

Agenda: Off Circuit Tapchangers

- Introductions
- Membership
- Old Minutes
- **Mission-Develop Functional Life Test and Report for De-energized Tap-changers**
- **Reports from Quality Switch, ABB, Reinhausen, and others on test results**
- Documents

- ☐ **P.J.H. Proposed Life Test**
- ☐ **PJH Proposed Report**
- Discussion
- Future Work
- Adjourn

Agenda: Off Circuit Tapchangers

Meeting Minutes from Lombard, IL

MEETING MINUTES

Westin Lombard Yorktown Center, Lombard, Illinois – October 27, 2009

Chairman: Phil Hopkinson

Secretary: Scott Choinski

The Task Force on Life Tests, De-energized Tap Changers was called to order at 9:35 AM on October 27, 2009. There were 42 attendees, 20 members, and 22 guests with 1 requesting membership. A quorum was not present. There were no patents to disclose. Reviewed the Agenda for the meeting, and the Minutes from the April 21, 2009, meeting in Miami, Florida, were approved.

1. 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. No known field failures from tapchangers that pass test.
2. Issues for test –
 - Test Validity. Suppose we wanted to define life as equal to oil-Cellulose. What time and temperature to have equal life as oil-cellulose (110 C for 180,000 hrs)? Calculations show that test to date not equivalent to insulation life.

Testing is currently being conducted with Ag-Sn and Sn-Sn contacts in FR3 have been stable for 14 days as of the date of this meeting. Test will need to be repeated in oil as previously unstable contacts have been stable in FR3.
 - Issue of Oil Volume. Large liquid volume important for test validity and it is important to replicate real environment
3. Extended discussion on conducting the test. Earl Rawls wants to conduct a test, but needs more details to set up the test.

Agenda: Off Circuit Tapchangers

Meeting Minutes from Lombard, IL

3. Extended discussion on conducting the test. Earl Rawls wants to conduct a test, but needs more details to set up the test.
4. Bengt Stenestam presentation. There are considerations that need to be better defined in conducting the test. Examples are statistical variations (material quality), oil quality, wiping effect on contacts. Pass criteria for the test may be too rigid.
5. Agree on Technical Paper – not many comments have been received. Goal is for TF paper and not solely a Phil Hopkinson paper.
6. New Business

There was no new business.

The meeting adjourned at 10:55 AM.

Working Group for Off-Circuit Tapchangers

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 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**

Missing

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

• Complete description of test details

Working Group for Off-Circuit Tapchangers by Philip J. Hopkinson

Agenda items for March 9, 2010 Meeting:

- Presentation by Larry Dix on Functional Life Test
- Paper review of Comments by Bengt-Olof Stenestam
- Comments by Reinhausen and others
- Tentative paper
 - Authors
 - Venue: Panel Session or Transaction
 - Timing

General requirements for Off-Circuit Tapchangers

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

Note that the 110 Max oil temperature is consistent with Section 9.2.1 of IEEE Loading Guide C57.91-1995

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.

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
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

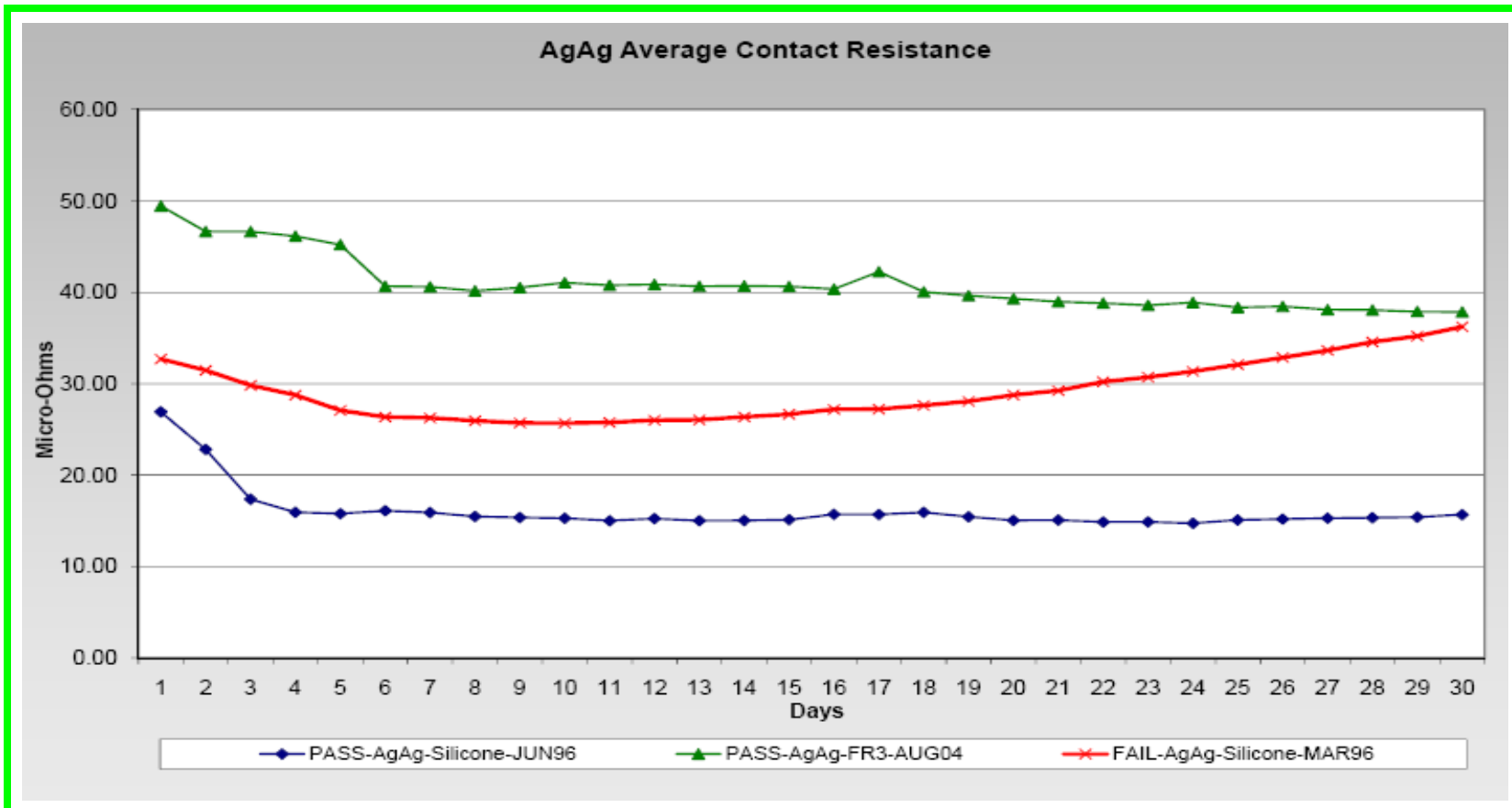
Issue 1: **Test Validity**

- 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**

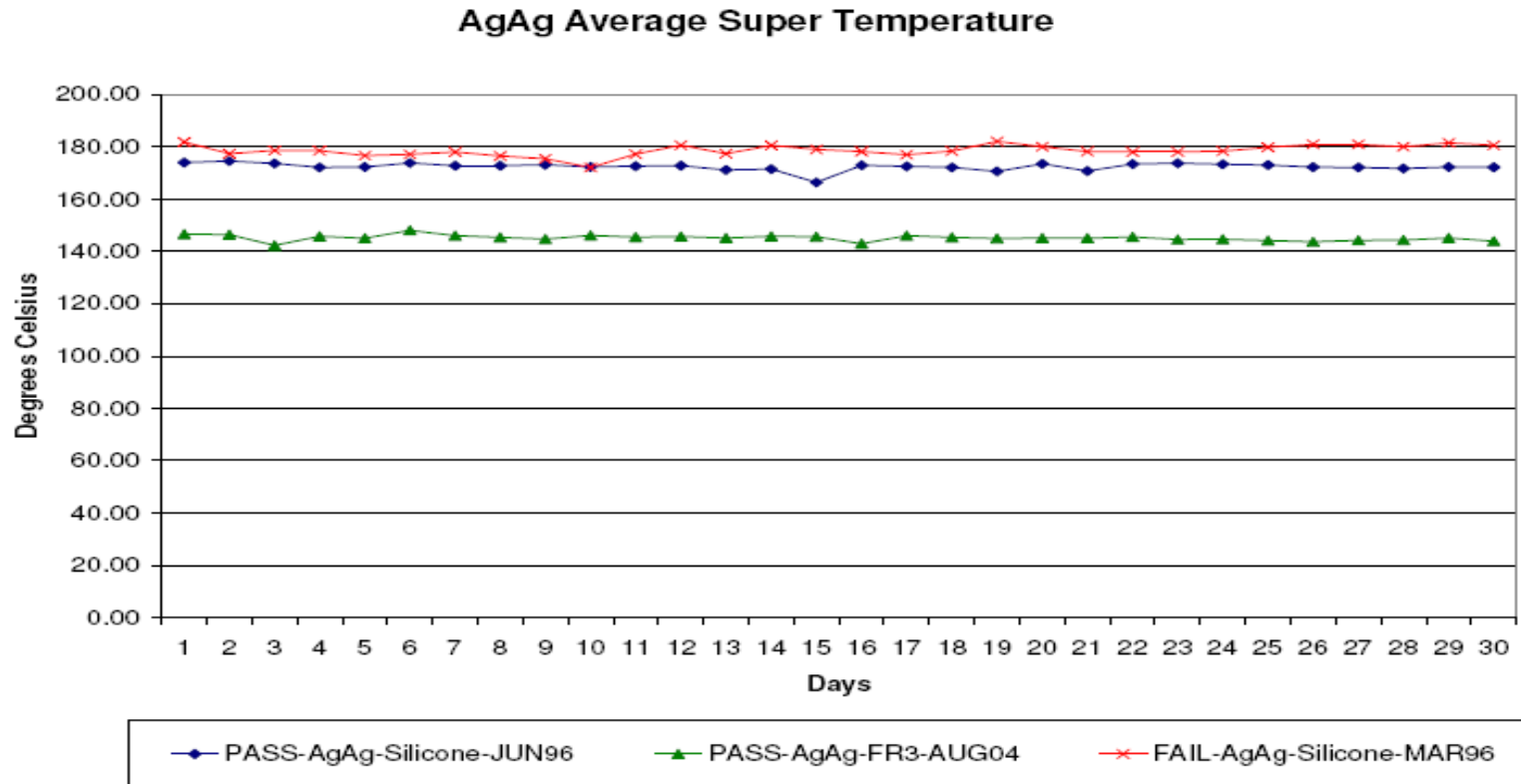
Functional Life Tests-Issues



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

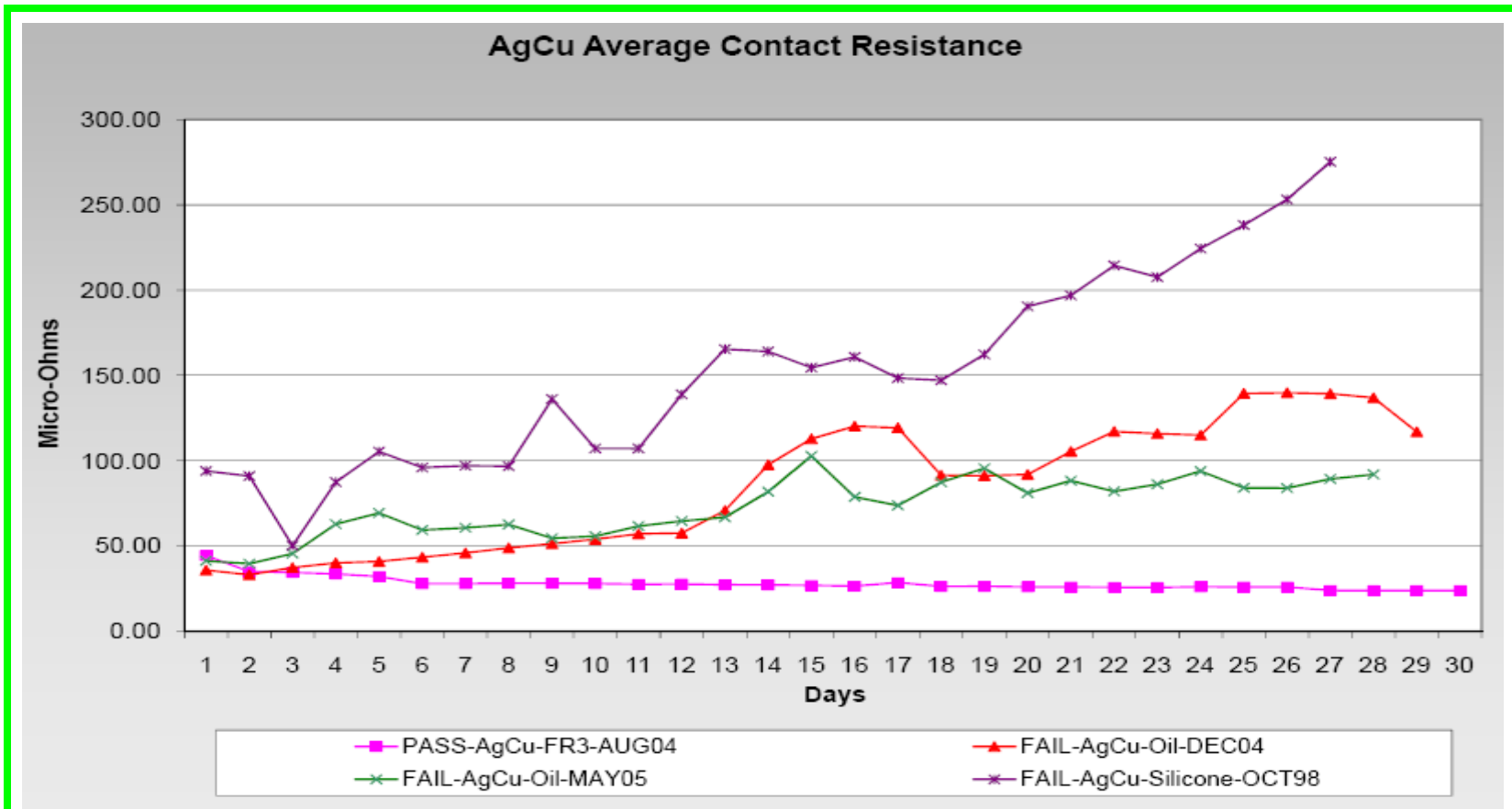
Functional Life Tests-Issues



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

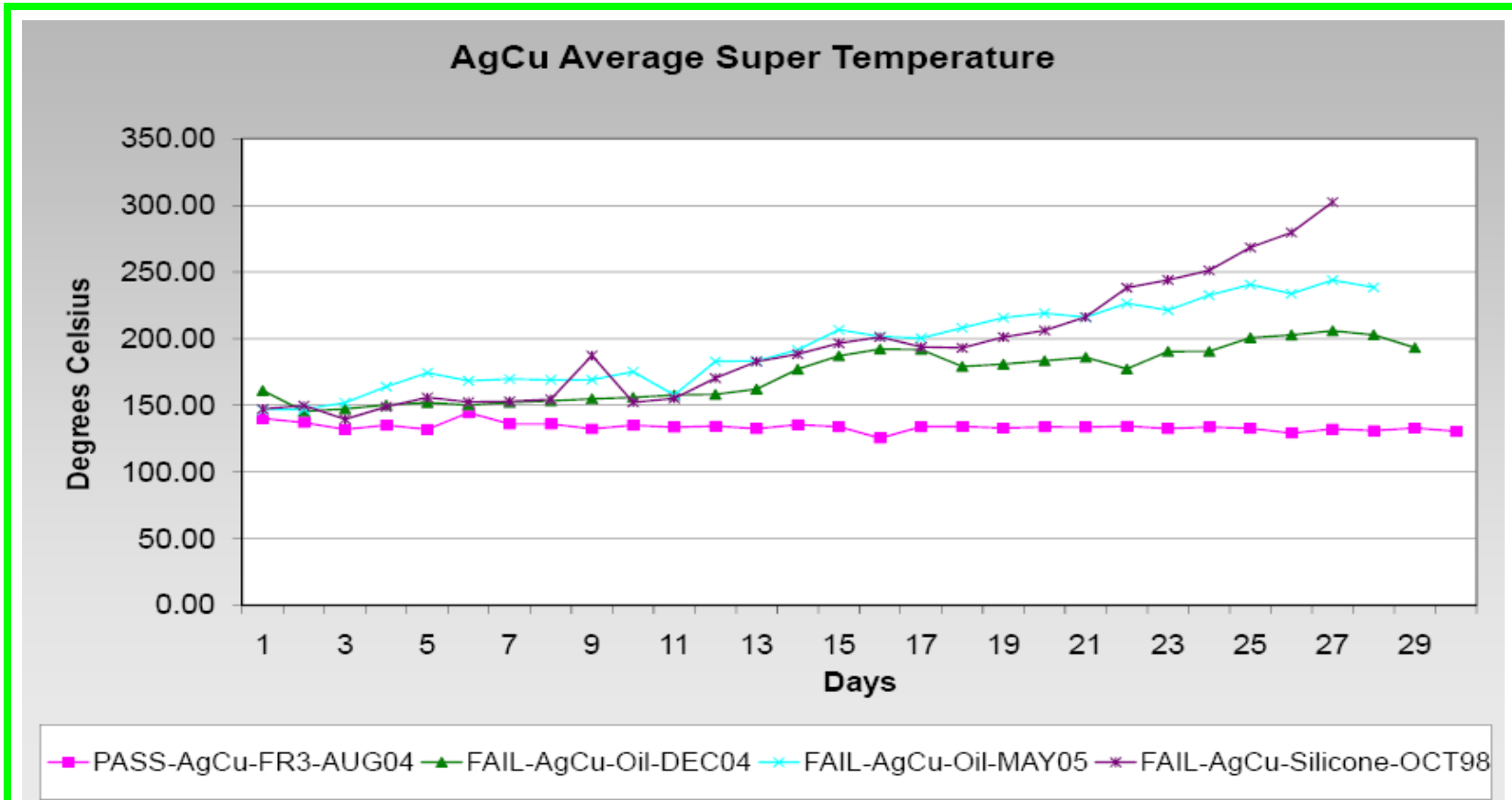
Functional Life Tests-Issues



Observations:

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

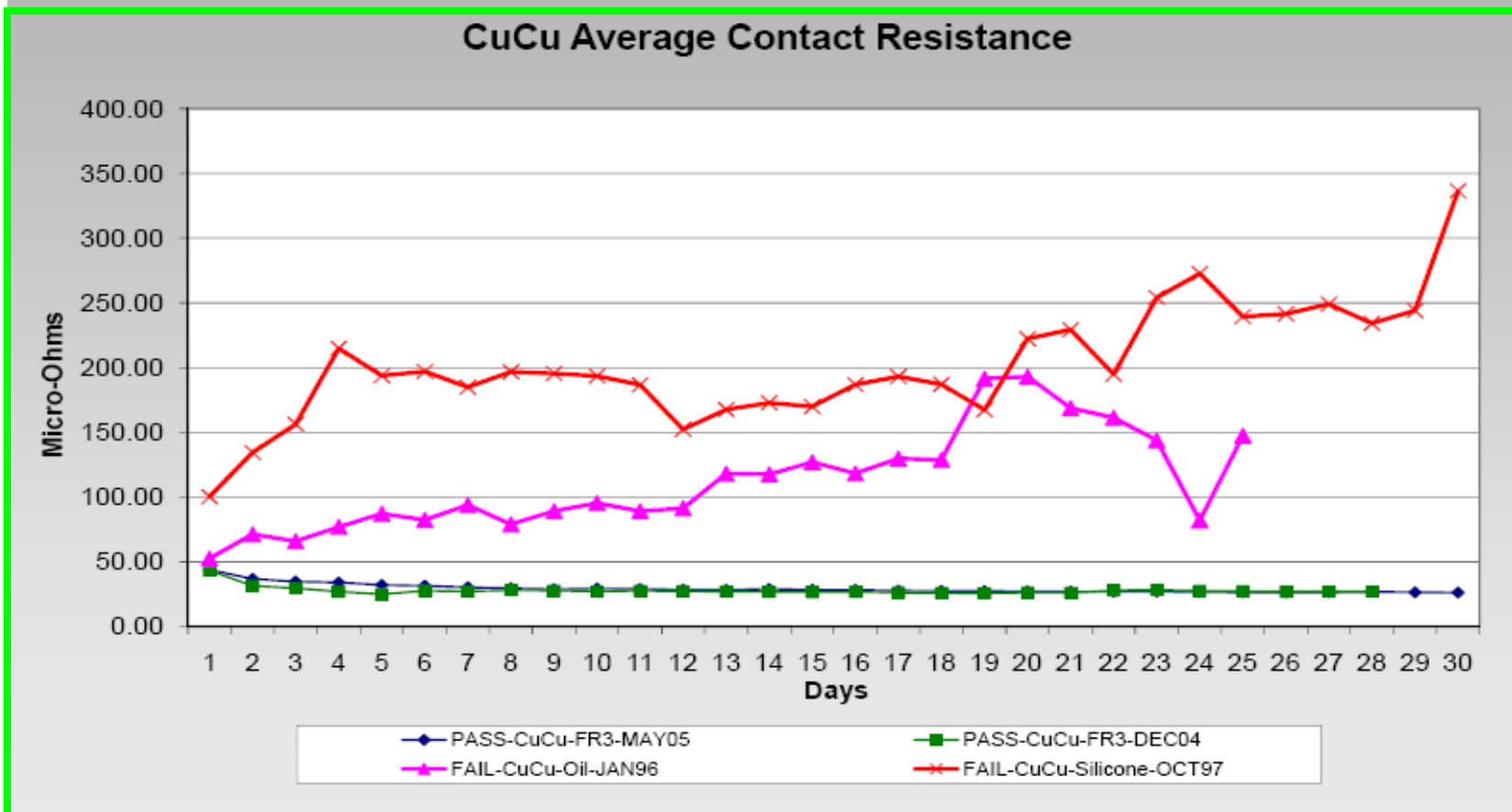
Functional Life Tests-Issues



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.

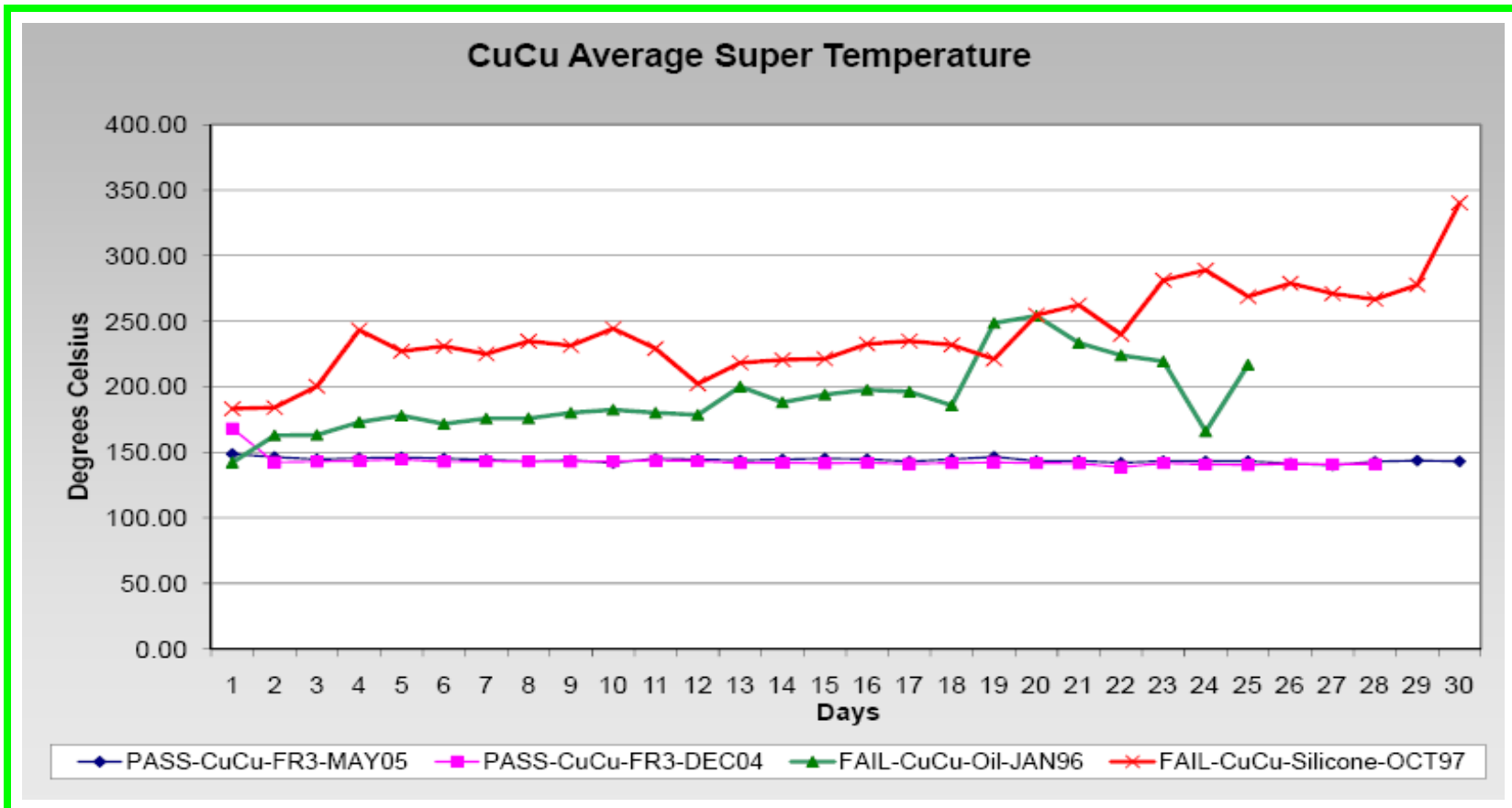
Functional Life Tests-Issues



Observations:

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

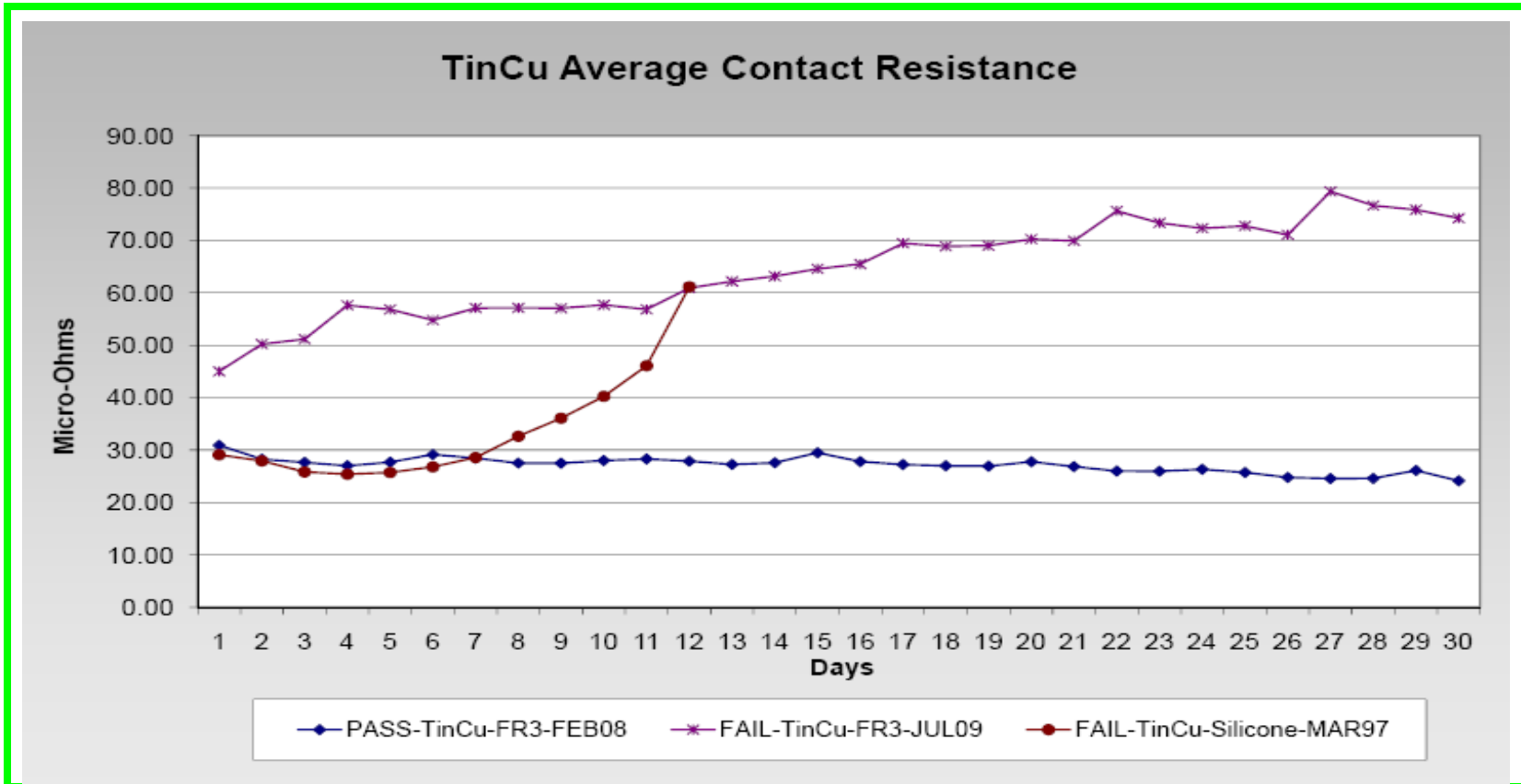
Functional Life Tests-Issues



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

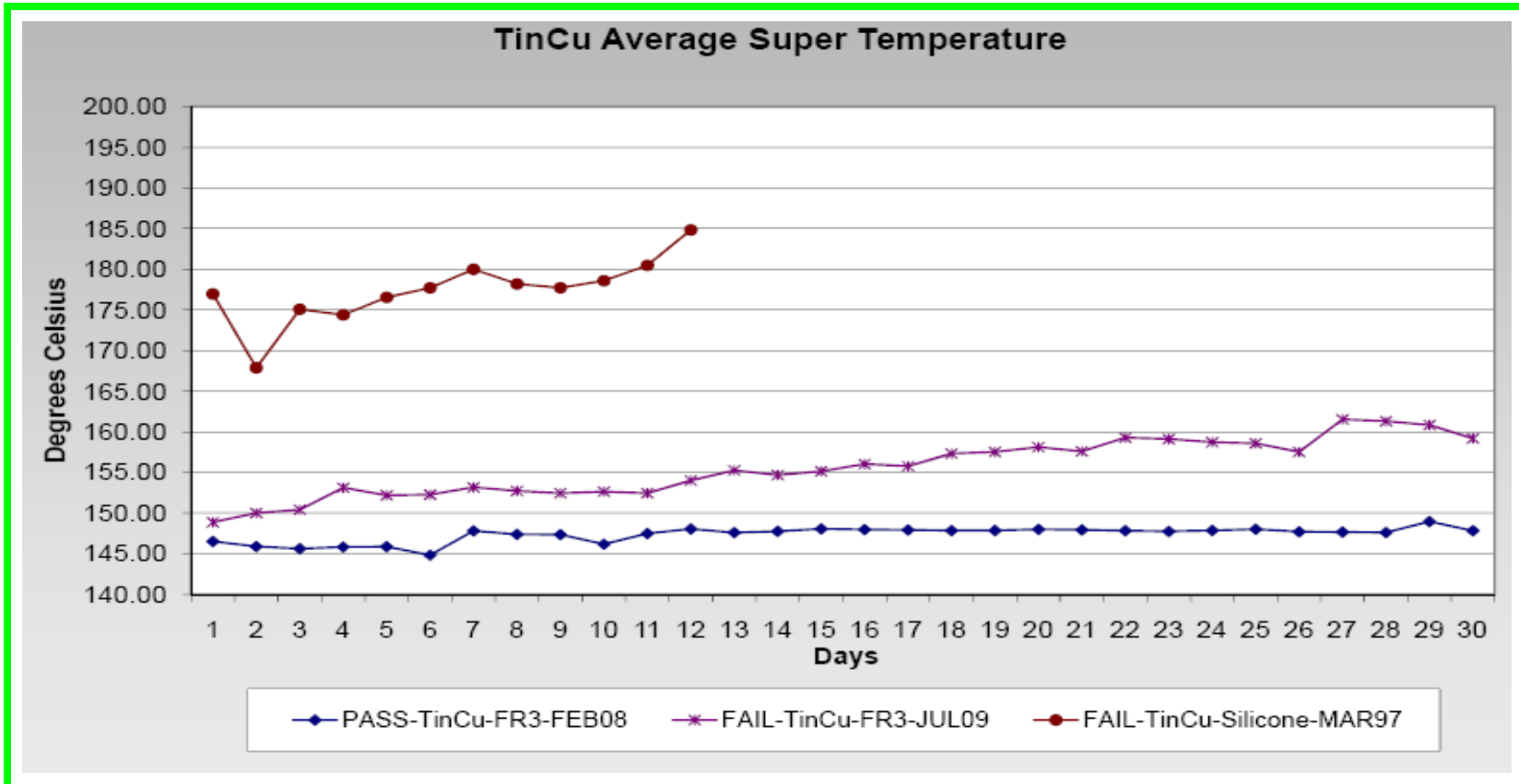
Functional Life Tests-Issues



Observations:

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

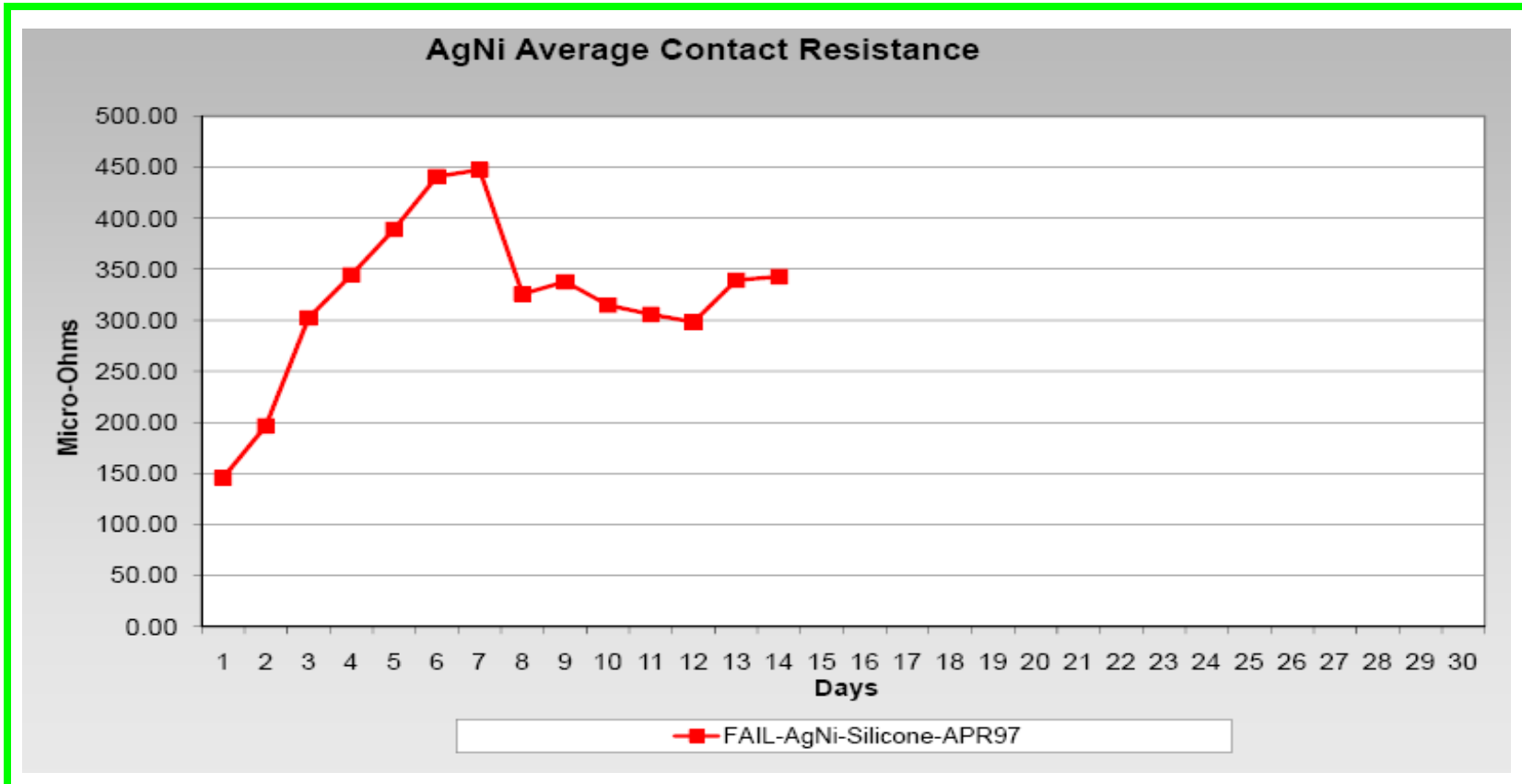
Functional Life Tests-Issues



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

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

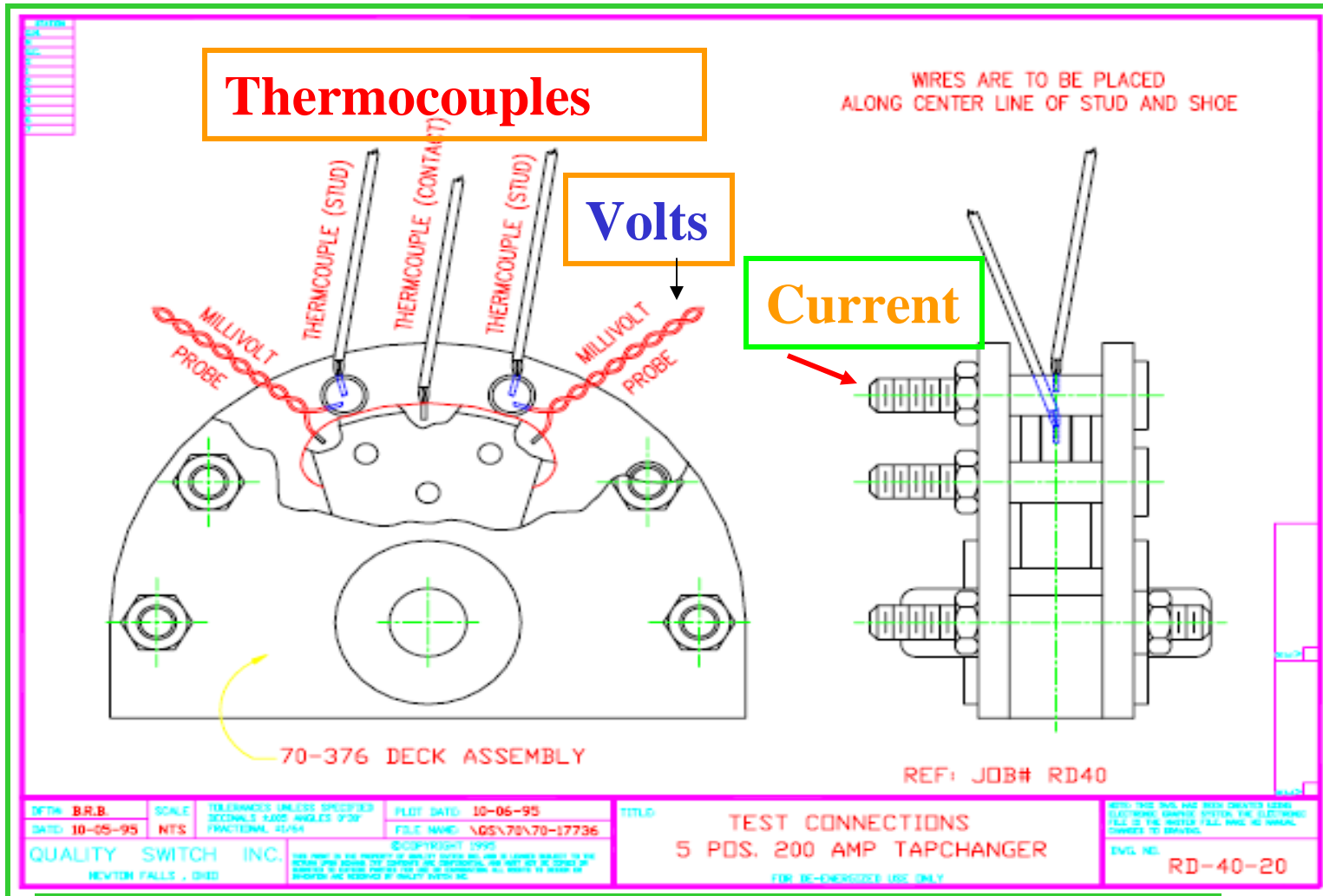
Functional Life Tests-Issues

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

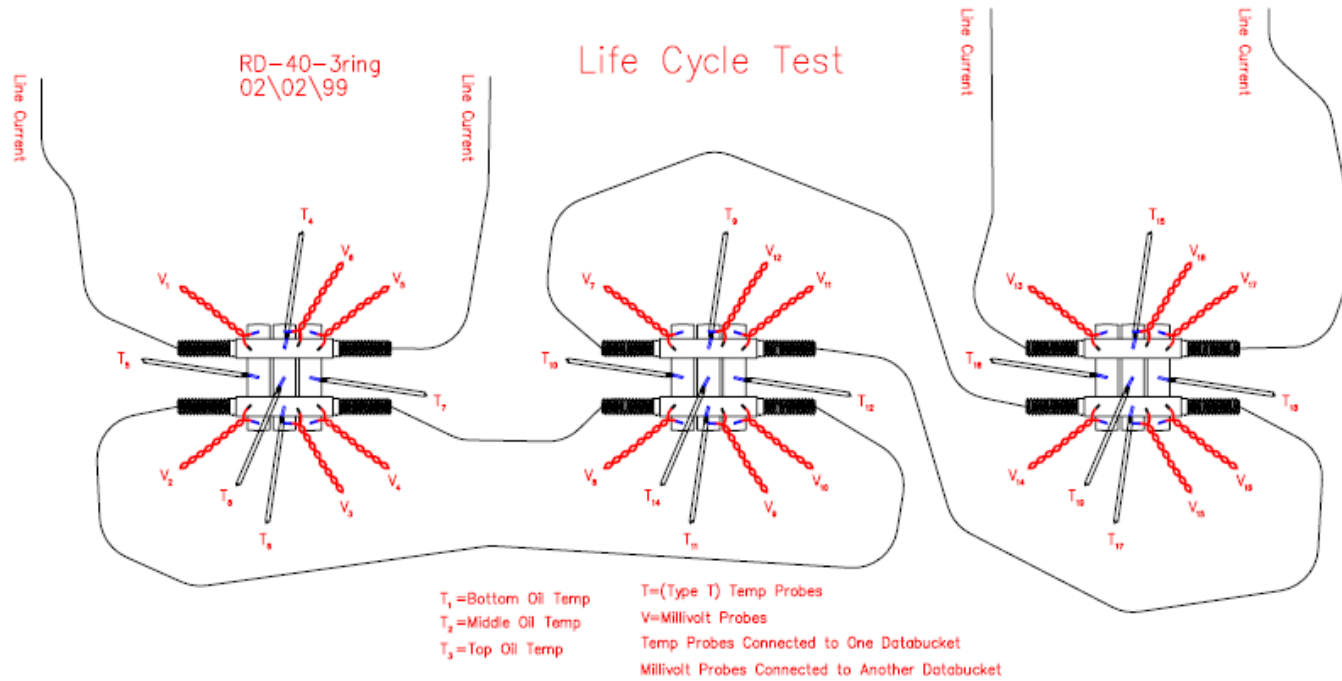
Most important to use complete tapchangers and not just contact pairs.

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

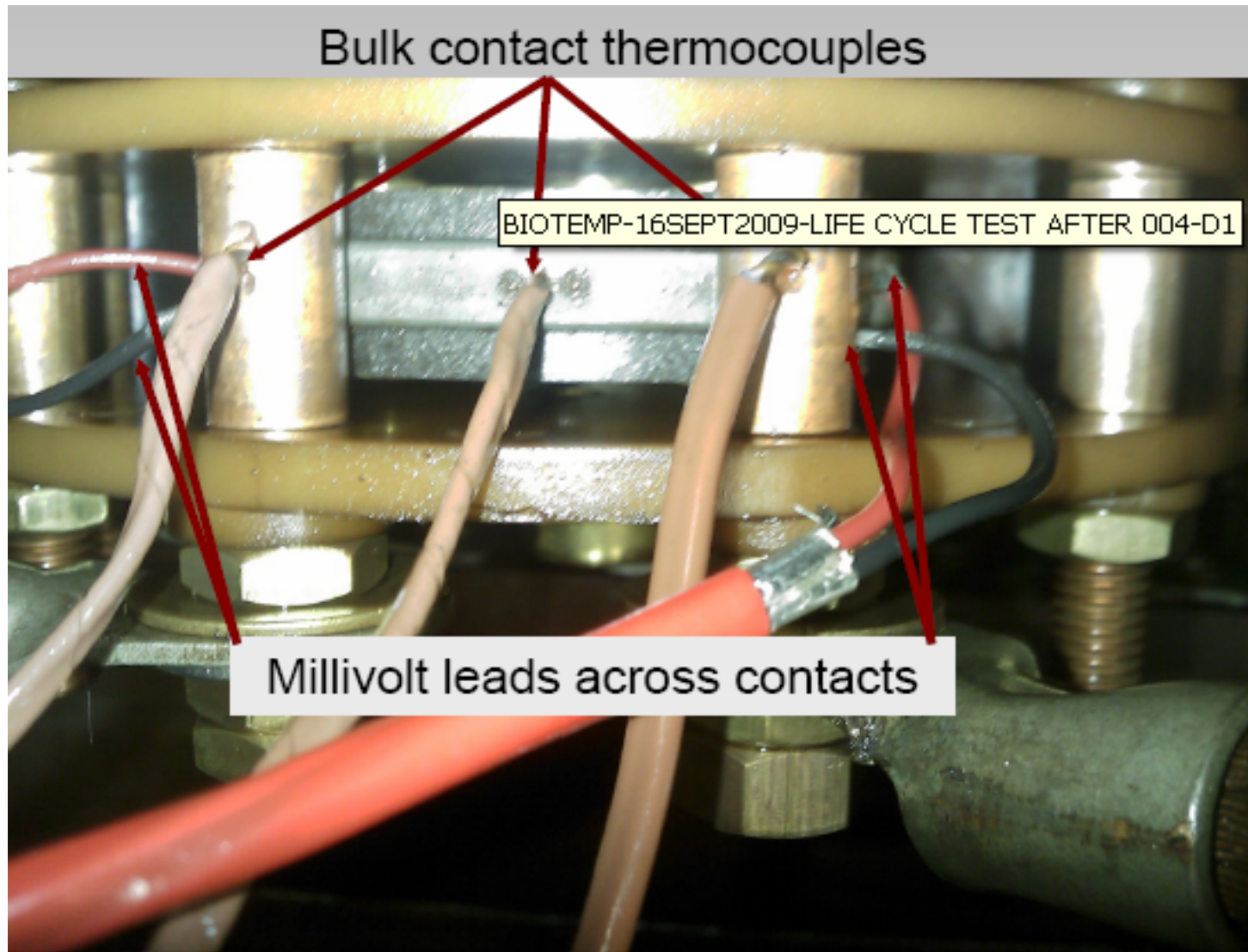
Important to replicate real environment

Functional Life Tests-Issue of Oil Volume



Important to replicate real environment

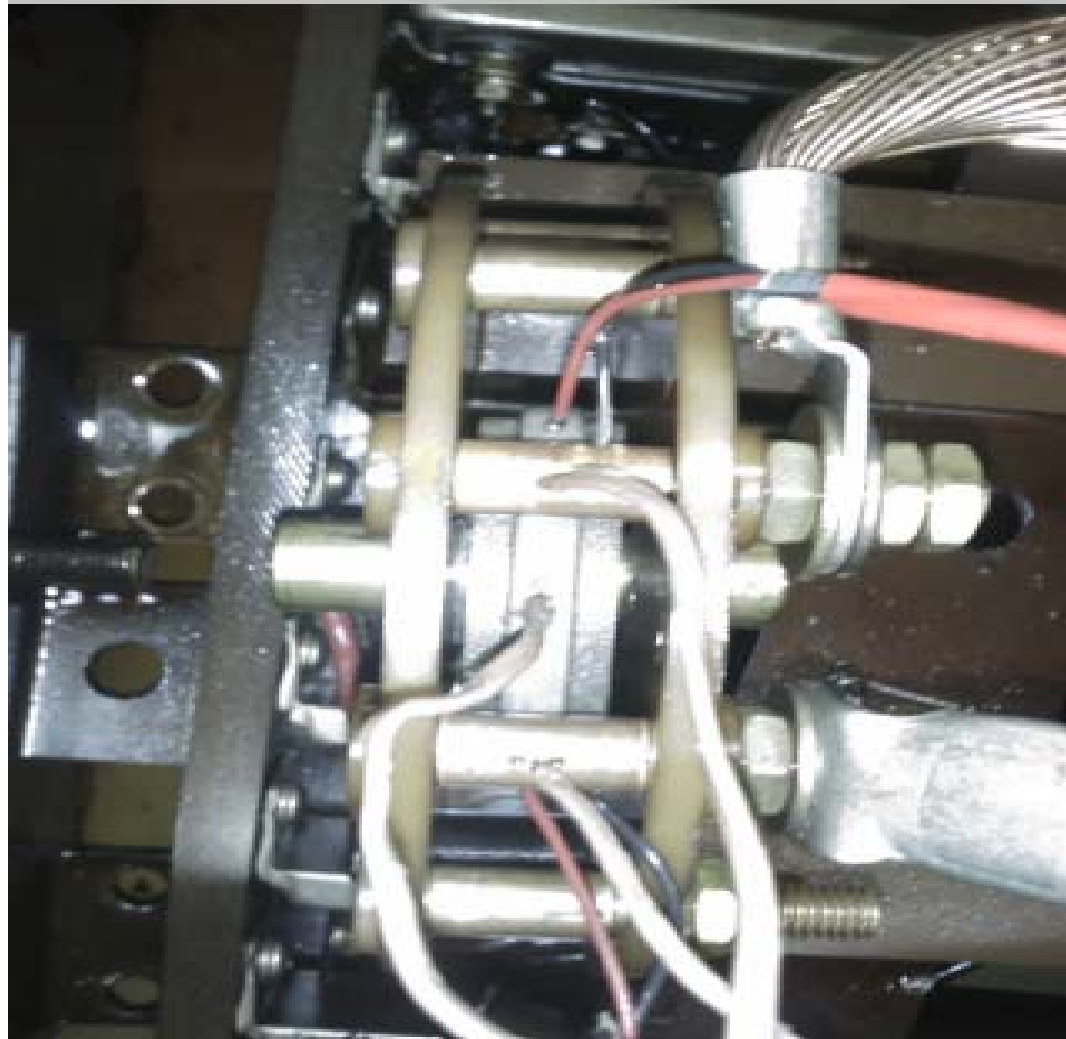
Functional Life Tests-Issue of Oil Volume



Important to replicate real environment

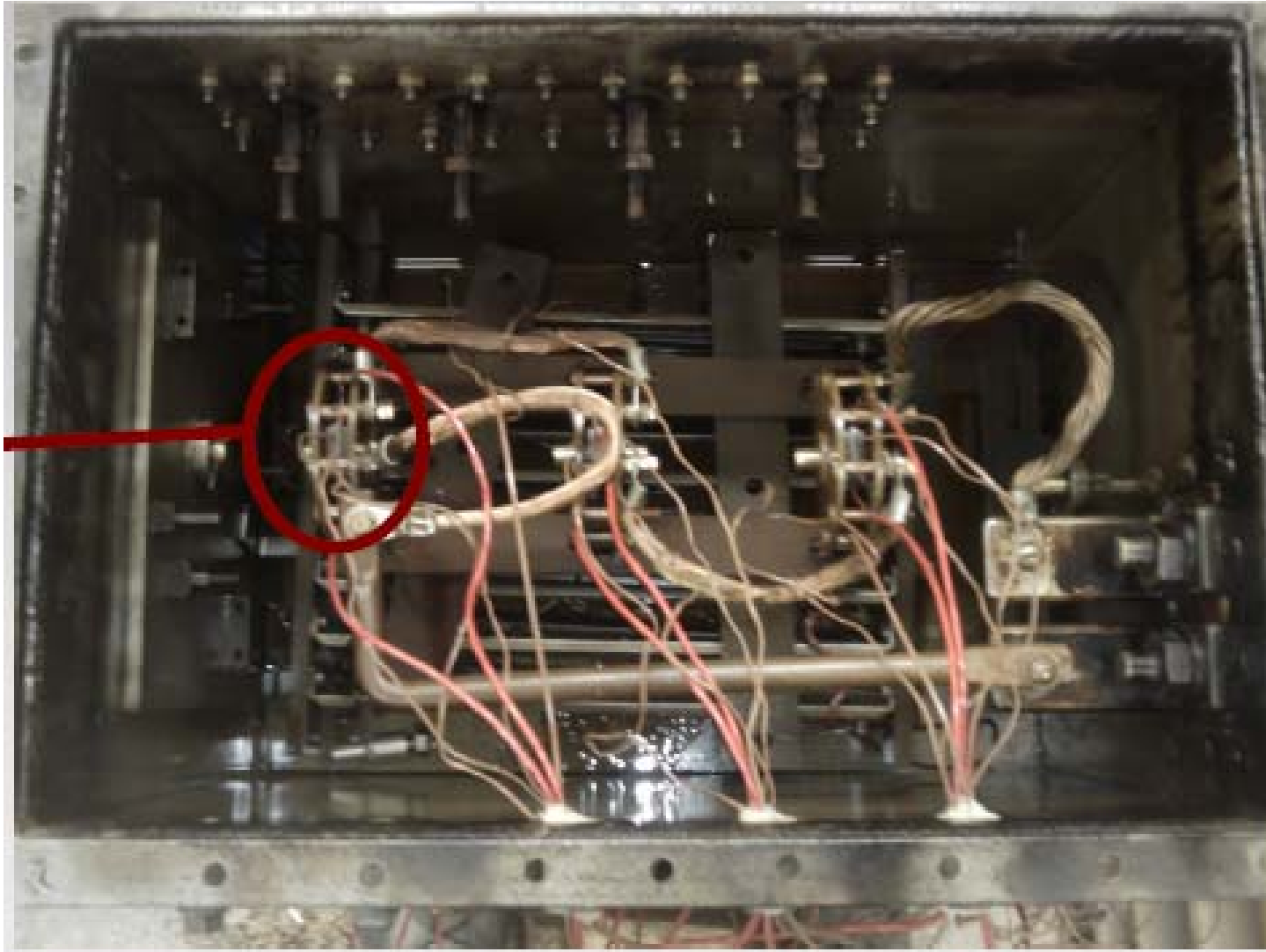
Functional Life Tests-Issue of Oil Volume

Double nut with flat and Bellville washer



Important to replicate real environment

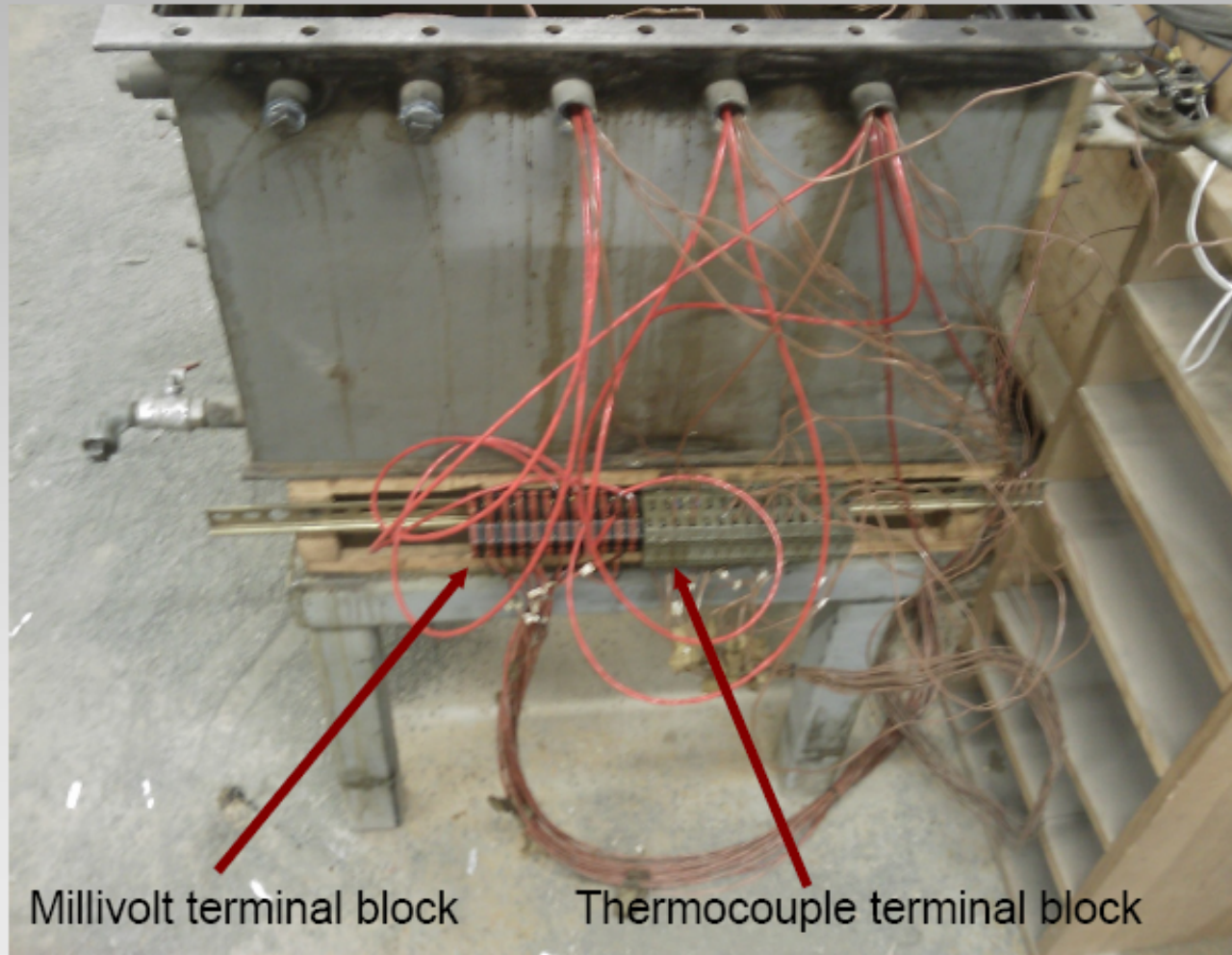
Functional Life Tests-Issue of Oil Volume



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
- (5) 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 **2011**
- Freeze test at present definition
Completed now
- Agree on Technical Paper **Fall 2009**