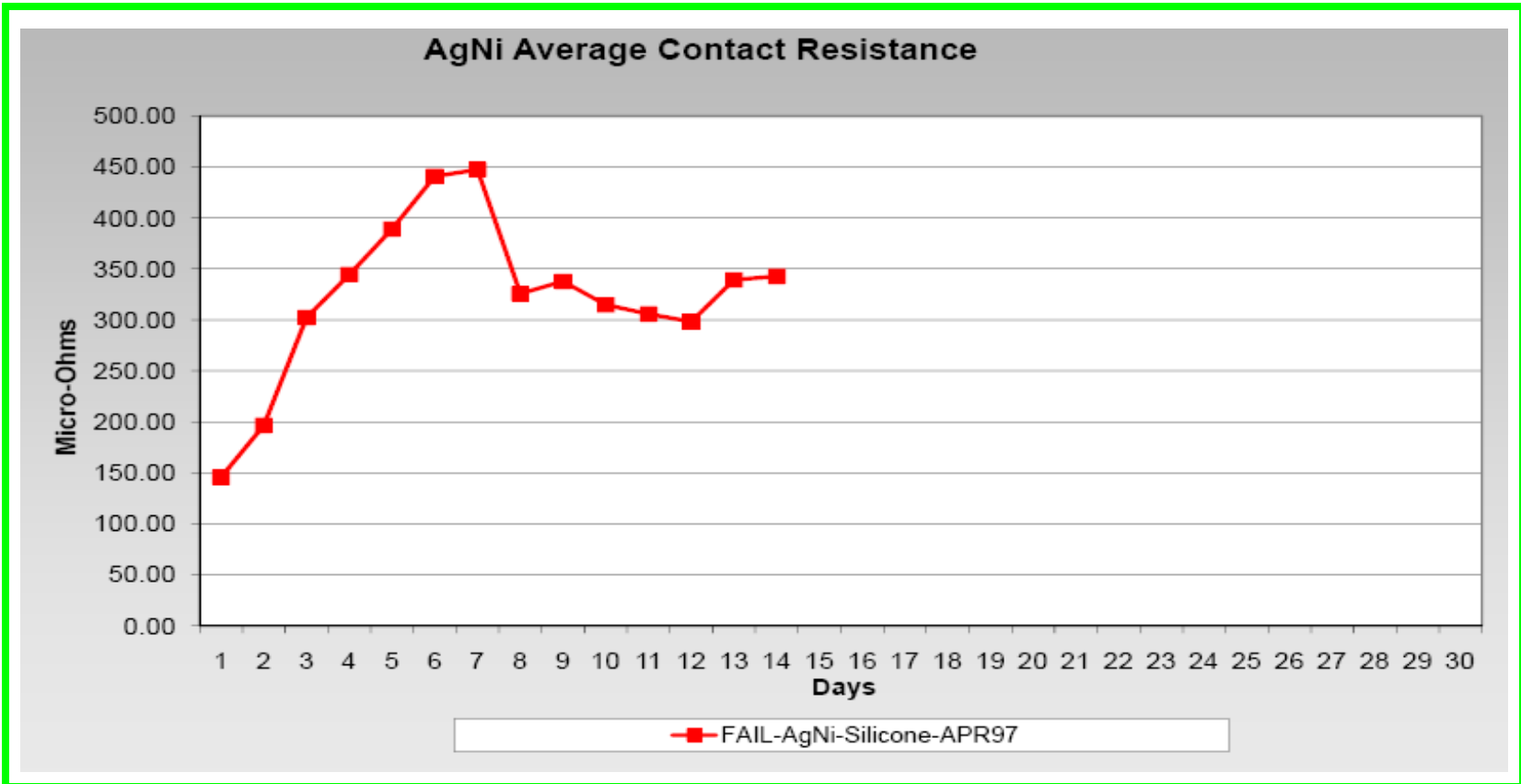
Functional Life Tests-Issues



Observations: This one has one clear failure and one uncertainty

- Tin-CU Silicone clearly failed
- Tin-CU FR3 Feb 2008 passed
- Tin-CU FR3 July 2009 appears to have failed but a longer test may be needed to be certain.

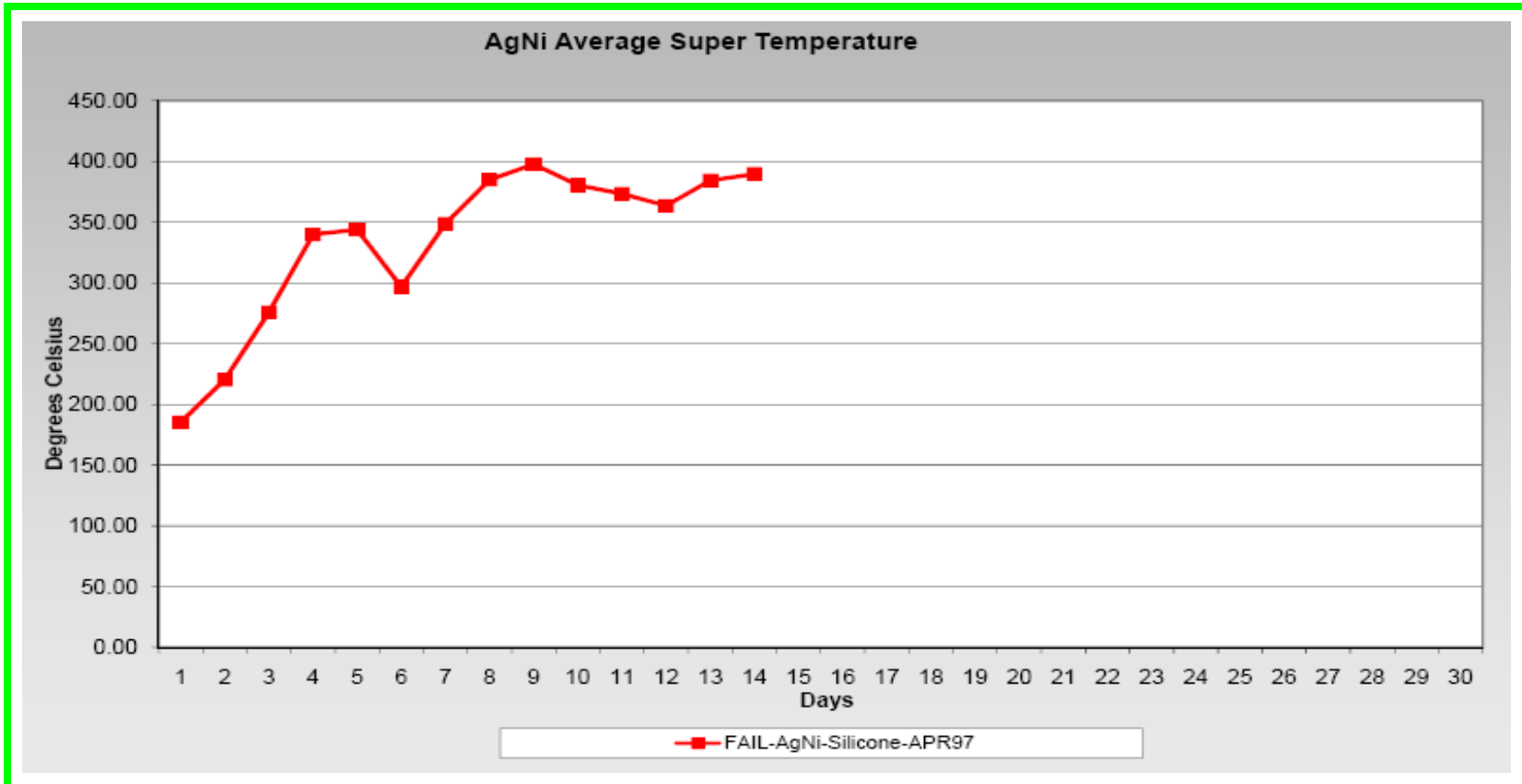
Functional Life Tests-Issues



Observations:

- Ag Silicone clearly failed

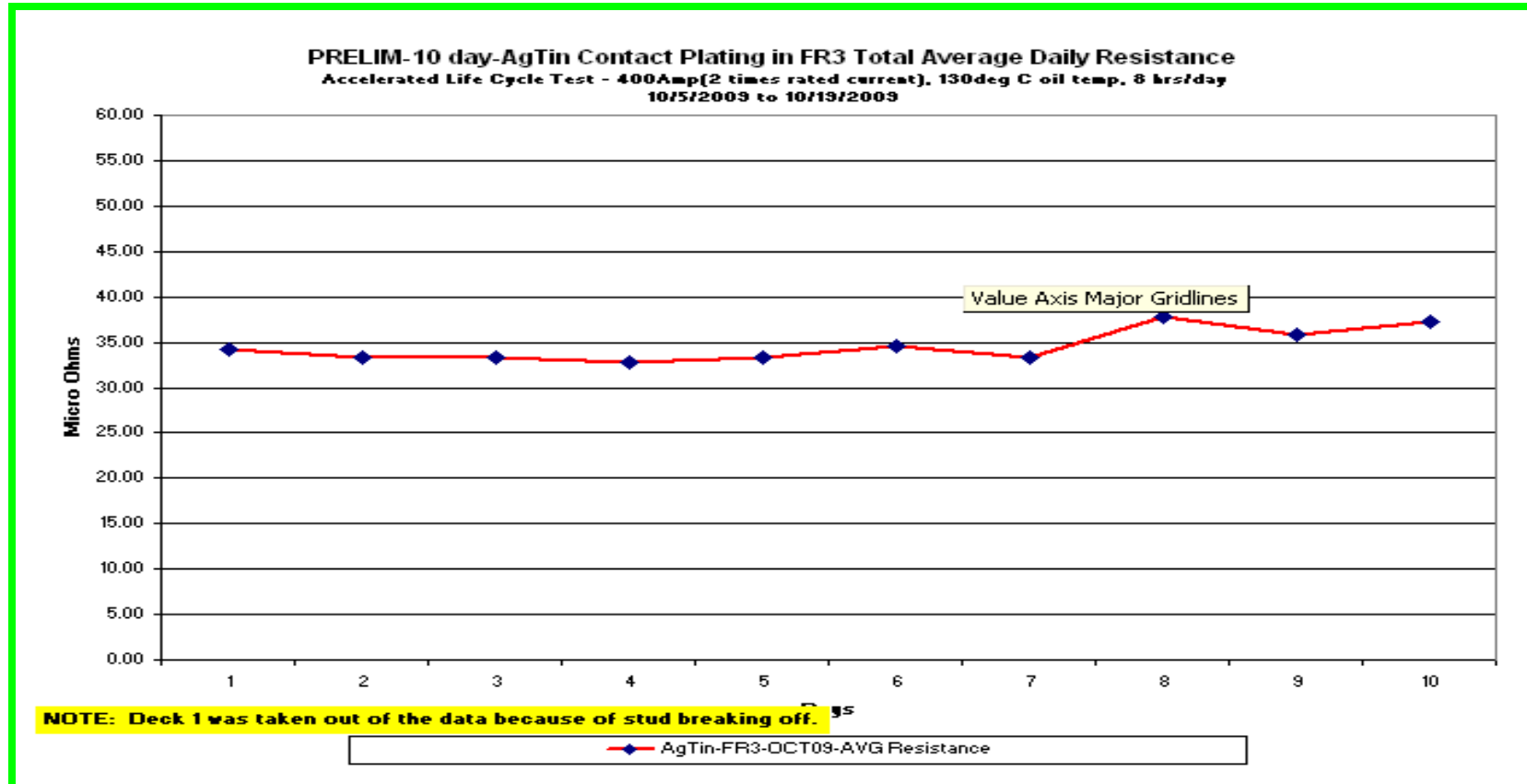
Functional Life Tests-Issues



Observations:

- Ag Silicone clearly failed with thermal runaway

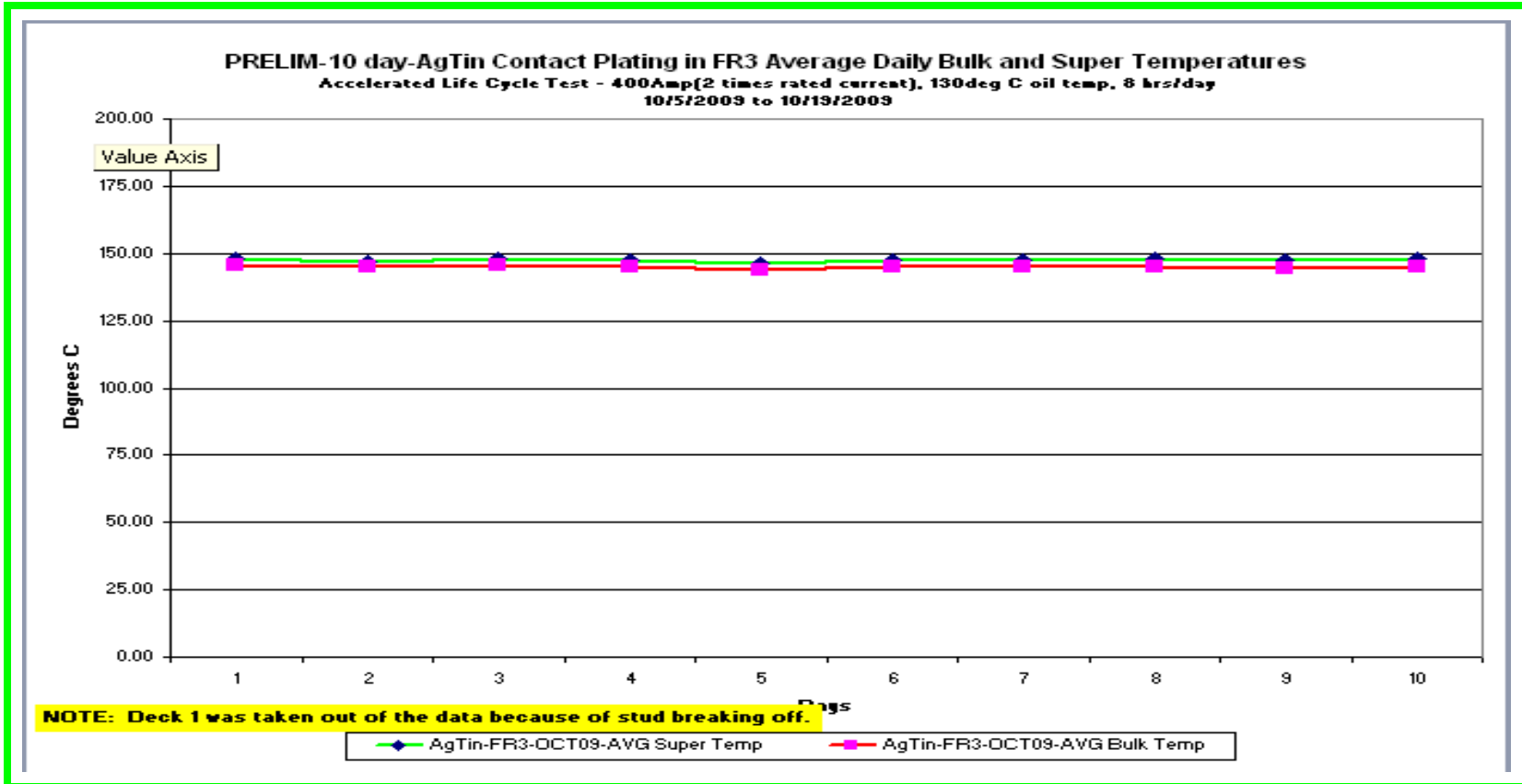
Functional Life Tests-Issues



Observations:

- Ag Tin in FR3 looks pretty good so far with slight uptick

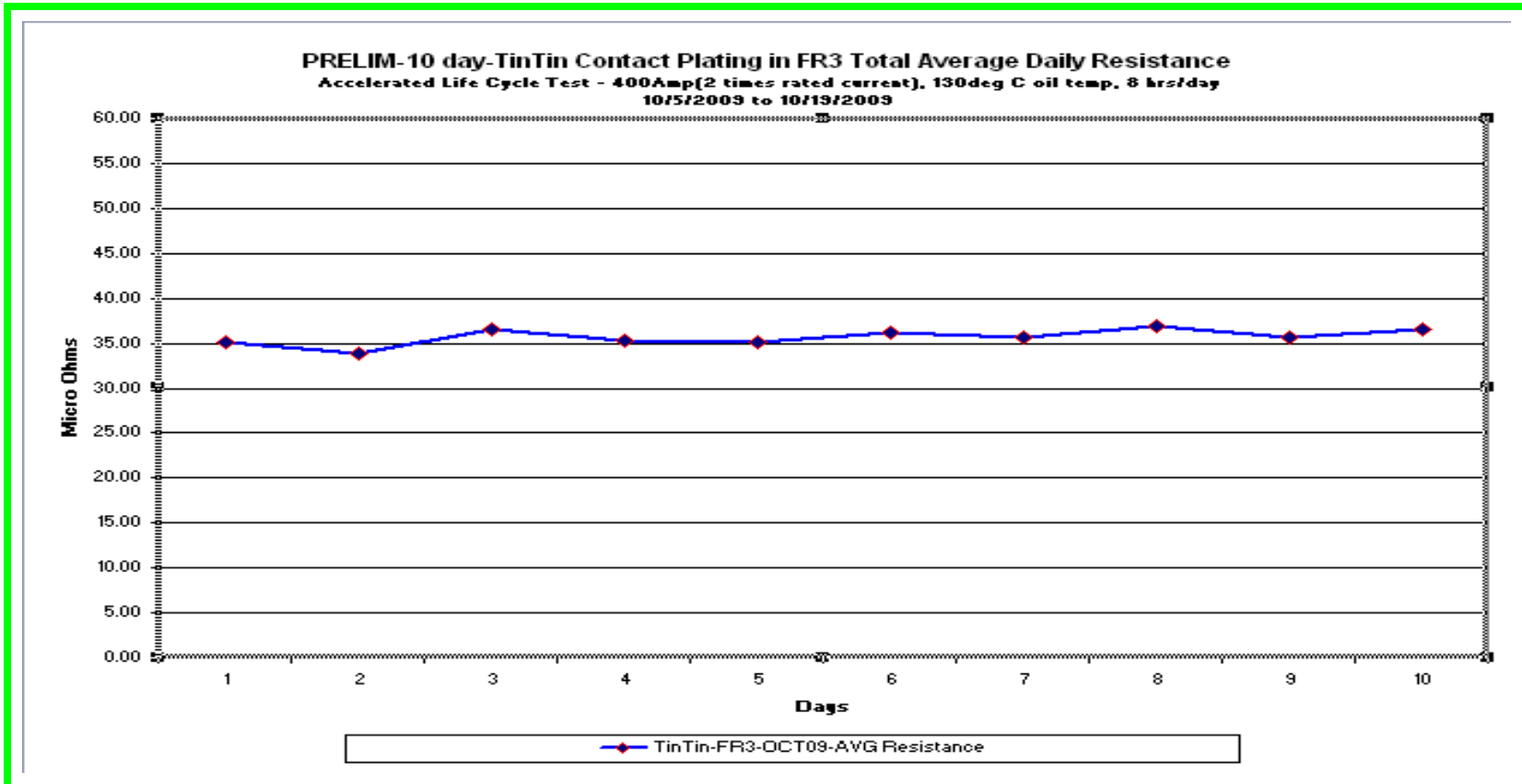
Functional Life Tests-Issues



Observations:

- Ag Tin in FR3 looks absolutely stable through 10 days in super temperature

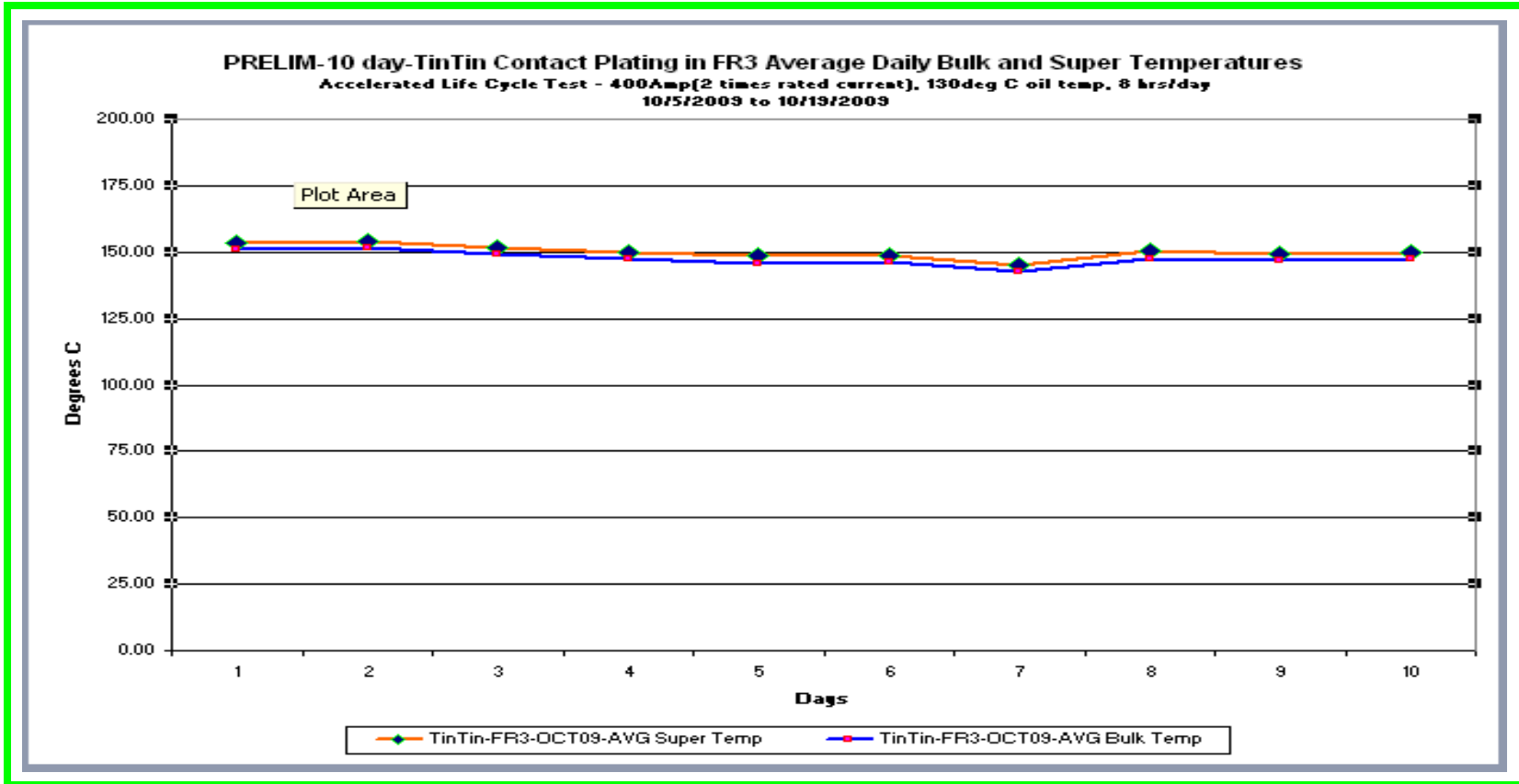
Functional Life Tests-Issues



Observations:

- Tin-Tin in FR3 appears to be stable after 10 days

Functional Life Tests-Issues



Observations:

- Tin-Tin in FR3 absolutely looks stable after 10 days

Functional Life Tests-Issues

Several Important factors for Pass-Fail

1. Average performance of 6 pairs of contacts
2. Worst case actor
3. Absolute resistance test
4. Super temperature performance as sensitive test of stability

Conclusion:

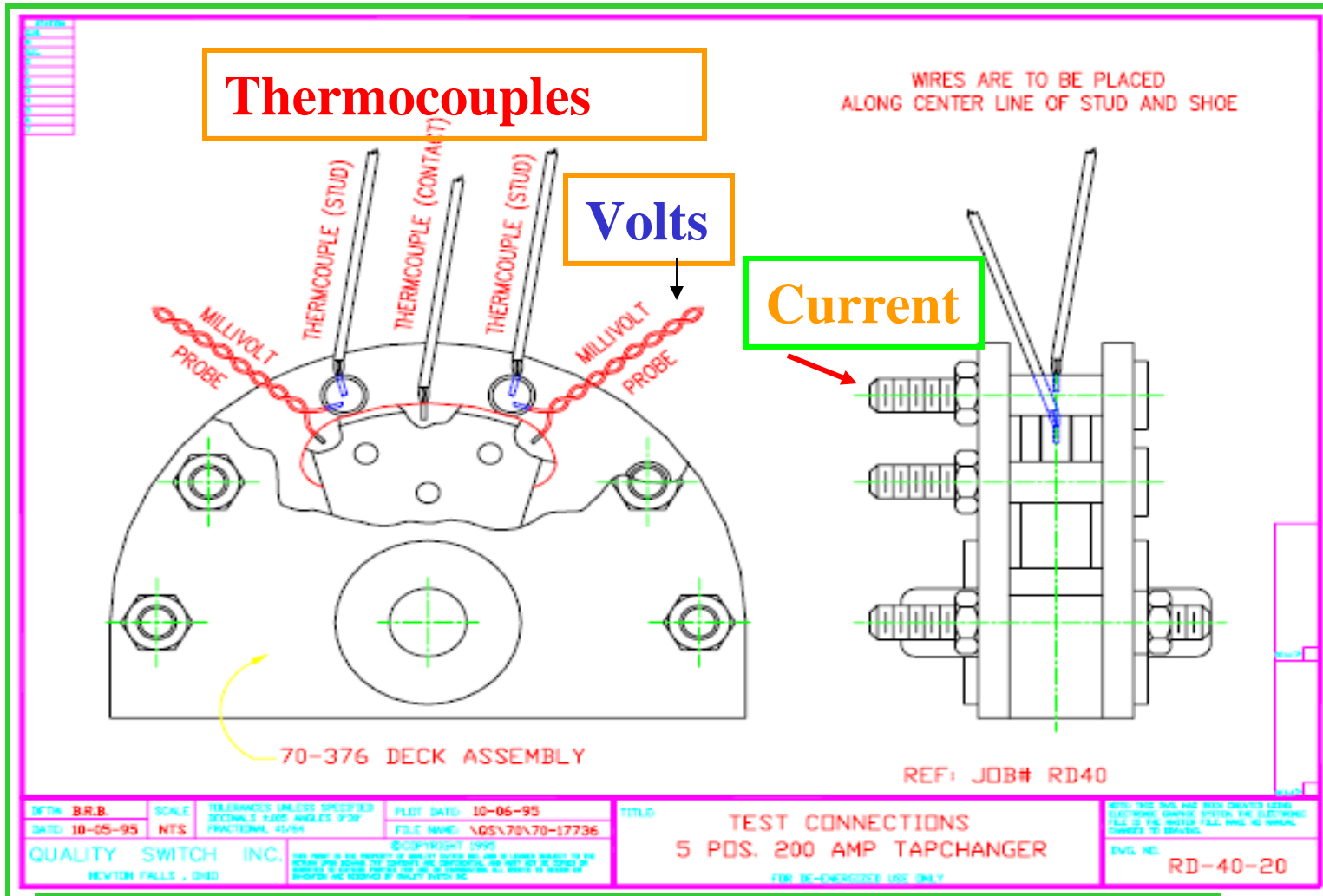
Pass-Fail Criteria can be improved by factoring in Super Temperature with resistance

Functional Life Tests-Issues

A look at test setup

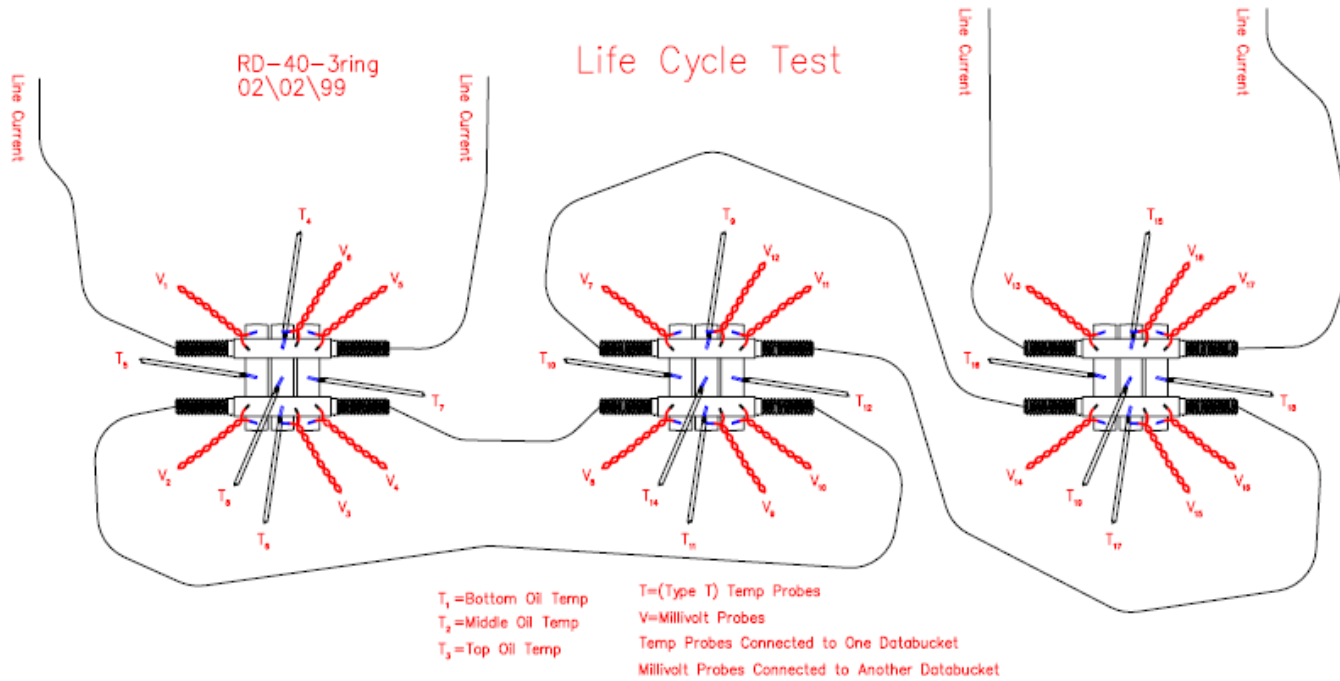
1. Use real 3-phase tapchangers
2. One tapchanger gives 6 contact pairs
3. Make sure that thermocouples get accurate bulk temperatures
4. Contact voltage requires minimal loops

Functional Life Tests-Connections



**Tapchanger thermocouple and voltage measurements,
courtesy of Quality Switch**

Functional Life Tests-Multiple decks in series



**Hi gh Current Tapchanger (>500 amp rated)
Connections, courtesy of Quality Switch**

Functional Life Tests-Issue of Oil Volume

Large liquid volume important for test validity

1. Most representative of real transformer environment
2. Will contain dissolved gases
3. Provides opportunity for replacement of oxidized liquid
4. Should slow down thermal runaway

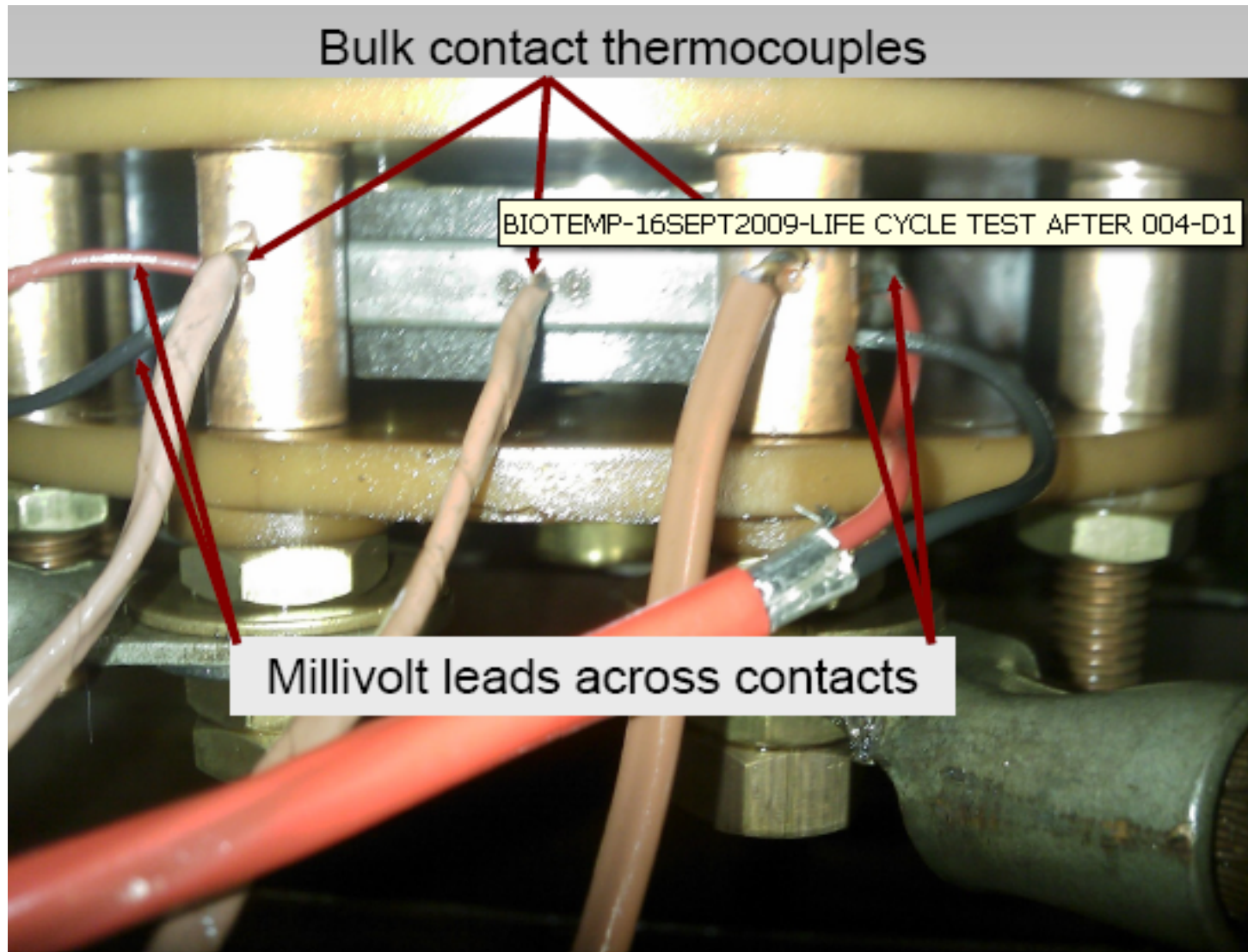
Important to replicate real environment

Functional Life Tests-Issue of Oil Volume



Important to replicate real environment

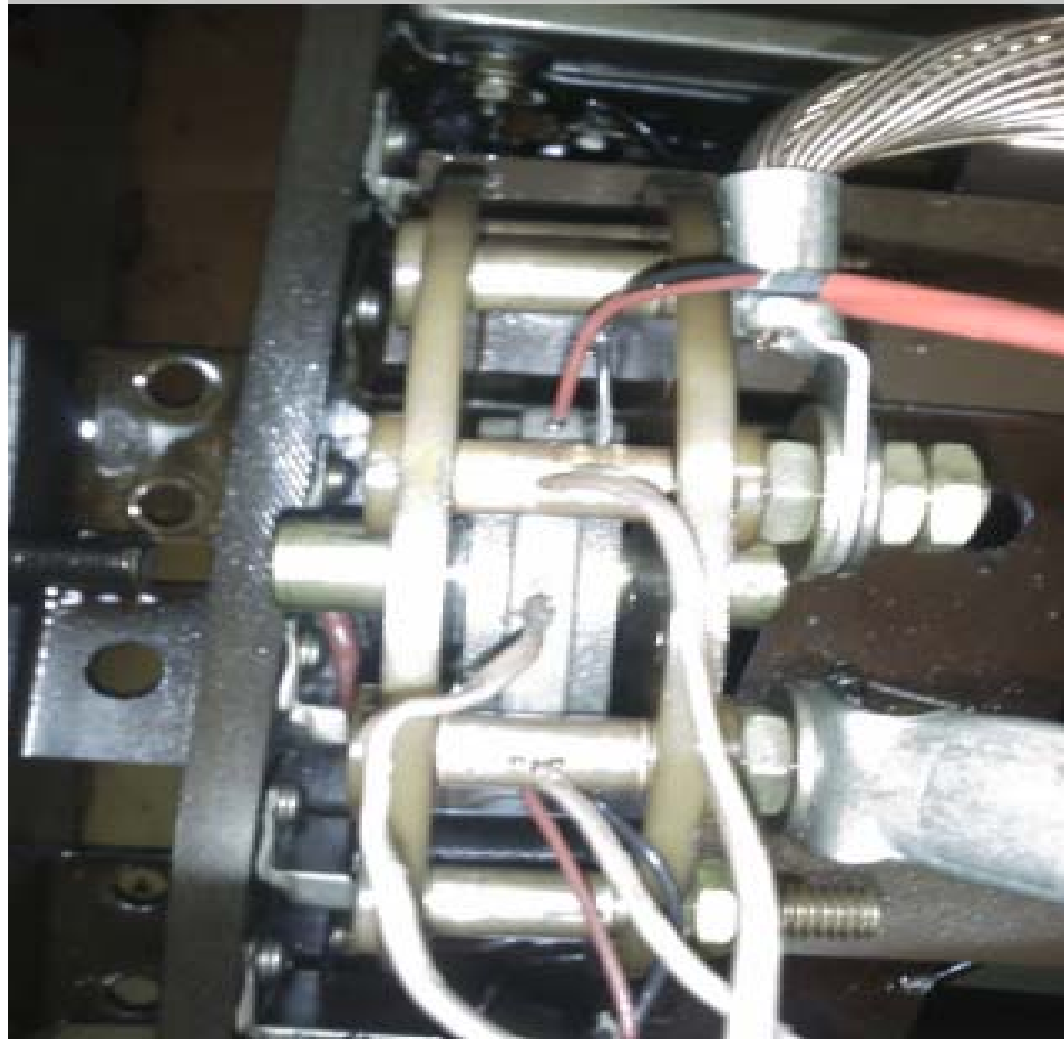
Functional Life Tests-Issue of Oil Volume



Important to replicate real environment

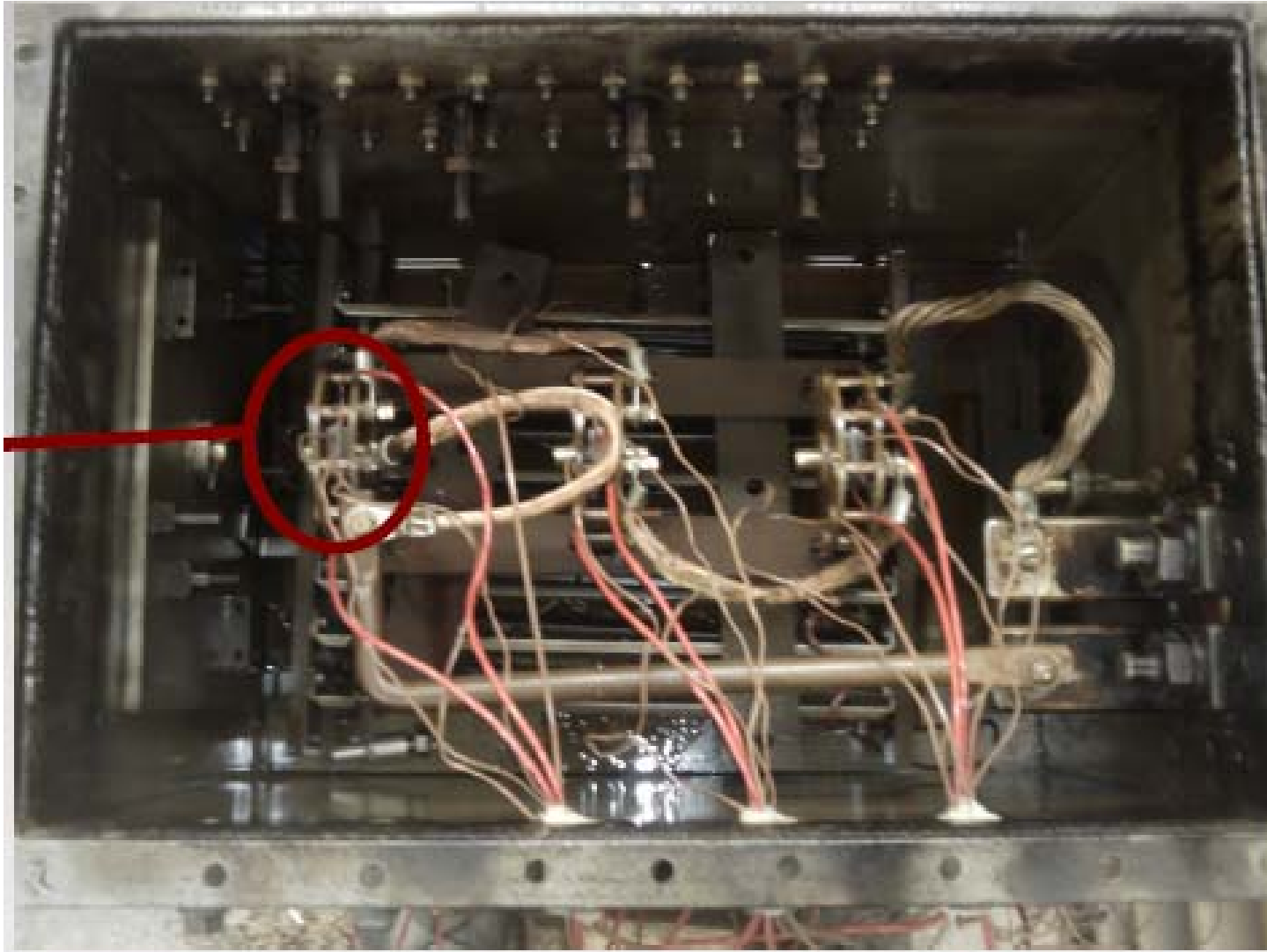
Functional Life Tests-Issue of Oil Volume

Double nut with flat and Bellville washer



Important to replicate real environment

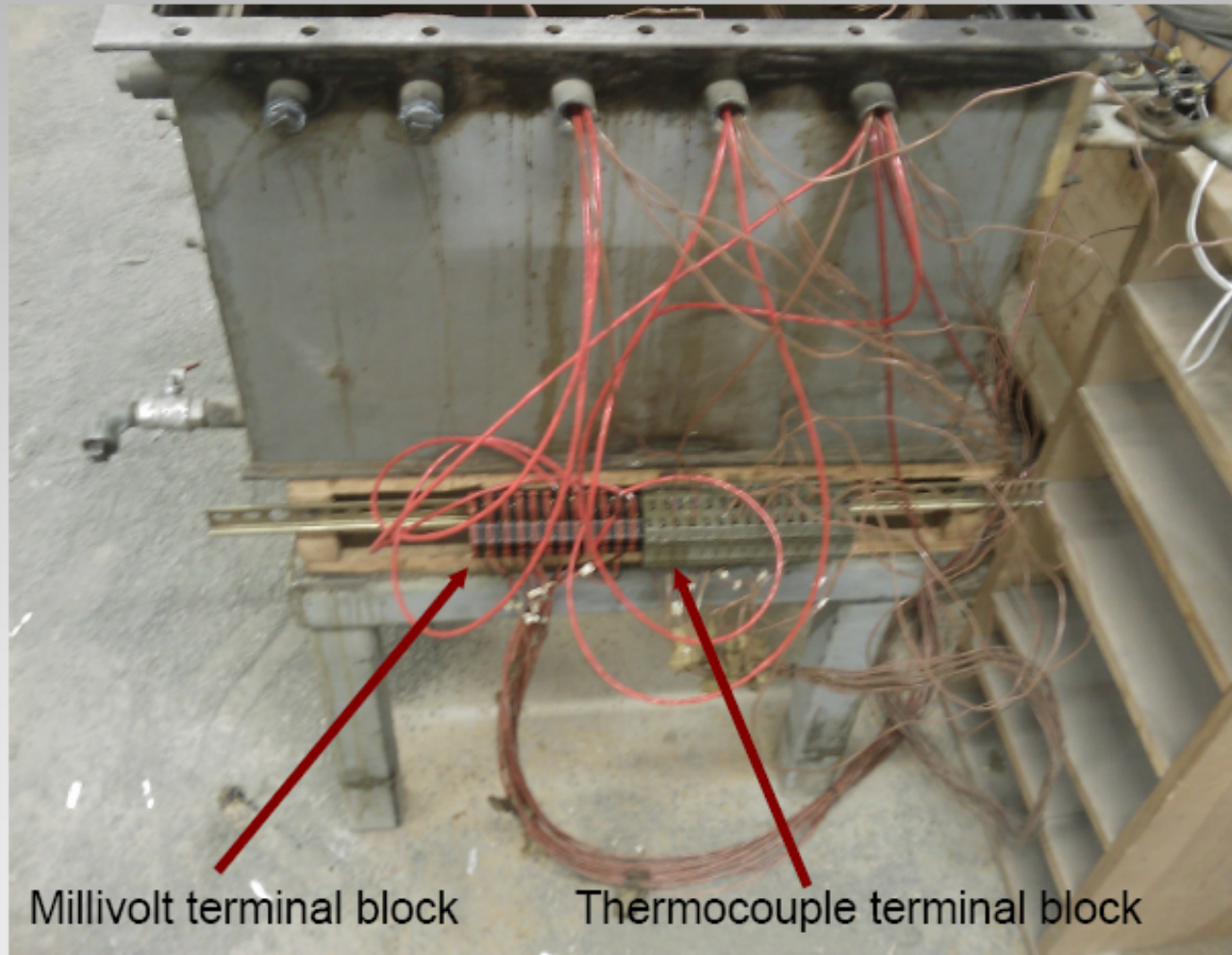
Functional Life Tests-Issue of Oil Volume



Important to replicate real environment

Functional Life Tests-Issue of Oil Volume

Terminal blocks on outside of tank. Connect inner tank wires to data logger.



Important to replicate real environment

Functional Life Tests-Issue of Oil Volume

130 C Liquid Temperature a good selection

1. Possible in real transformer at 2XN load for ½ hour in 30-40 C ambient.
2. Reflects IEEE C57.91 Loading Guide
3. Provides representative viscosity and activity
4. Provides sufficient acceleration to be reproducible

Important to replicate real environment

Assessment Time De-energized Tapchangers

Completed Work

- Functional Life Test Defined
- (3) Manufacturers have performed test
- **Test correlates with Harsh Duty field experience- switches that pass do well.** Example transformers – rolling mills

Limitation: General Purpose Transformers with light duty work OK with unstable contacts

Assessment Time De-energized Tapchangers

Completed Work-2

- Draft Technical Report issued

Limitation: To date: Only two authors on paper

Assessment Time De-energized Tapchangers

Derivation-oil temperature versus current

- Basic relationships
- Super temperature = Oil temp + bulk temp + super/bulk
- Hold super temp constant:

For Stable Silver-Silver Contacts		Avg of Method 1 and 2		
Current, times normal		2	3	4
Tbulk rise		18	35	55
T super rise over bulk		3	7	12
T super + bulk		21	42	67
Tgoal		151	151	151
Toil		130	110	84
Case		Base	Alt1	Alt2

Conclusions; Alternative currents and oil temperatures should work and give consistent results

Assessment Time De-energized Tapchangers

Derivation-oil temperature versus current

$$T \text{ super} = T \text{ oil} + T \text{ bulk/oil} + T \text{ super rise/bulk}$$

T Bulk/oil at rated current = 6

Current XN	Toil	T Bulk/oil	Toil+Tb/oil	Tbulk'	V	Method 1		
						Tsuper/Tbulk	Tbulk + Tsuper/bulk	
1	144	6	1	6	0.008	1	7	
2	130	18	1	18	0.016	3	21	
3	110	35	1	35	0.024	7	42	
4	84	55	1	55	0.032	12	67	
Difference between 4XN and 2XN								46

Method 1				
Current, times normal		2	3	4
Tbulk rise		18	35	55
T super rise over bulk		3	7	12
T super + bulk		21	42	67
Super Temperature = Tgoal		151	151	151
Toil		130	110	84
Case		Base	Alt1	Alt 2

Contacts	Super Temp, C
Silver-Silver	151
Copper-Copper	167
Tin-Copper	163
Ag-Ni	223

Conclusions; Alternative currents and oil temperatures should work and give consistent results

Assessment Time De-energized Tapchangers

Remaining Work

- Modified tests for other currents and bath temperatures
- Unified definition of the Functional Life Test
- Agree on Technical Paper
- Transmit materials for inclusion in C57.131

Assessment Time De-energized Tapchangers

Recommendations

- Stop data Quest in 1 more meeting at Spring **2010**
- Freeze test at present definition
Completed now
- Agree on Technical Paper **Fall 2009**
- Transmit materials for inclusion in C57.131
Spring 2010