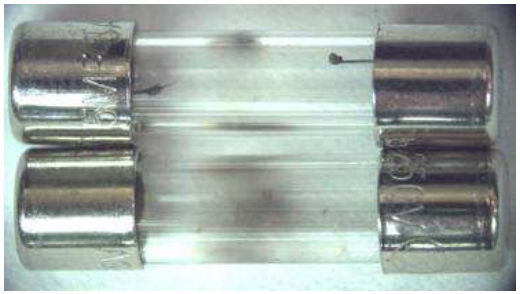
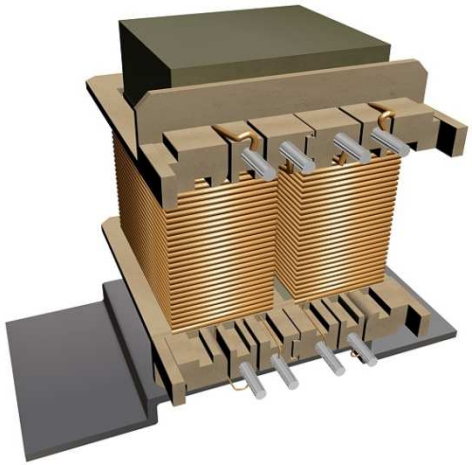

inFIRE CONFERENCE 2008
FIRES, SAFETY, AND INFORMATION
UNITING THE PIECES
HOSTED BY
SAFETY ENGINEERING LABORATORIES, INC.
OMNI DETROIT HOTEL AT RIVER PLACE
MAY 5-8, 2008
Damage To Consumer Appliances' and Electronics' Transformers and Fuses Under Simulated Fire Conditions
Safety Engineering Laboratories, Inc.
Donald Hoffmann, Ph.D., P.E., C.F.I.
Presented by Erik Swonder, MSEE
inFIRE
The International Network for Fire Information and Reference Exchange

Spo[CEA]search

- Fuses



- Transformers



Electronic Devices in the Area of Origin Often become Focus of Investigation

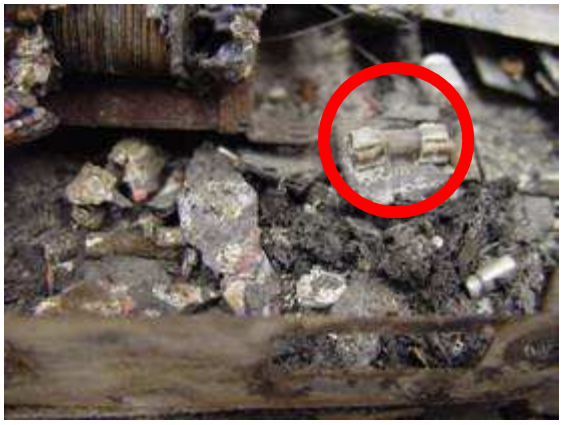
Research Helps Identify or Eliminate Electronic Devices in the Course of the Investigation

Research Also Provides New Tools To be Used in Investigations

Fuse Testing

- **Fire Damage to Electronic Devices**
- **Fuses and their Operation**
- **Forensic Examination of Fuses**
- **Test Conditions**
- **Gross and Microscopic Damage to fuses**

Fuses from Fire Tests



FUSES

- An overcurrent protective device with a circuit-opening fusible part that is heated and severed by the passage of overcurrent through it. (IEEE Std 100-1972)

NFPA 921 on Fuses

- 24.5.2.4.1:

"The fusing element in a fuse can be one of several metals. In all fuses the element has the proper cross section and electrical resistance for the temperature to rise to the melting point if current exceeds a specific level for a specified duration. If the excess current is moderate (e.g., less than twice the rating), the fuse element will melt without vaporization. If the current is very high, as with a dead short, the element will usually partly vaporize to give an opaque deposit on a window or glass tube of the fuse."

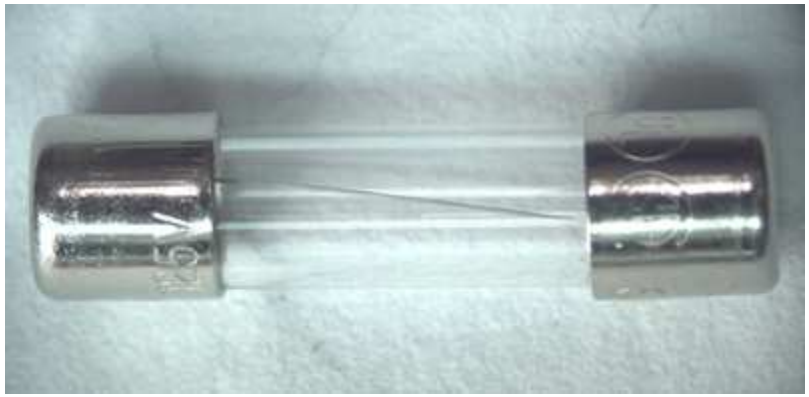
FUSES

- **Circuit protection devices**
- **Highly engineered**
- **Different:**
  - **Sizes and construction**
  - **Voltage and current ratings**
  - **Response time**
  - **Secured differently**

20 mm Glass Fuses

- Found in small electronic devices (TVs, VCRs, printers, etc).
- 3 Amp Slow Blow and Fast Acting fuses with tin coated copper fuse elements

Slow Blow



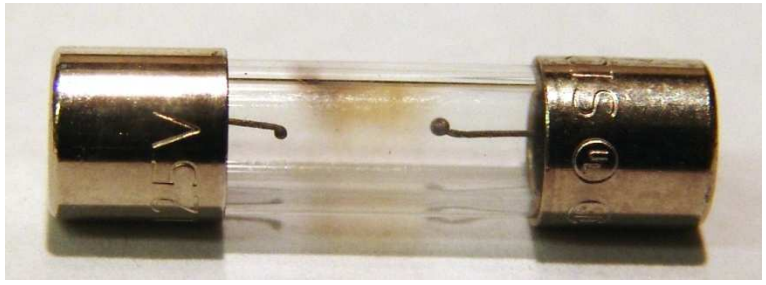
Fast Acting

Operation of Fuses

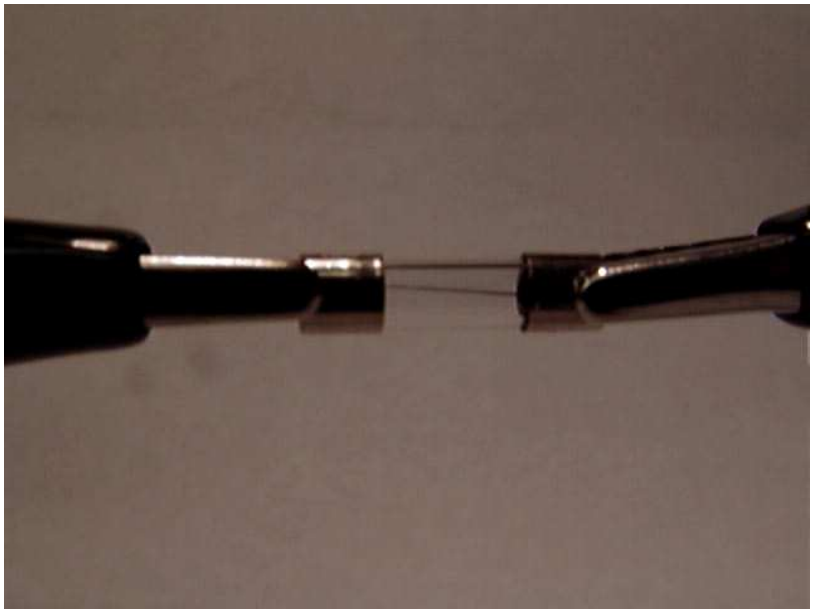
- ‘Fail-safe’ and irreversible
- Temperature dependent
  - Melting temperature of element
  - Ambient conditions
- Conditions
  - Overcurrent
  - Overload
  - Fatigue

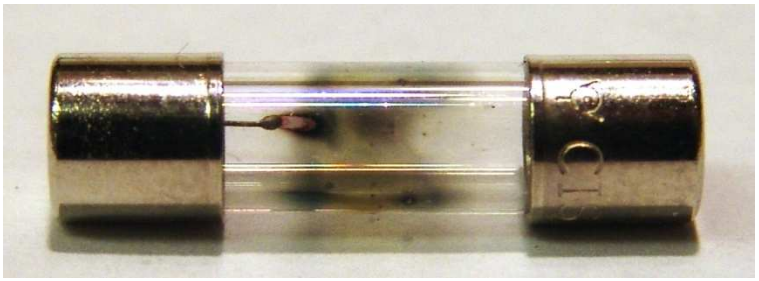
Fuse Opening from Overcurrent

150%



200%



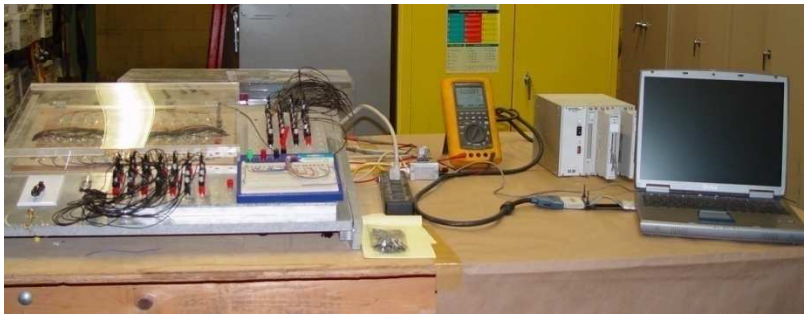


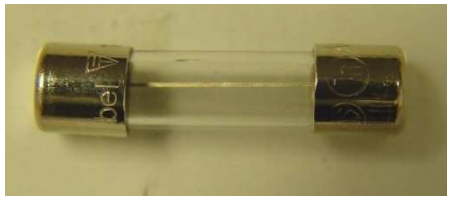
Forensic Examination of Fuses

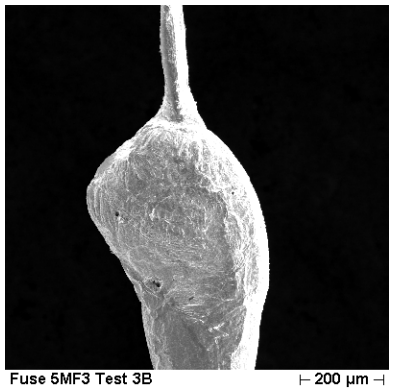
- Electrical Continuity
- X-ray Examination
- Gross appearance
  - Element condition
  - Staining on the glass case
- Challenges
  - Embedded in plastic
  - Dark discoloration
  - Non-destructive

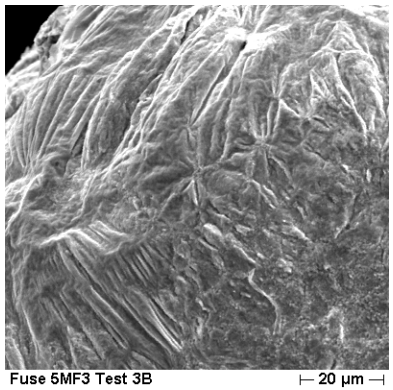
Fuse Testing

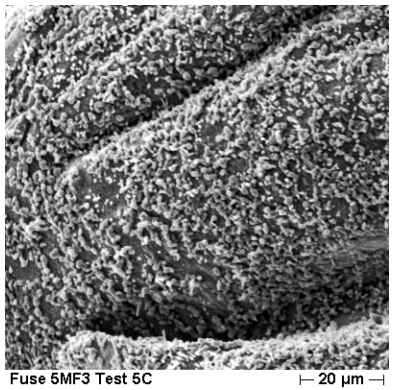
- 16 different 1-6.3 amp 20 mm glass fuses
- 12 Conditions of current and intense heat
- Examination of damage
  - Gross
  - Microscopic







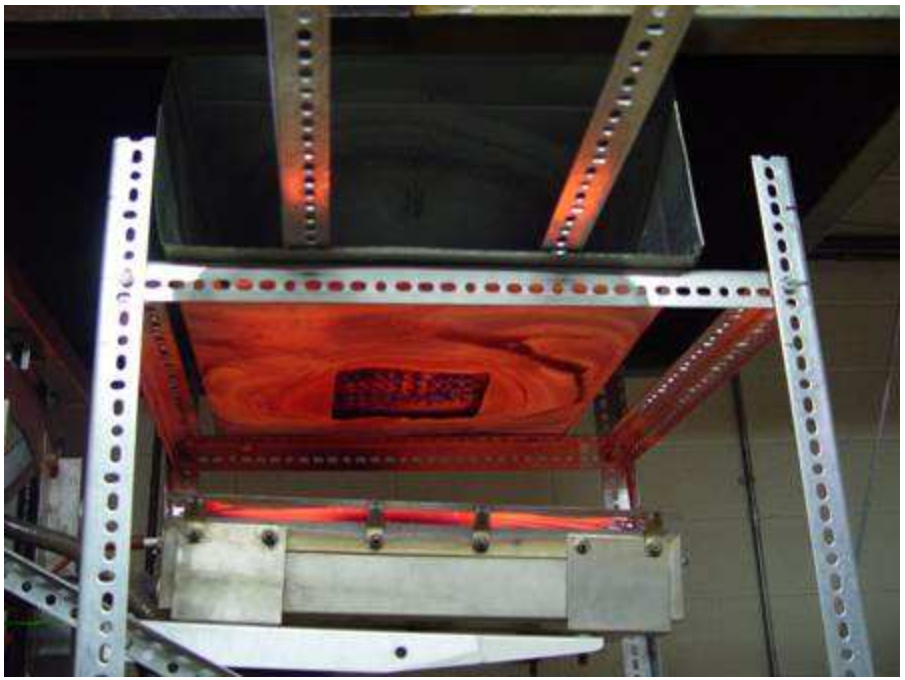




Test Conditions

- 12 Conditions of current and heat
  - 50%, 100%, 150% and 200% of the rated current
  - Energize at ambient conditions then expose to heat
  - Energize simultaneous with exposure to heat
  - Intact and broken glass exposed to heat (i.e., no electrical history)

Heat Exposure



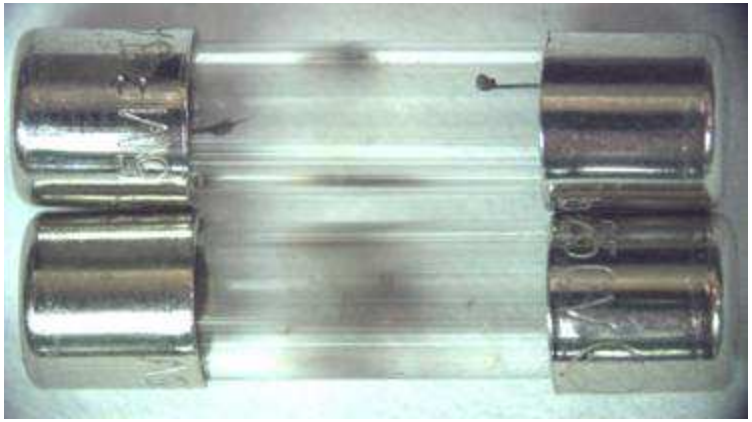
Max Heat Flux = 39 kW/m^2

Temperature = up to 1400☜F (760☜C)

Preliminary Results

- Discoloration
  - Heat exposure resulted in uniform discoloration but varied in intensity
  - Opened electrically resulted in a ring, spot or band but varied in intensity
- Location of open ends of element
  - Both symmetric and asymmetric with respect to the center of the fuse

Discoloration

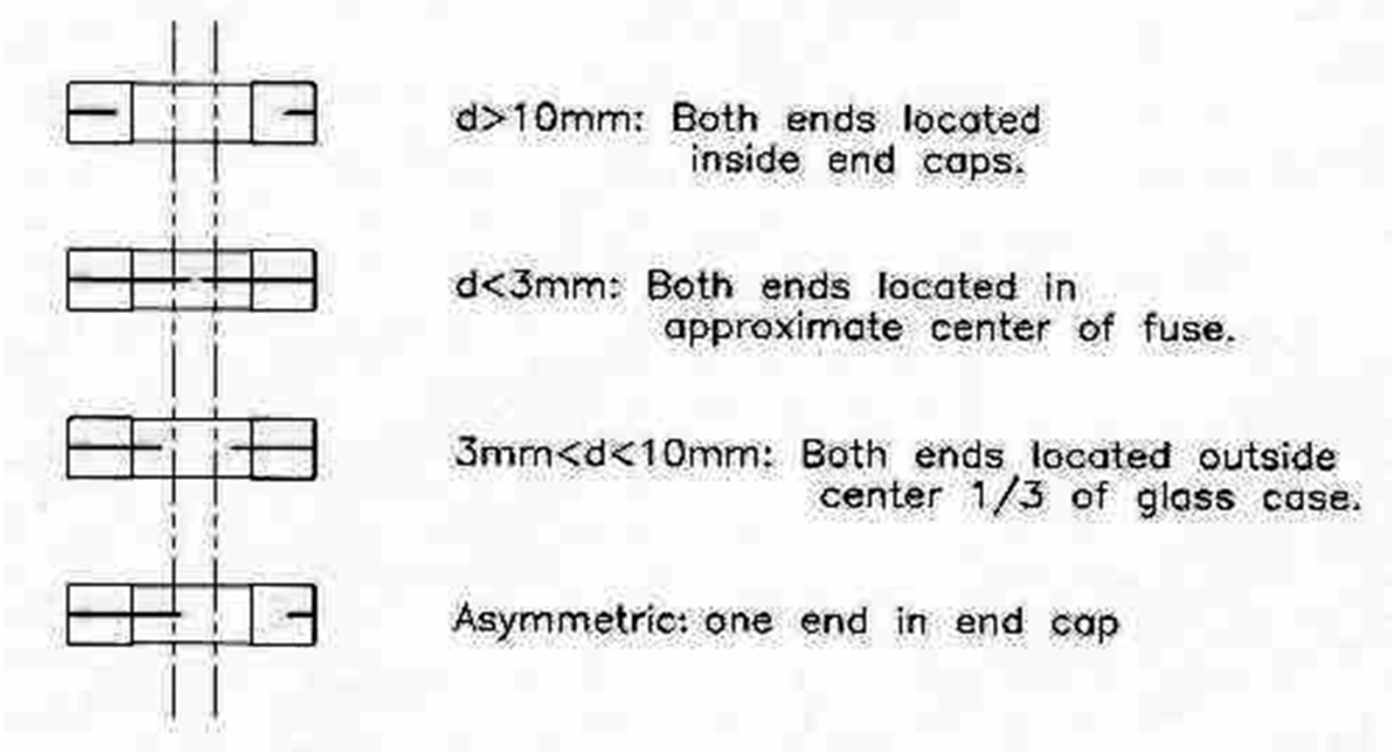


Opened electrically

Heat exposure

Location of open ends of element

- Possible locations of the ends of a Fast Acting fuse element



Duration of Continuity

Depends on temperature and construction

FUSE	Fuse Response	50% (sec)	150% (sec)	200% (sec)	50% + heat (sec)	100% + heat (sec)
5MF3	Fast	>300	2.3-5.7	0.3-1.0	30.5-160.3	16.7-31.7
5TT3	Slow	>300	26-203.3	5.3-7.2	21-106.3	9.0-20.3

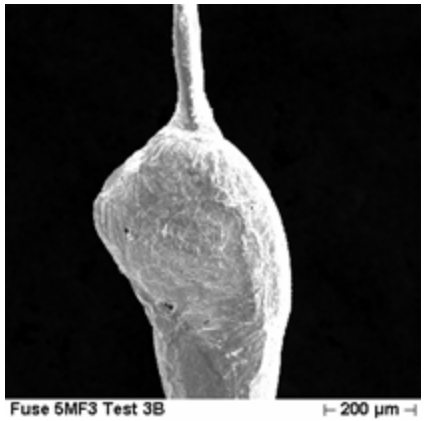
5MF3 Fuse secured by solder and crimping.

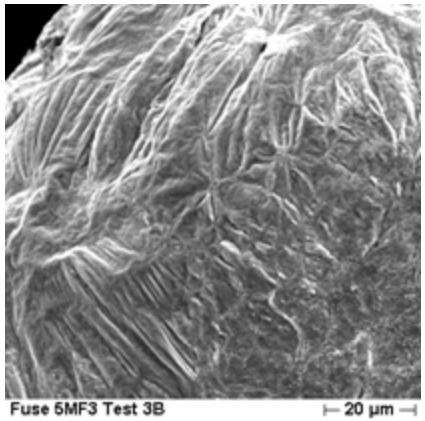
5TT3 fuse element secured by solder only.

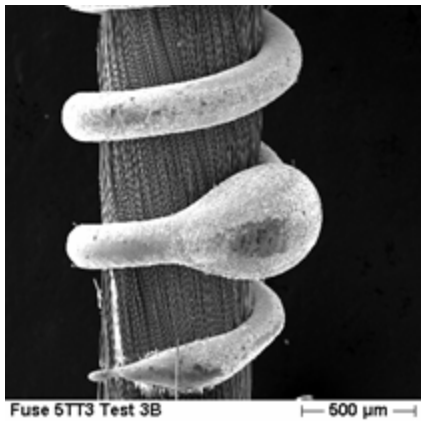
Typical solder melts at ~150-200☜C

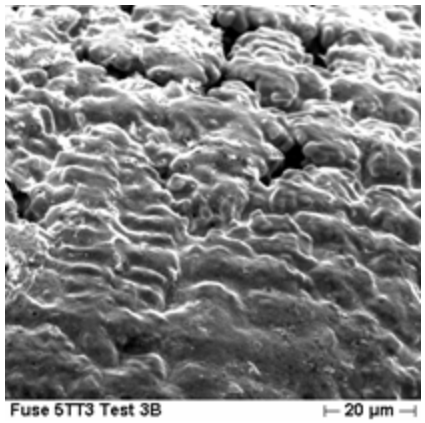
SEM Examination

- **Parting arc (bright flash)**
- **$T>T_m$ Cu = 1983°F (1084°C)**
- **Rapid cooling**
- **Did not vaporize completely**
- **Localized damage to glass fibers of slow blow fuse**









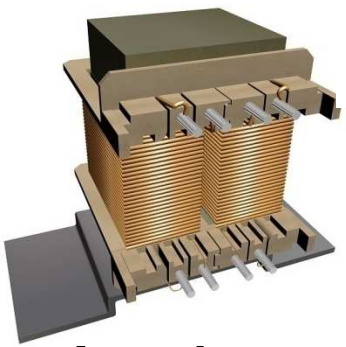
Results of Fuse Testing

1) Opened electrically at ambient conditions when the current exceeded the rated current;
2) Opened electrically at the rated current but higher than ambient temperatures
3) May lose continuity due to a melted element when they are both energized at or below the rated current and exposed to temperatures typical of fire environments, and
4) May lose continuity due to loss of solder when they are either energized or non-energized and also exposed to temperatures typical of fire environments (T ~ 1400°F).

Conclusions

- An open fuse can result when an energized device is exposed to an external fire.
- Fuses melt/open under certain conditions of current and heat.

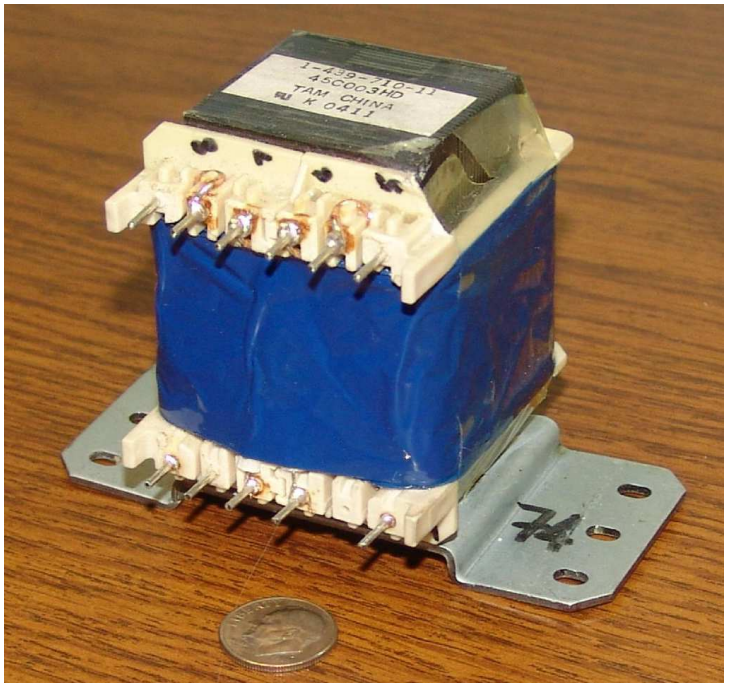
Transformers



- Testing of energized and non energized transformers was conducted
- Testing included inducing faults in the Primary under heated and ambient temperatures and evaluating the damage
- The primary winding thermal fuse was disconnected for purposes of testing transformers not thermally protected

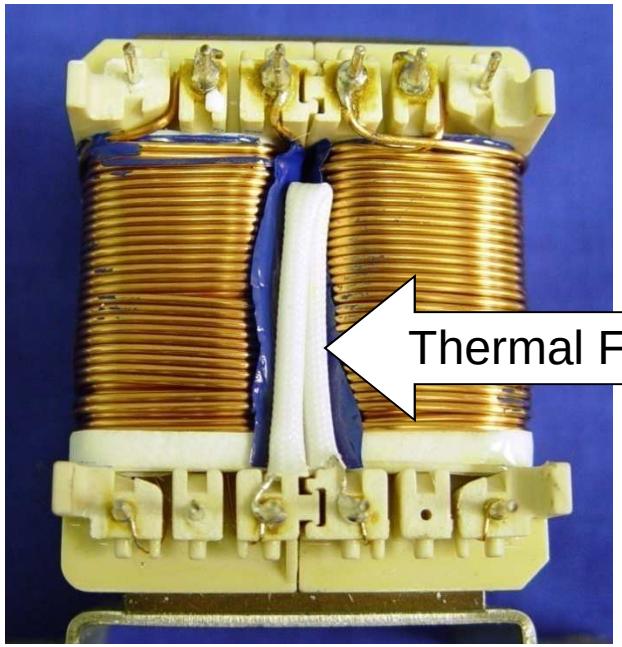
Transformers

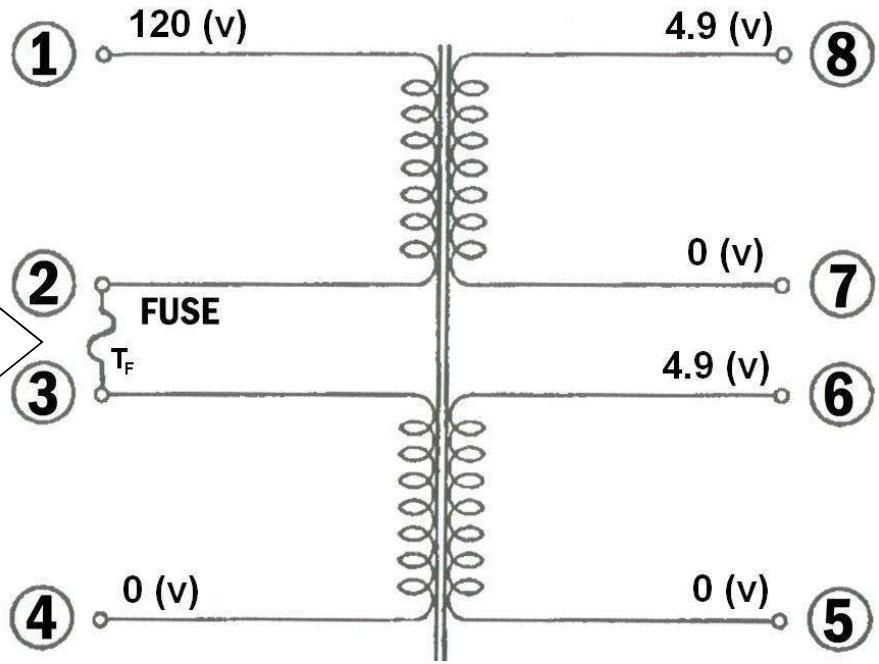
- Transformer Characteristics
  - Primary Input
    - 120V, 60 Hz
  - Rated Output
    - 9.8V_{dc}, 2.0 A (with an associated rectifier)



Transformers

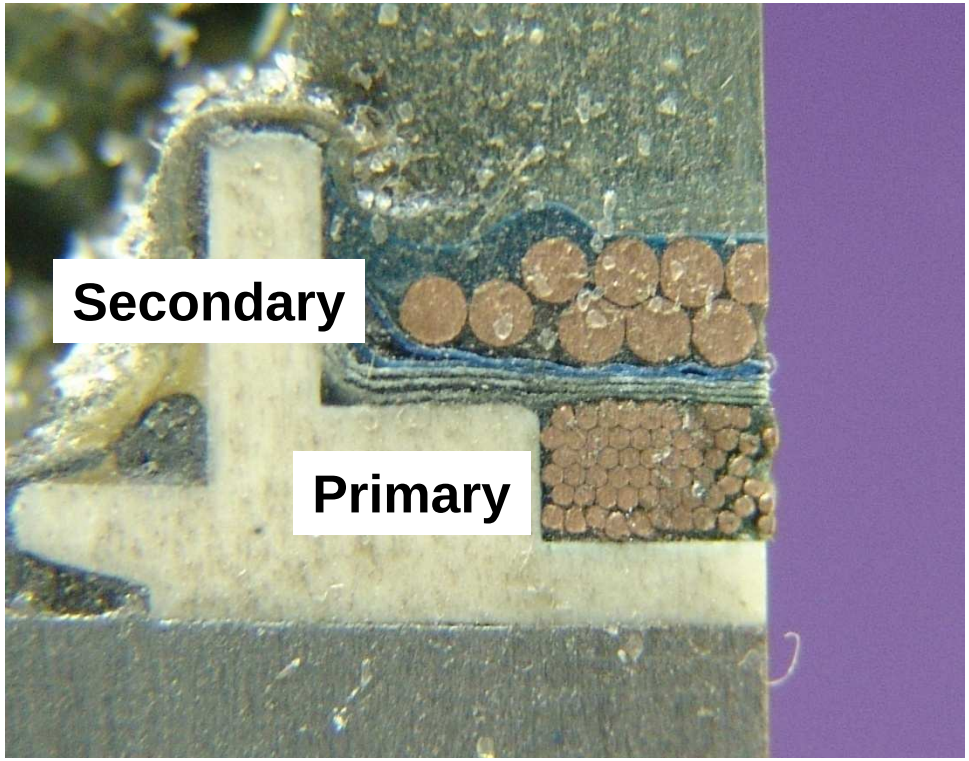
- Transformer Wiring Diagram

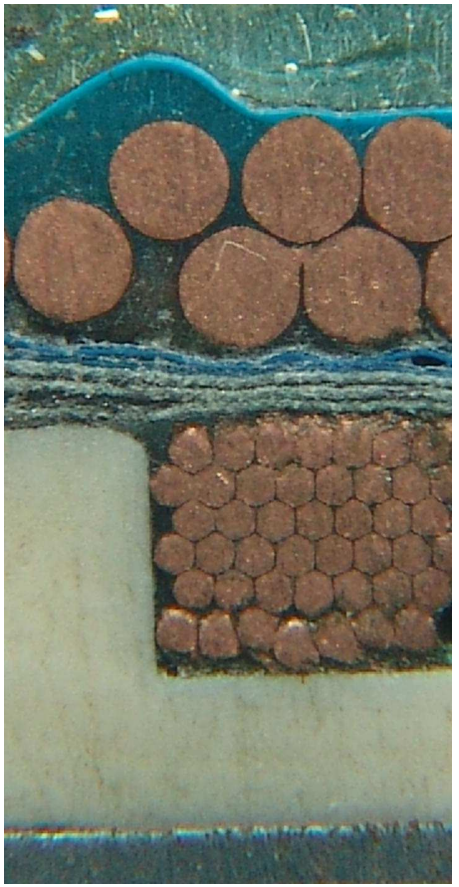




Transformers

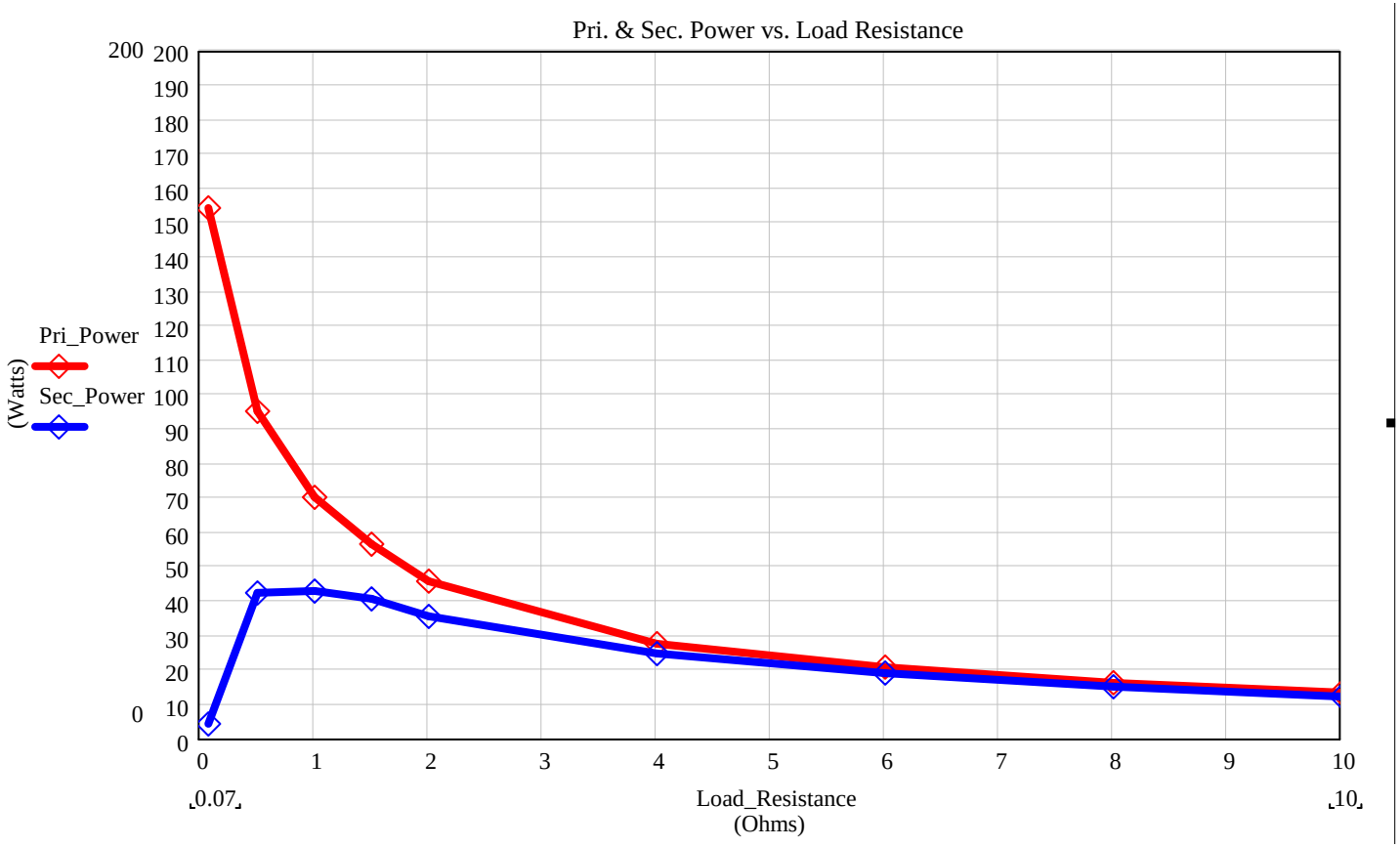
- Transformer Cross Section





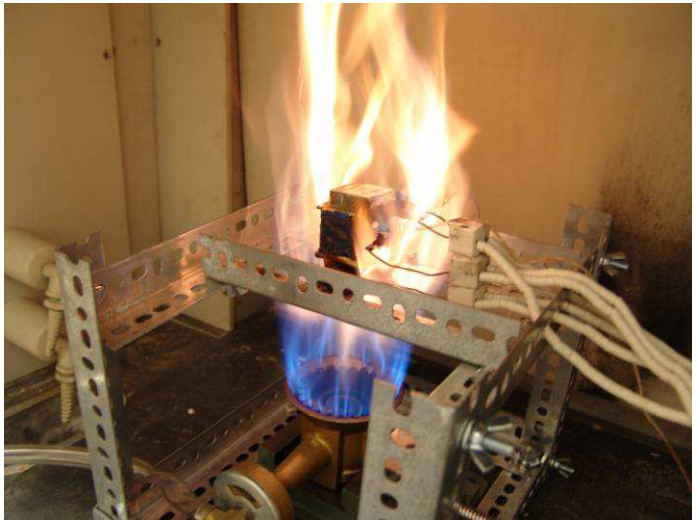
Transformers

- Transformer characteristics



Transformer

- Testing
  - Heated not energized (oven and gas burner)
  - Heated energized at rated load (oven and gas burner)
  - Internal Heating (no external heat)
  - Internal Heating with external heat (gas burner)
  - Internal heat Thermal Protection not bypassed.

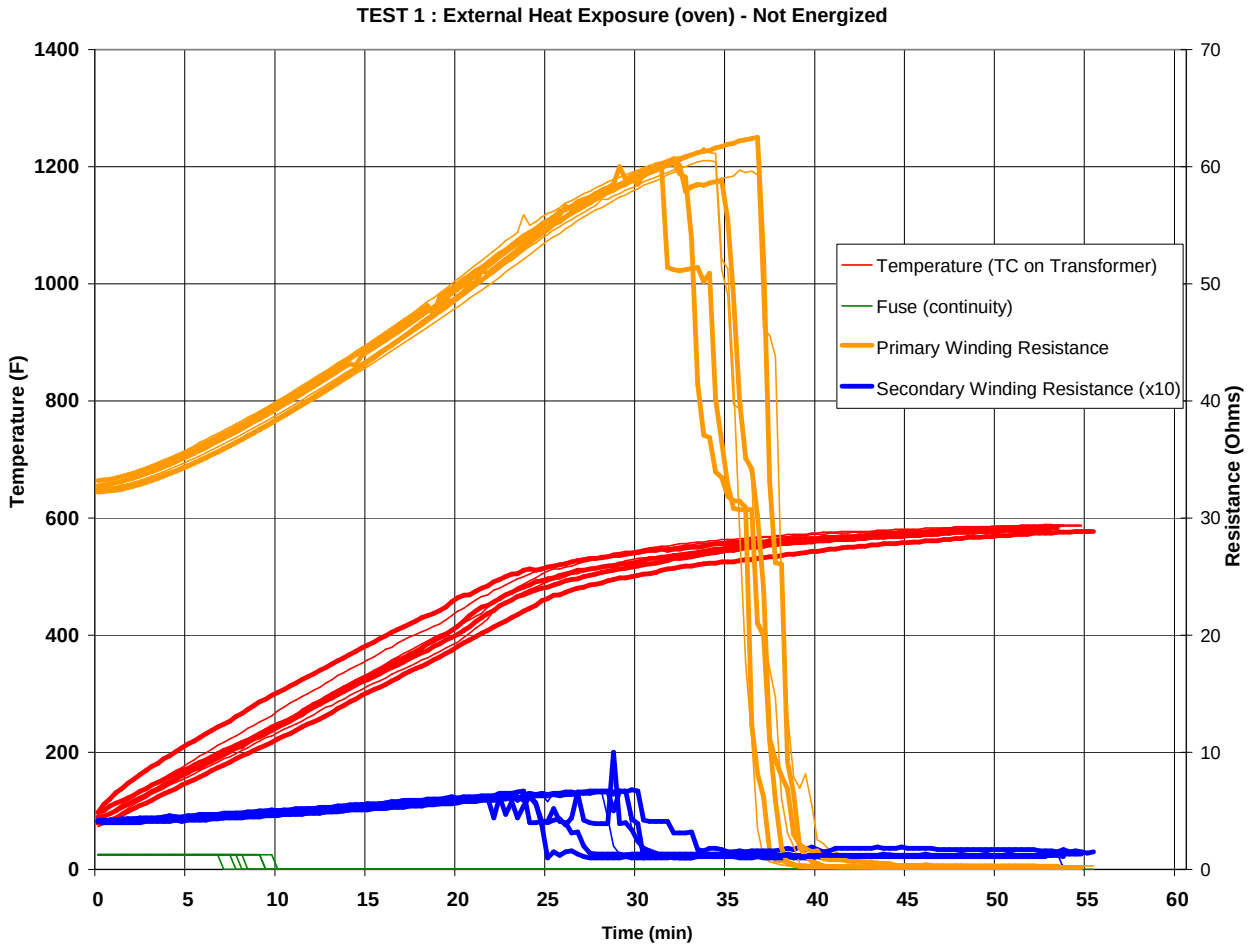


Transformer Damage

- Internal heating, Oven 600F, Fire Exposure

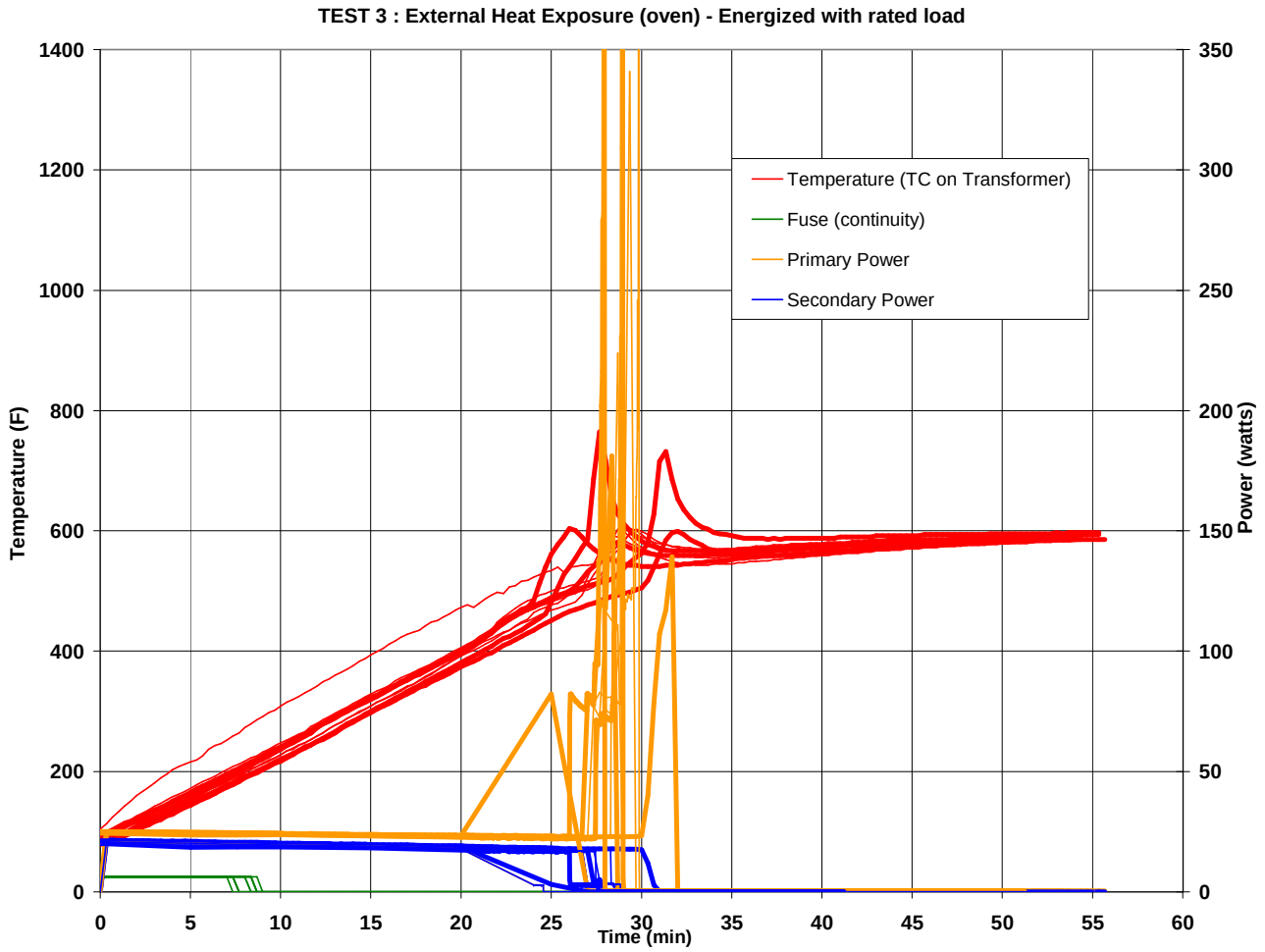
Transformer

- Heated not energized



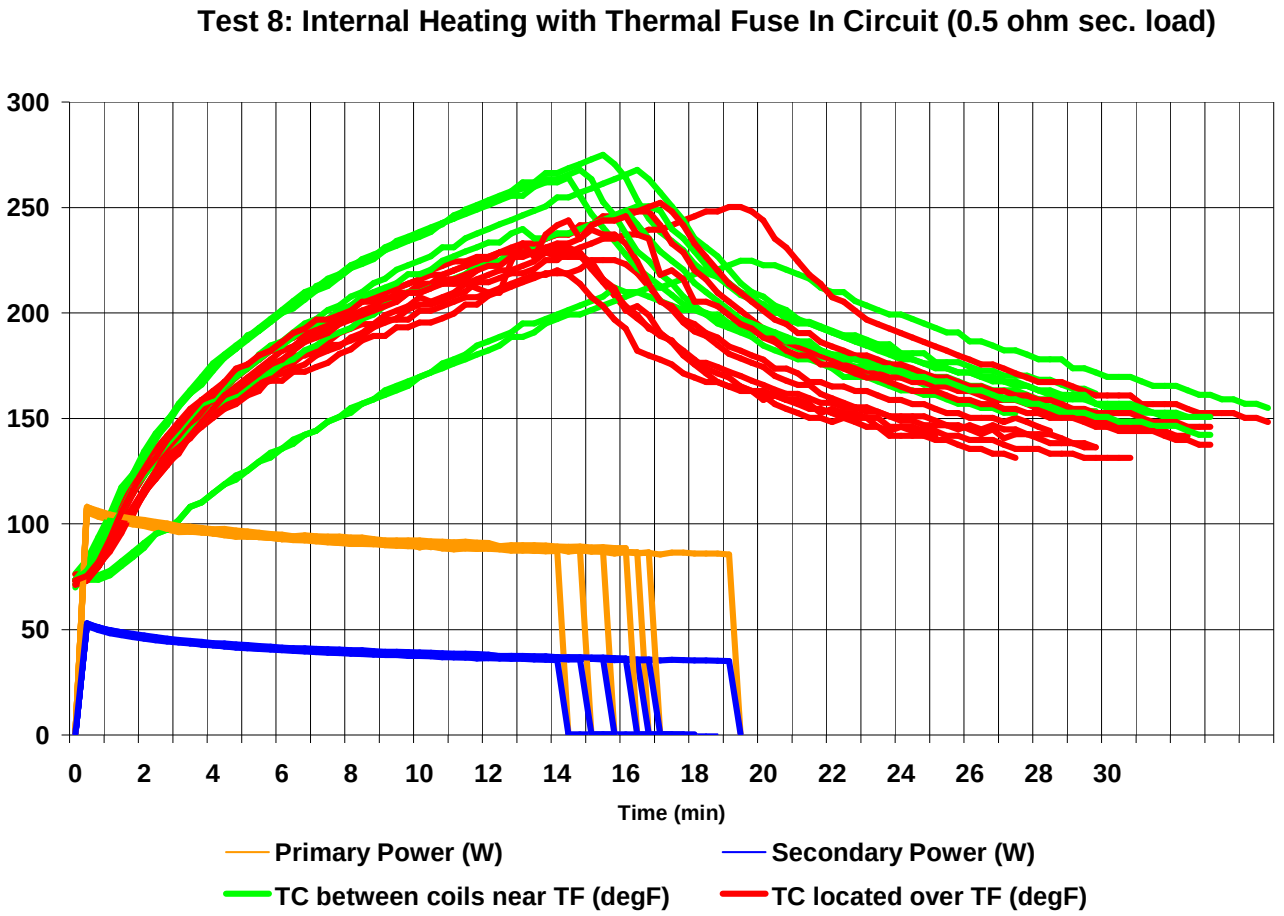
Transformer

- Heated operating at rated load



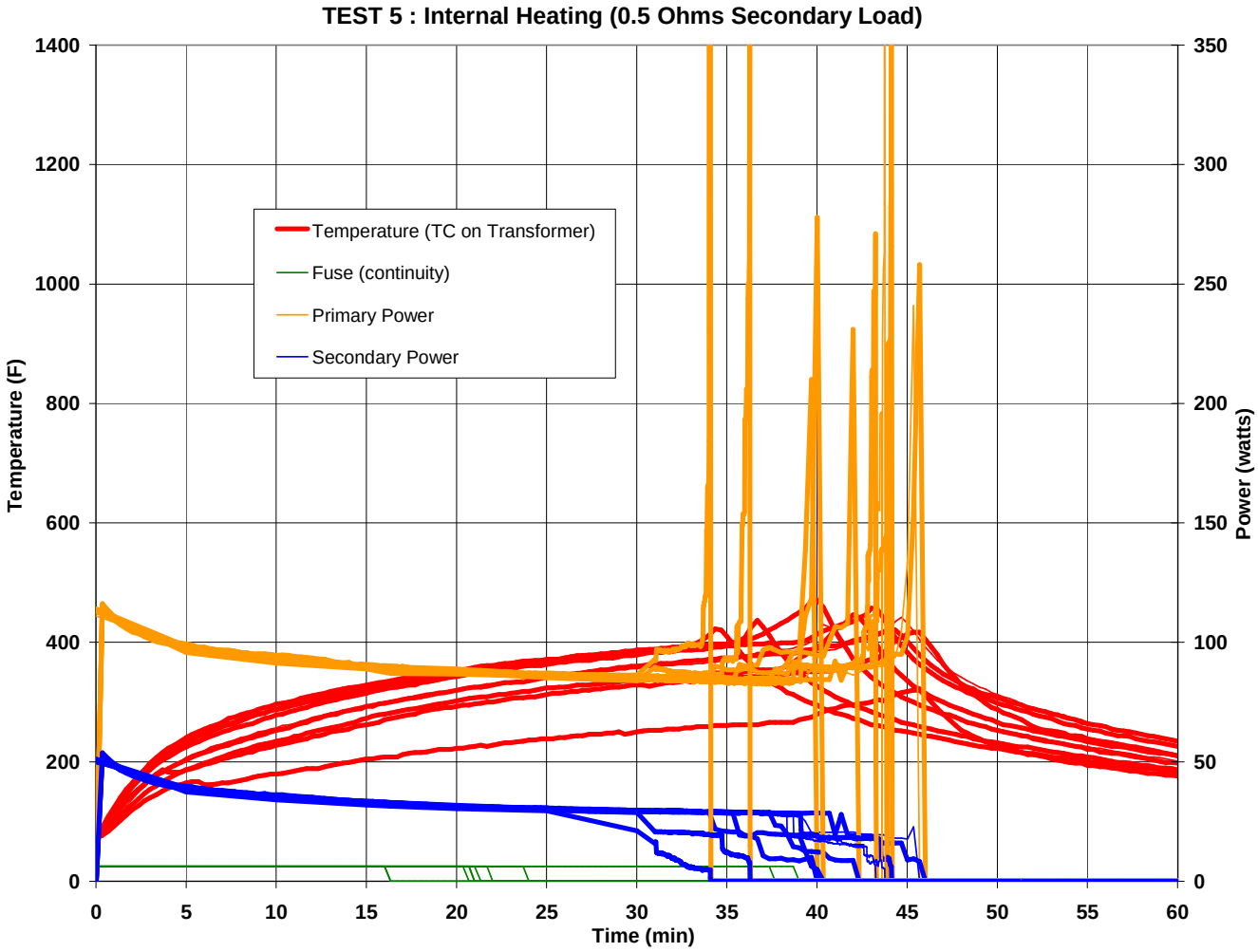
Transformer

- Internal Heating with Thermal Fuse



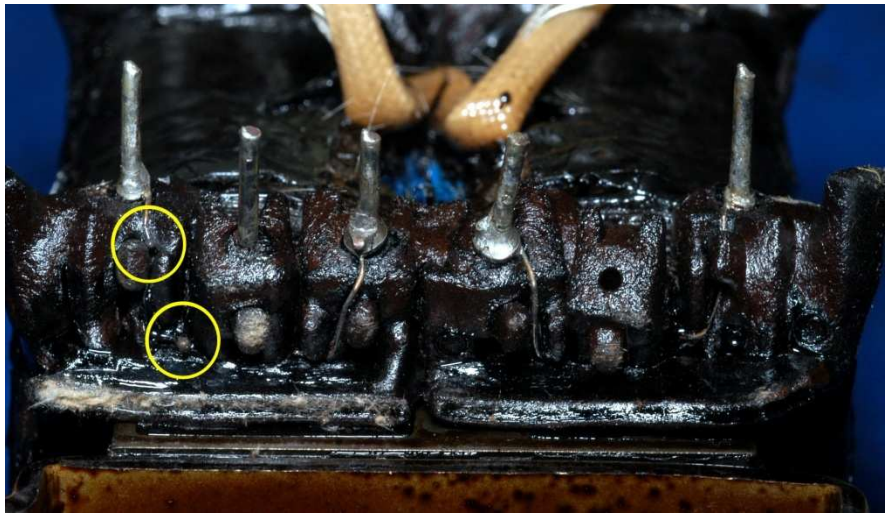
Transformer

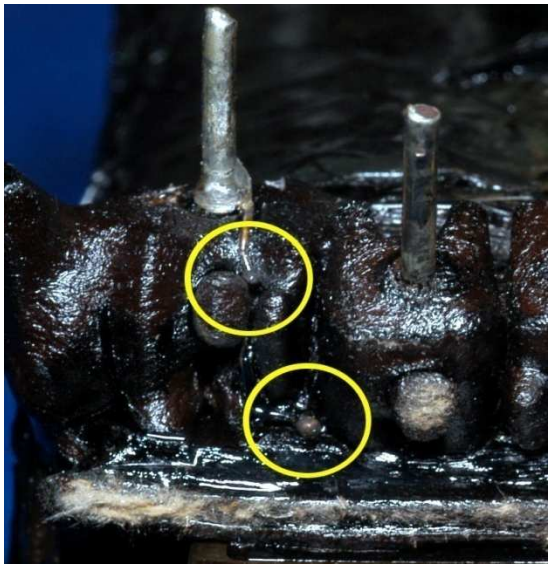
- Internal Heating



Transformer

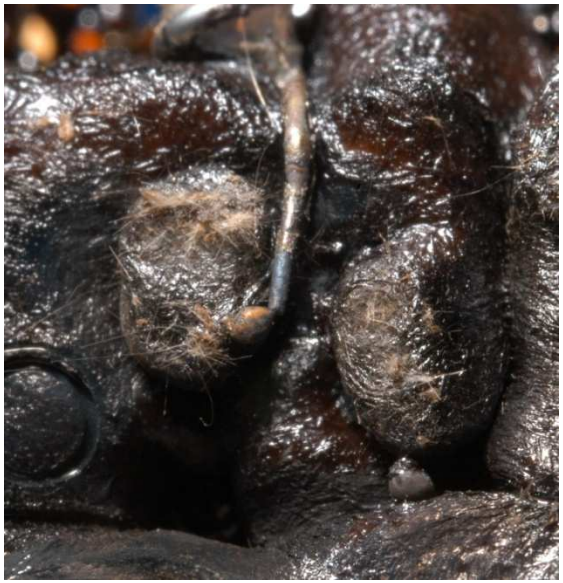
- Heated at rated load





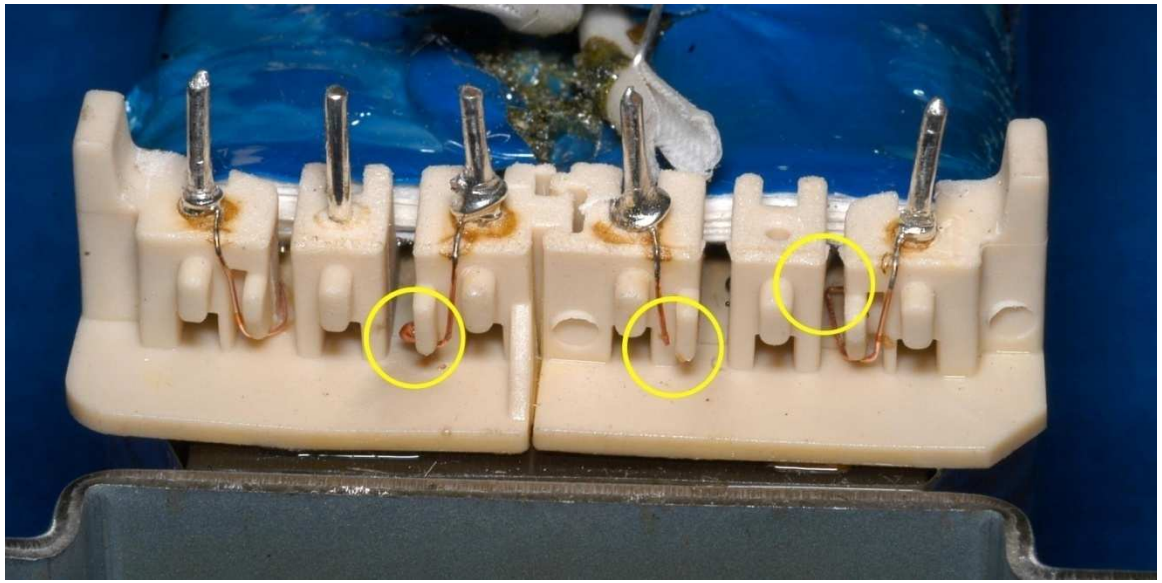
Transformer

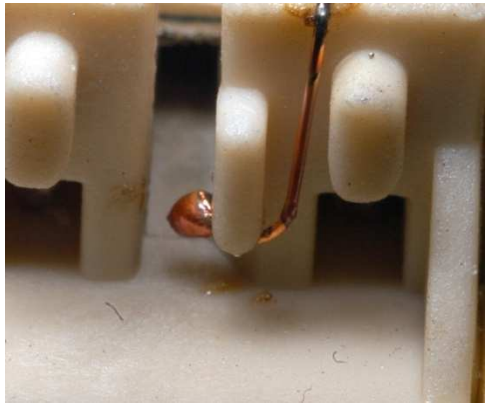
- Heated at rated load



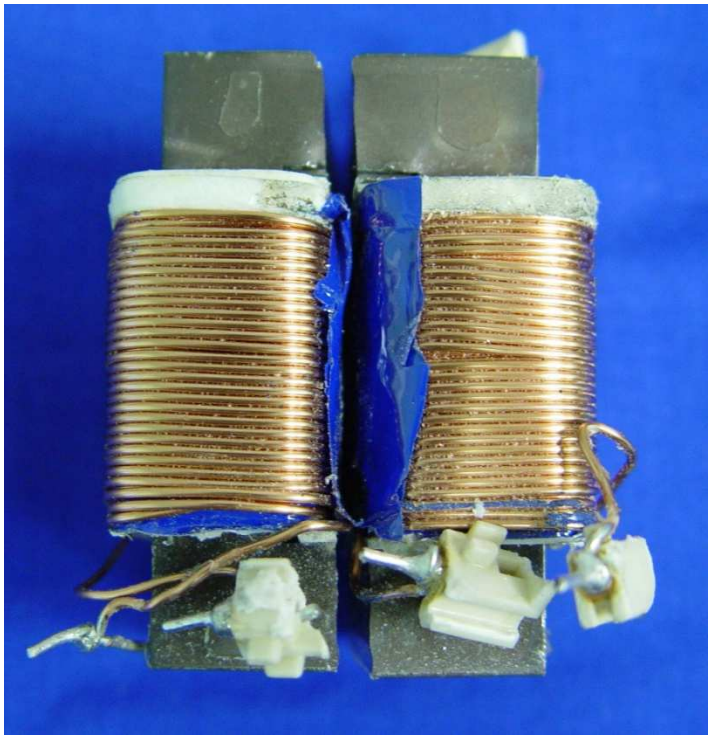
Transformer

- Internal Heating

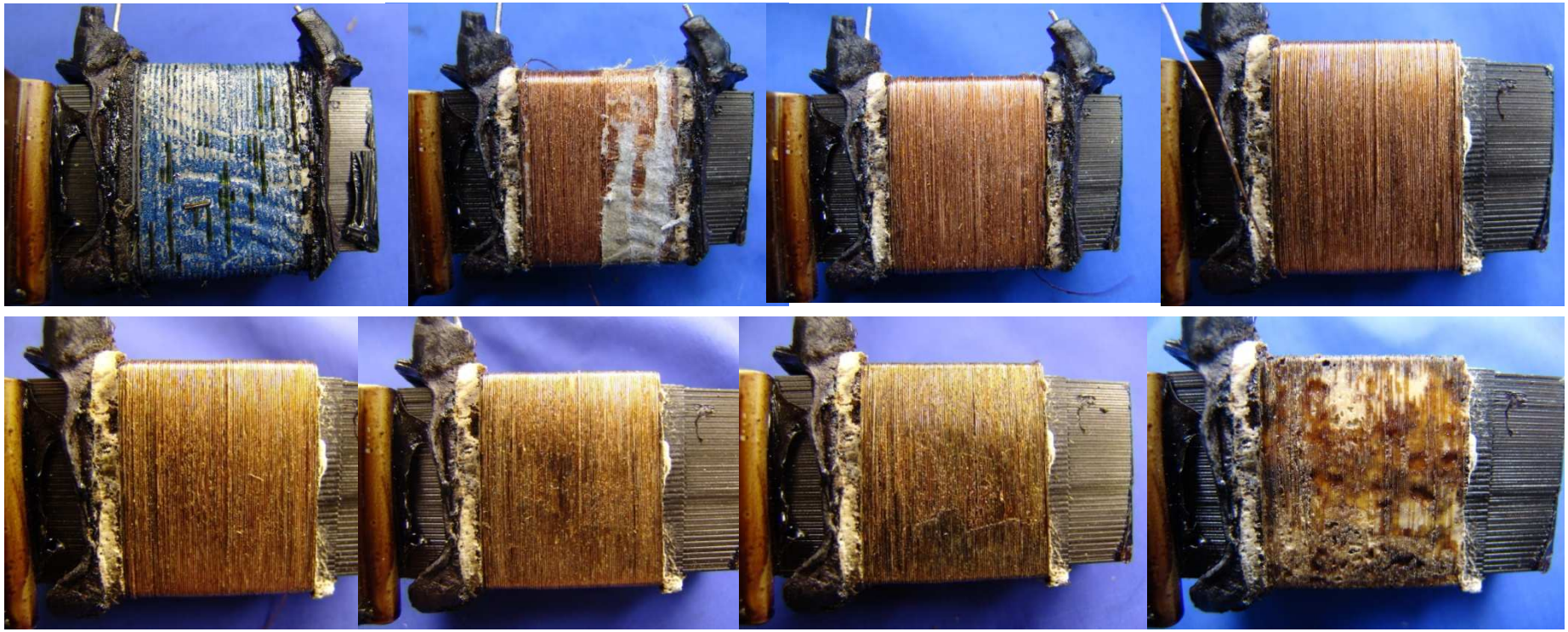




Transformer Unwinding



Transformer Unwinding

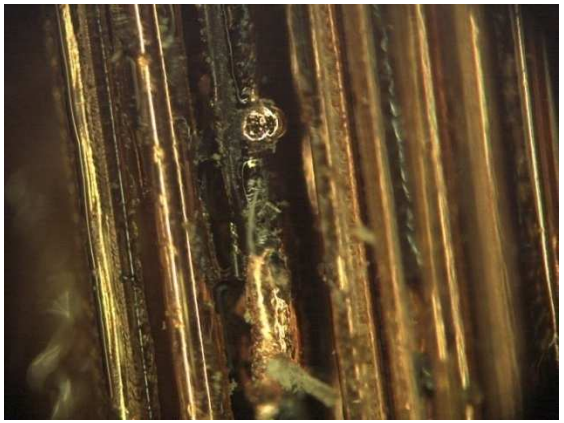


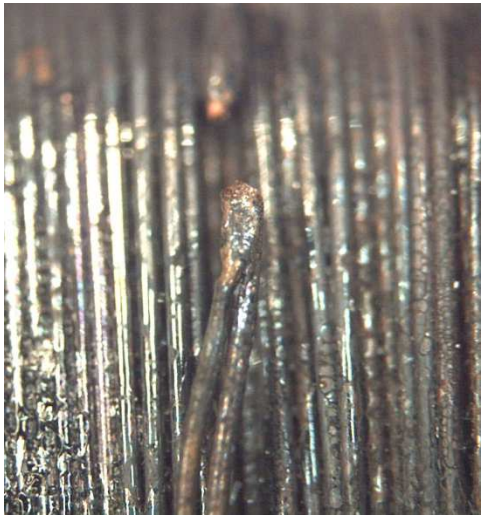
Transformer

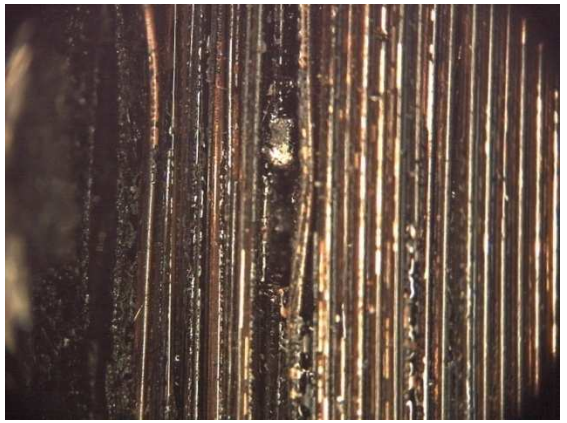
- External Heating Not Energized
  - Resistance measurements indicated shorting in primary and secondary windings
  - Unwound
    - No discontinuities in windings
    - No localized melting/fusing between windings

Transformer

- External Heating Energized Rated Load
  - Resistance measurements all open (Primary)
  - Unwound
    - Localized arcing found between winding layers

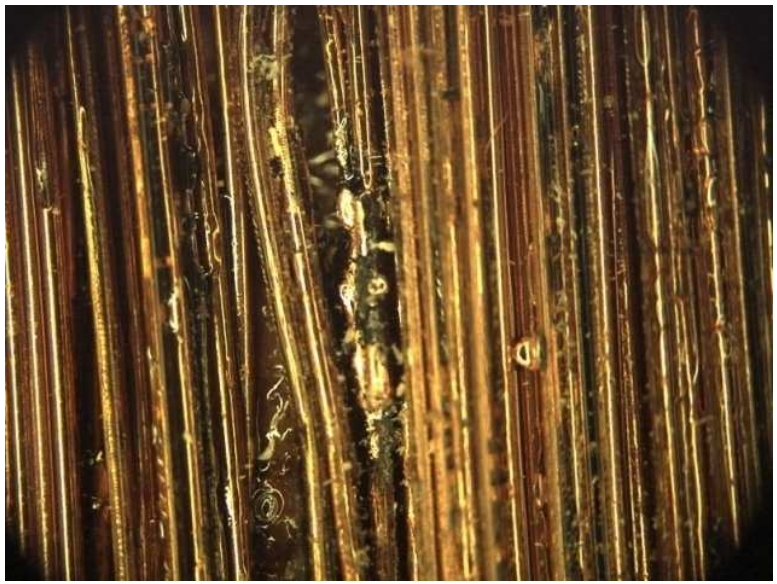






Transformer

- Internal Heating
  - Fuse bypassed
  - Arcing found mostly on inner most layers
- Internal Heating in Fire
  - Fuse bypassed
  - Arcing on multiple layers from outside in



Transformer

- Summary of Testing

CEA Transformer - Summary of Unwinding Examination

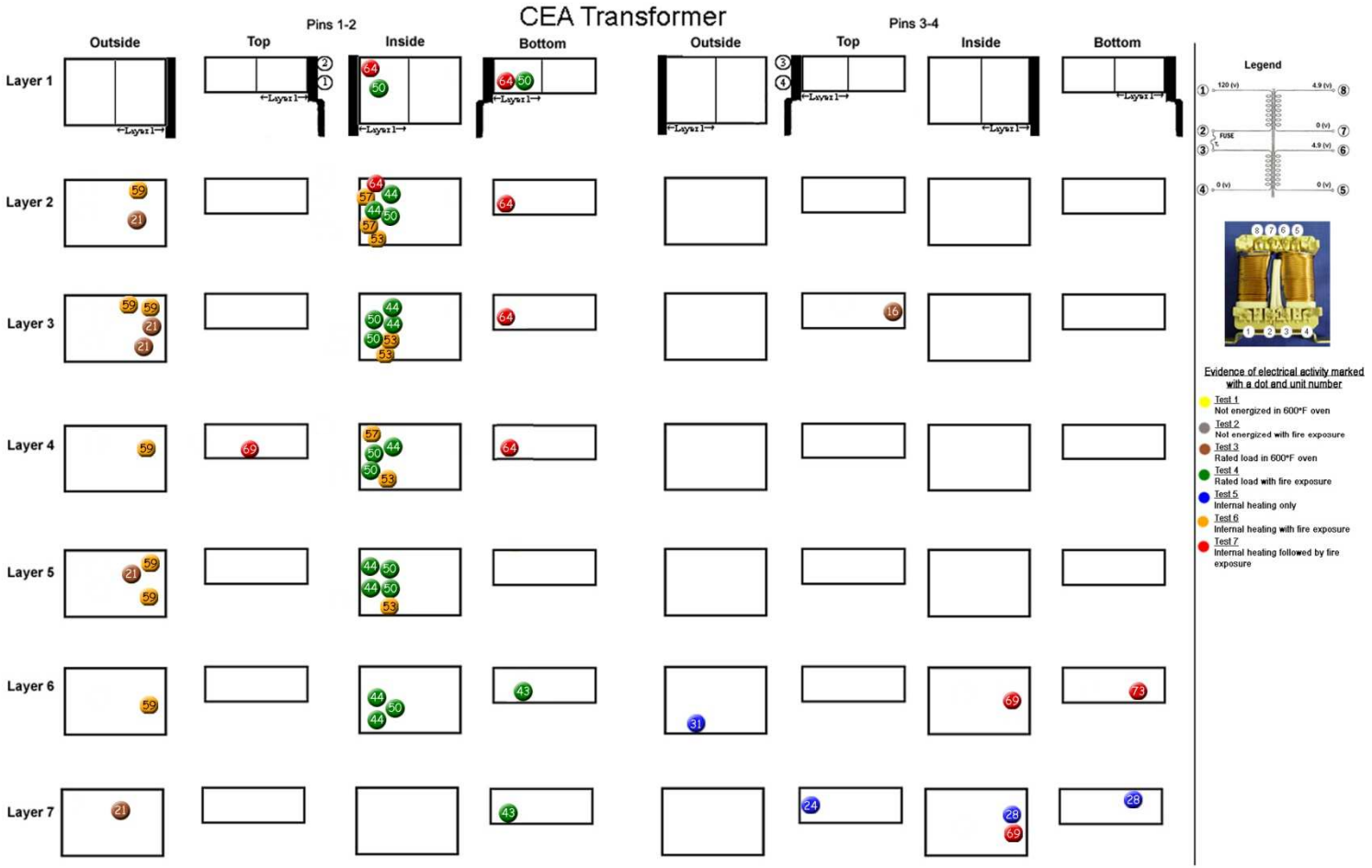
Test	Type of Heating	External Heat Source	Post-test evaluation of Primary Winding start and finish leads to Pins 1-4	Evid. of electrical activity found during unwinding process
1	External Heat Exposure Not Energized	Air-circulating Oven 600℉	All primary leads intact to Pins 1-4	Unit 10 - NO E.A. Unit 11 - NO E.A.
2	External Heat Exposure Not Energized	Natural Gas Burner	Evaluation incomplete because of damage to the brittle winding lead wires after fire exposure	Unit 33 - NO E.A. Unit 36 - NO E.A.
3	External Heat Exposure Energized with Rated Load	Air-circulating Oven 600℉	Each unit had 1 or more primary leads fused (OPEN) near Pins 1-4	Unit 13 - E.A. on layer 3 Unit 16 - NO E.A. Unit 17 - NO E.A. Unit 21 - E.A. on layers 2-7
4	External Heat Exposure Energized with Rated Load	Natural Gas Burner	Evaluation incomplete because of damage to the brittle winding lead wires after fire exposure	Unit 43 - E.A. on layers 6-7 Unit 44 - E.A. on layers 2-6 Unit 49 - NO E.A. Unit 50 - E.A. on layers 1-6
5	Internal Heat Energized with 0.5 ohm load	N/A	Each unit had 1 or more primary leads fused (OPEN) near Pins 1-4	Unit 24 - E.A. on layer 7 Unit 25 - NO E.A. Unit 28 - E.A. on layer 7 Unit 31 - E.A. on layer 6
6	External Heat Exposure while Internally Heating Energized with 0.5 ohm load	Natural Gas Burner	Evaluation incomplete because of damage to the brittle winding lead wires after fire exposure	Unit 53 - E.A. on layers 2-5 Unit 56 - NO E.A. Unit 57 - E.A. on layers 2 & 4 Unit 59 - E.A. on layers 2-6
7	Internal Heating Energized with 0.5 ohm load followed by External Heat Exposure	Natural Gas Burner	Evaluation incomplete because of damage to the brittle winding lead wires after fire exposure	Unit 64 - E.A. on layers 1-4 Unit 68 - NO E.A. Unit 69 - E.A. on layers 4, 6-7 Unit 73 - E.A. on layer 6
8	Internal Heating Energized with 0.5 ohm load (with thermal fuse in circuit)	N/A	All primary leads intact to Pins 1-4	Thermal fuse OPENED & post-test winding resistance measurements were unchanged, therefore, unwinding was unnecessary

E.A. - Evidence of electrical activity

Note: Thermal fuse was removed from circuit and replaced with a wire on ALL transformers in Tests 1-7.

Transformer

- Summary of Testing



Transformer

- Conclusion
  - Internal heating typically produced inner winding faults
  - External heating energized produced faulting throughout windings.
  - Location of electrical activity does not necessarily indicate failure mode

Transformer

- Conclusion
  - Lack of Fusing of primary leads indicates the transformer was not energized at the time of fire attack.
  - Fusing of the primary leads does not indicate transformer failed and caused fire but does indicate it was energized during the fire.

Transformer

- Conclusion
  - Internal Heating worst case did not ignite materials of transformer even when thermal fuse was bypassed.
  - Transformer failed during internal heating without ignition of combustibles.

Acknowledgements

Thank you for your attention!

Donald J. Hoffmann, Ph.D.
Erik Swonder, MSEE
Safety Engineering Laboratories, Inc.
27803 College Park Drive, Warren, MI 48088
Email: donh@safetyengineeringlabs.com
eriks@safetyengineeringlabs.com
Website: www.safetyengineeringlabs.com
Phone (586) 771-0660