IRMC 2024

Renaissance Las Vegas , NV
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324 Generator Failure Discoveries, Concerns, & Repair

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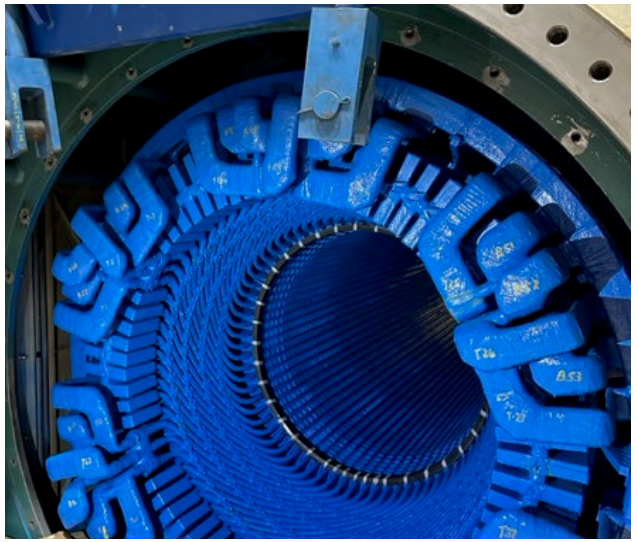
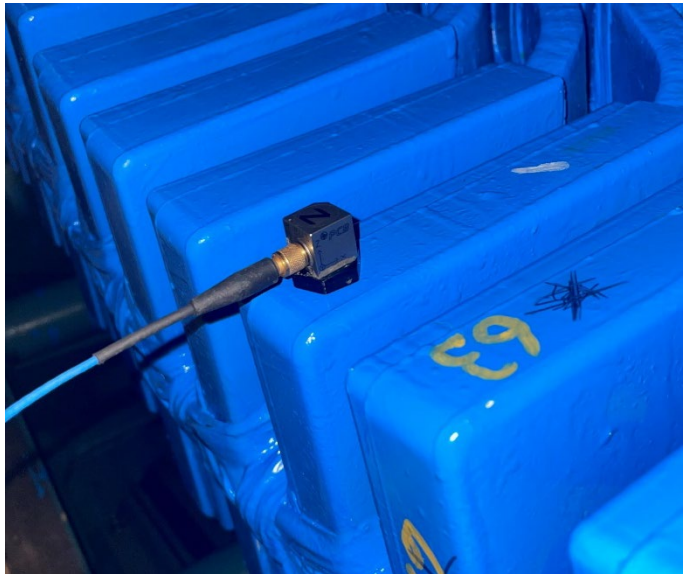
Background

- The Facility is a 2 on 1 combined cycle plant
  - Two Siemens Westinghouse 501F CT's with AEROPAC Generators.
  - One GE – D11 ST a 324 generator
- The 324 Generator - 320,100 kVA; 18 kV; 3600 rpm
- Maintenance outage several months prior to failure
  - Full stator rewedge followed by a DC HiPot
  - No lingering concerns
- In Service Failure Event
  - Ground Fault – T2 / T5
  - NEC selected to diagnose and propose repair options

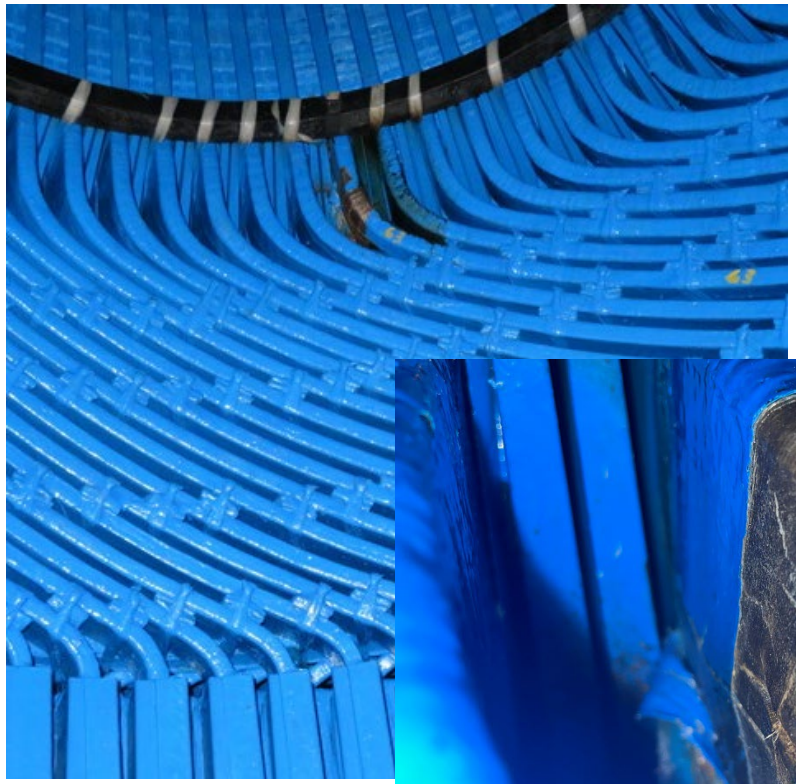
NEC Mobilization

- Early expectation that known issues with the EE end winding and in specific phase straps were at the core of the failure.
- TE end winding discovery identified as likely problem or at least contributor
- Bump testing performed





Inspection



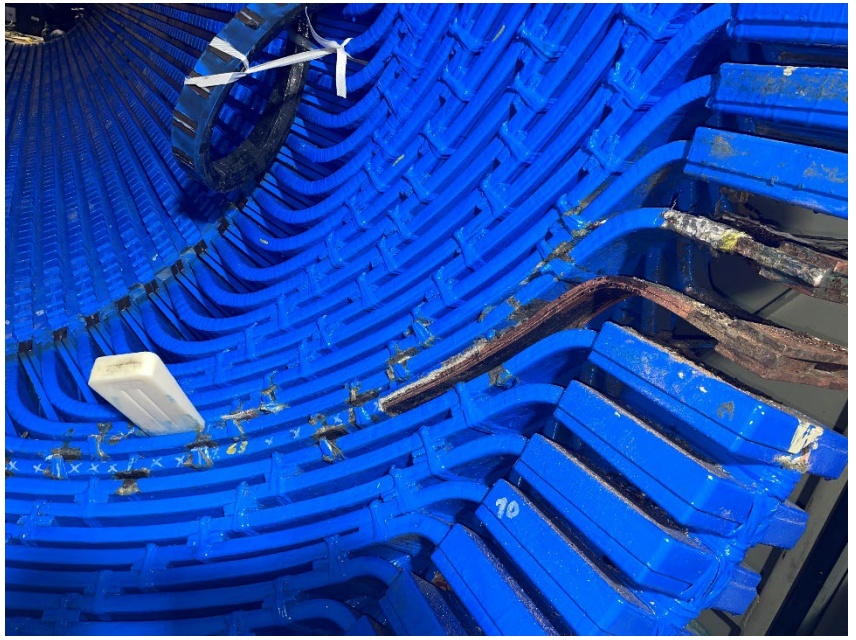
- Bulging and signs of overheating near core and at Series Connection
- Potential issue in series connection possible source of overheating?

Origin of Overheating?

- Connection stripped to investigate.
- No indications of heat generation from the brazed series connection
- Heat effected area indications inboard of the series connection

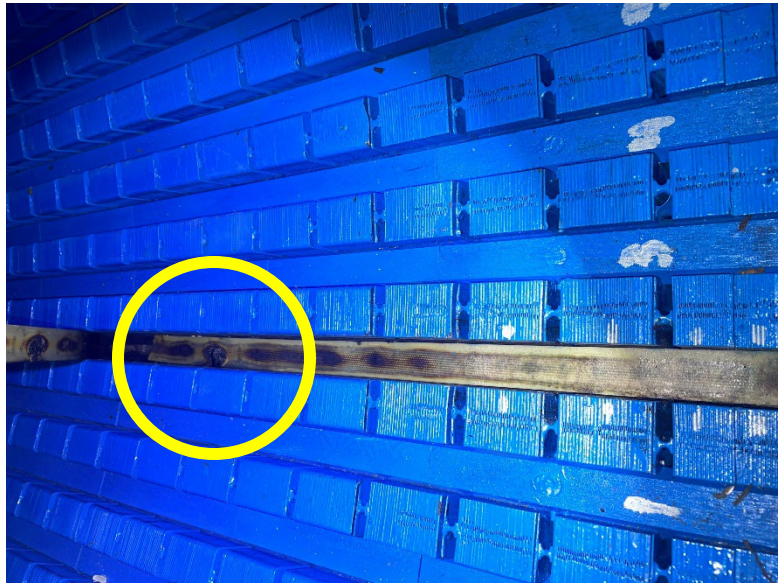
Origin of Overheating?

- Observation of overheating increased moving toward the core from the Series Connection
- Excavation of the bulge near the core
- Overheating evidence increased in proximity to the conductor stack



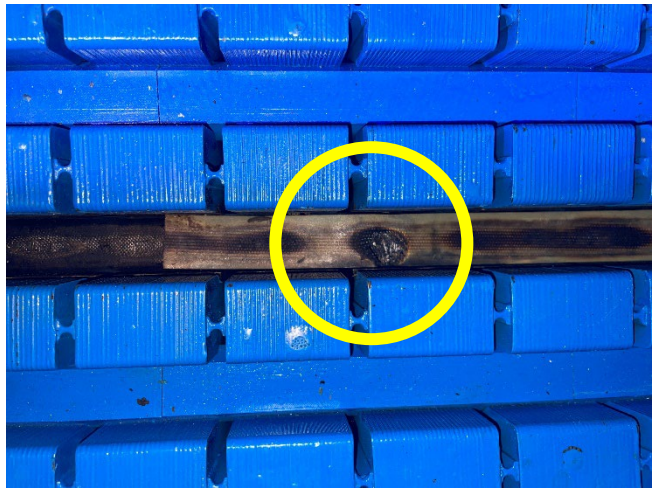
Origion of Overheating

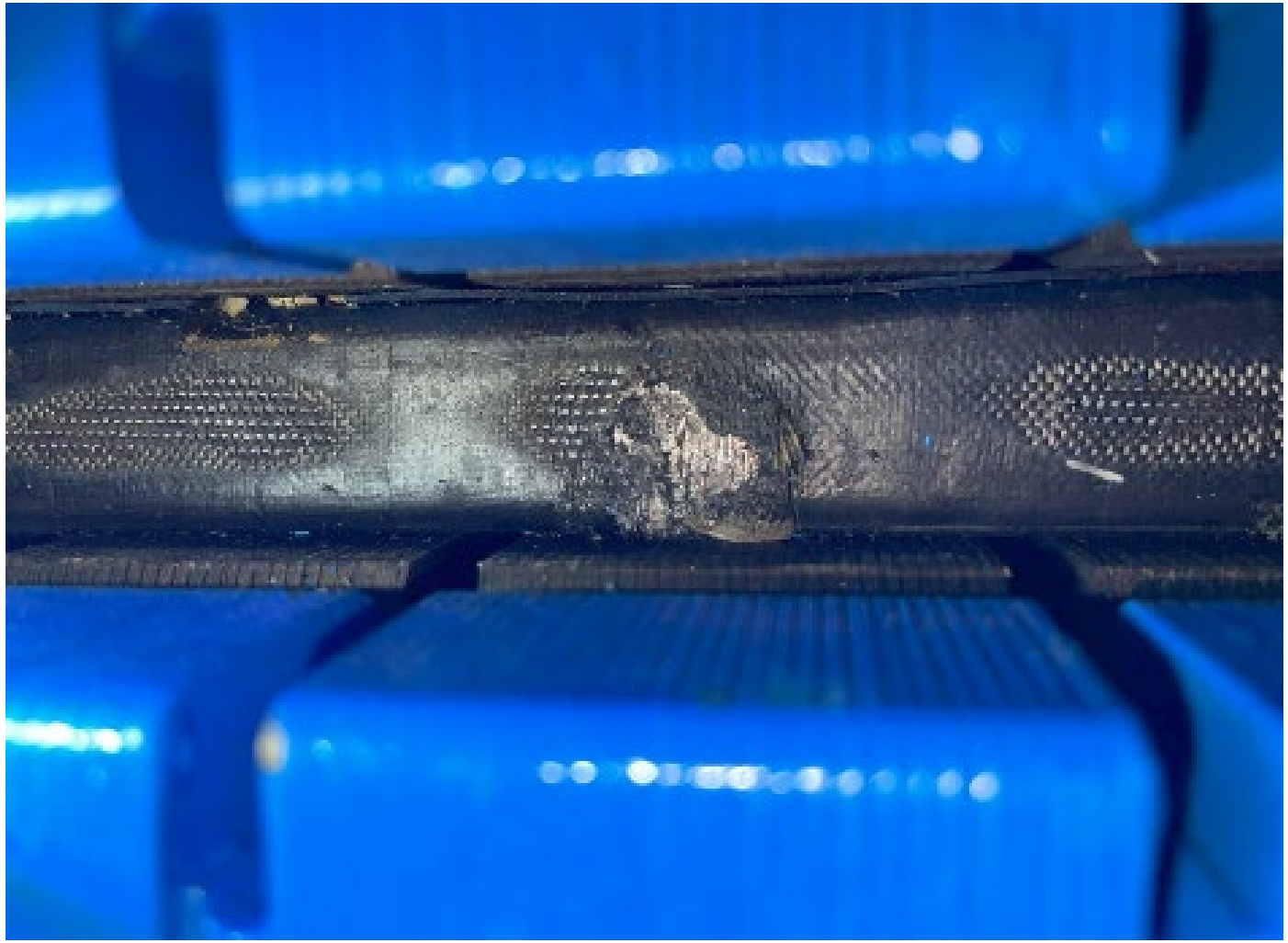
- Slot 63 core wedges removed exposing top filler overheating indications.
- Lifting the top filler exposed signific signs of overheating on the top coil.
- Top coil indications extended approximately 4’ into the slot from the turbine end with the worst indications between 10” to 18 “ from the turbine end of the core.



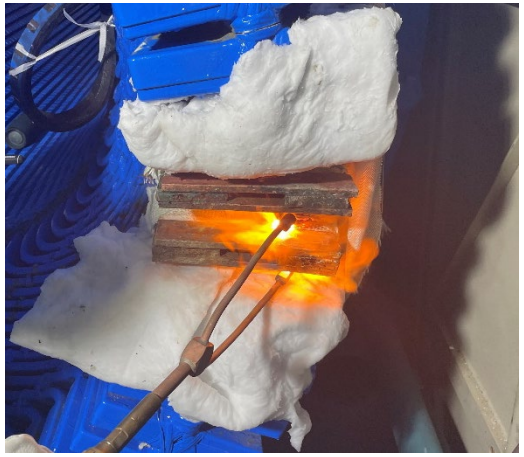
Probable Origin of Overheating & Point Of Failure

- Most significant burning found **14” from the TE of the core in slot #63**



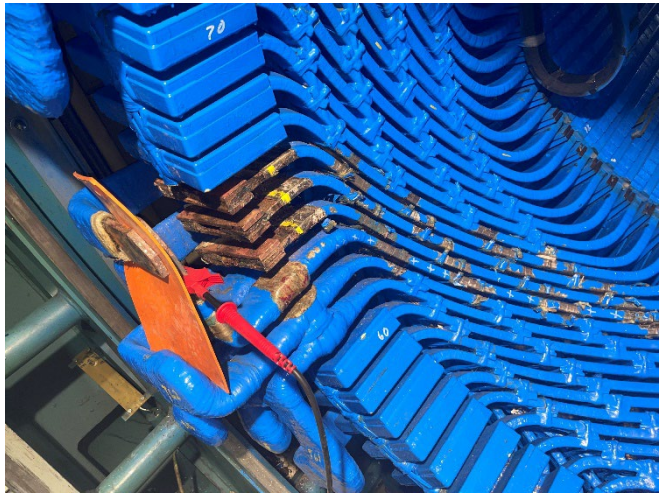


Isolation of Failed Coil #63

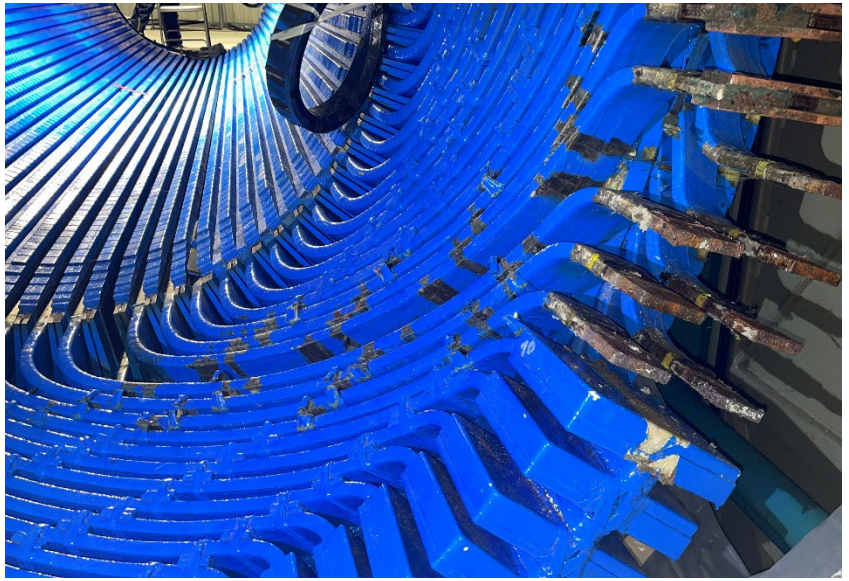


Top Coil Slot #63
Isolated from T2 – T5 Phase

- Good winding resistance (megger) testing results.
- Polarization Index (PI) - at 10 kV DC.
  - PI = R_{10min}/R_{1min}:
    - Phase A PI= 21.7GΩ/2.70GΩ= 8.04
    - Phase B PI= 21.7GΩ/3.57GΩ= 6.09
    - Phase C PI= 15.6 GΩ/3.03GΩ= 5.16
- A ramp test graded DC Hipot was performed on all three phases up to 37 kV DC with leakage measured at 37.0 kV DC:
    - A - 4.3 µAmps
    - B - 5.0 µAmps
    - C - 4.9 µAmps.

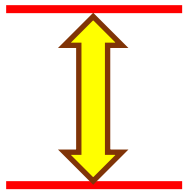


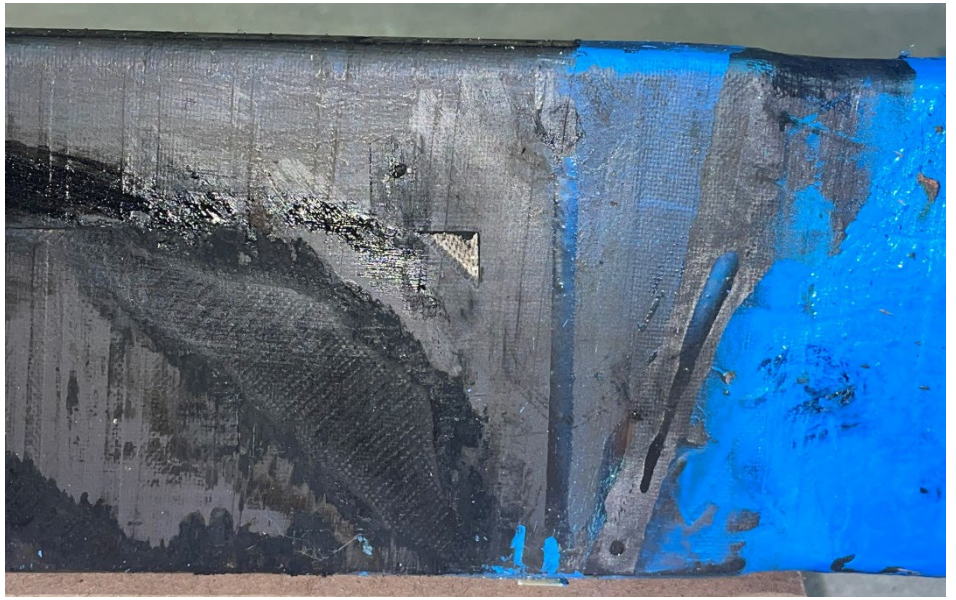
Failed Coil #63 Removal

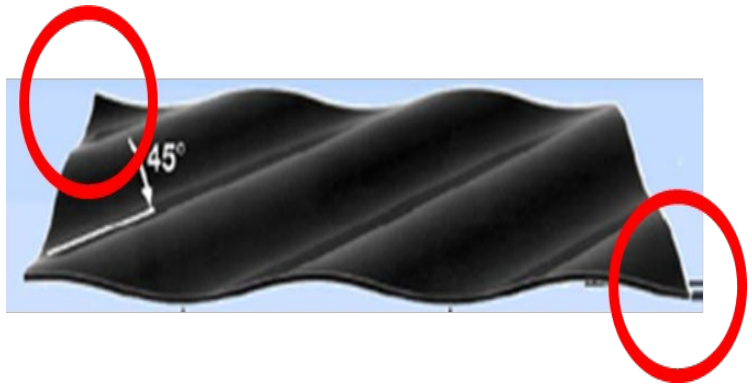


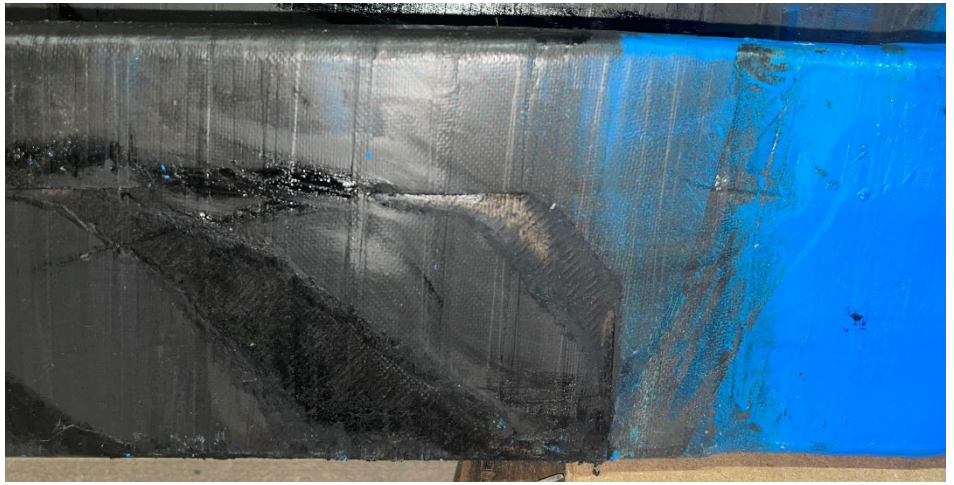
Side Ripple Filler Discovery

- Side Ripple Filler – Height
  - Significantly short
- Side Filler Material Preparation
  - Protruding corners, not rounded and/or oriented properly – “Birds Beaking”
  - Bar Abrasion



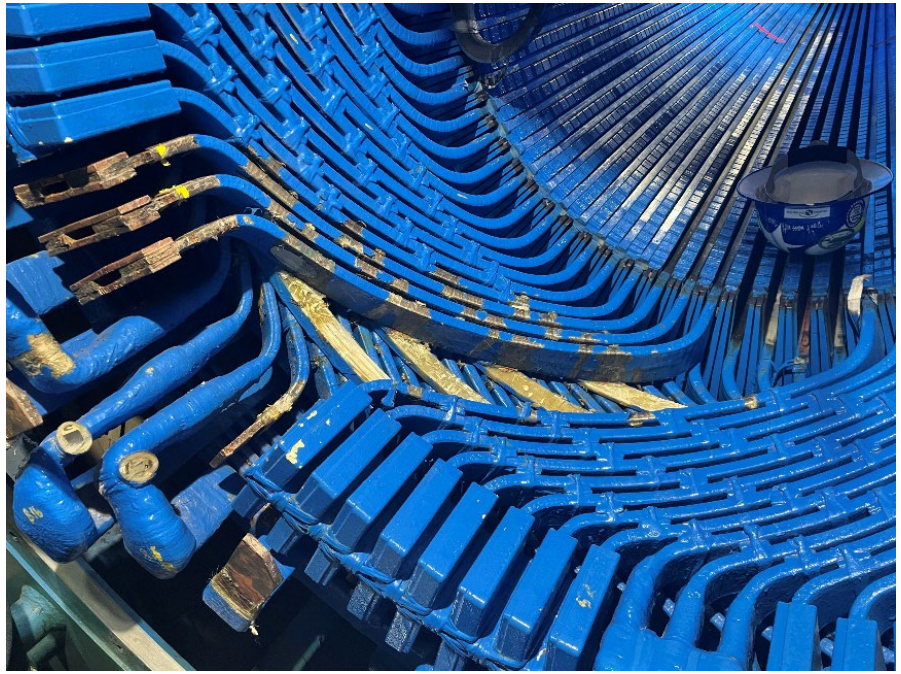






Coils Removed

- Failed Top Bar – Slot #63
- Three Adjacent Top Bars



NEC High Voltage Lab Investigation & Analysis

Failed Coil Arrival - Cracked Strand Discovery WHY?

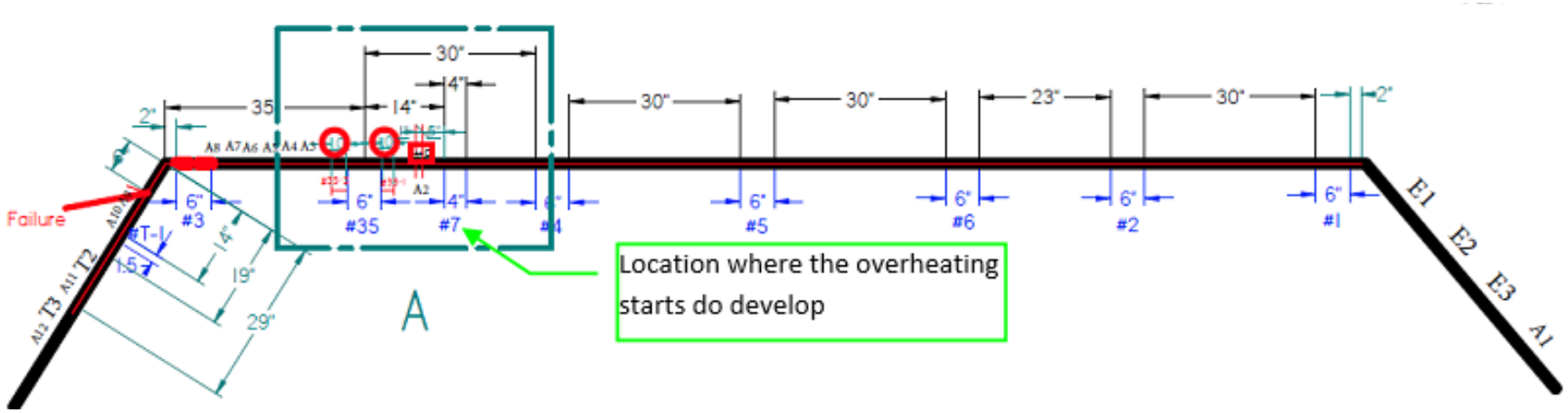
- Cracks in shipment due to copper hydrogen embrittlement from extreme heat in the generator hydrogen atmosphere

Initial Considerations & Observations

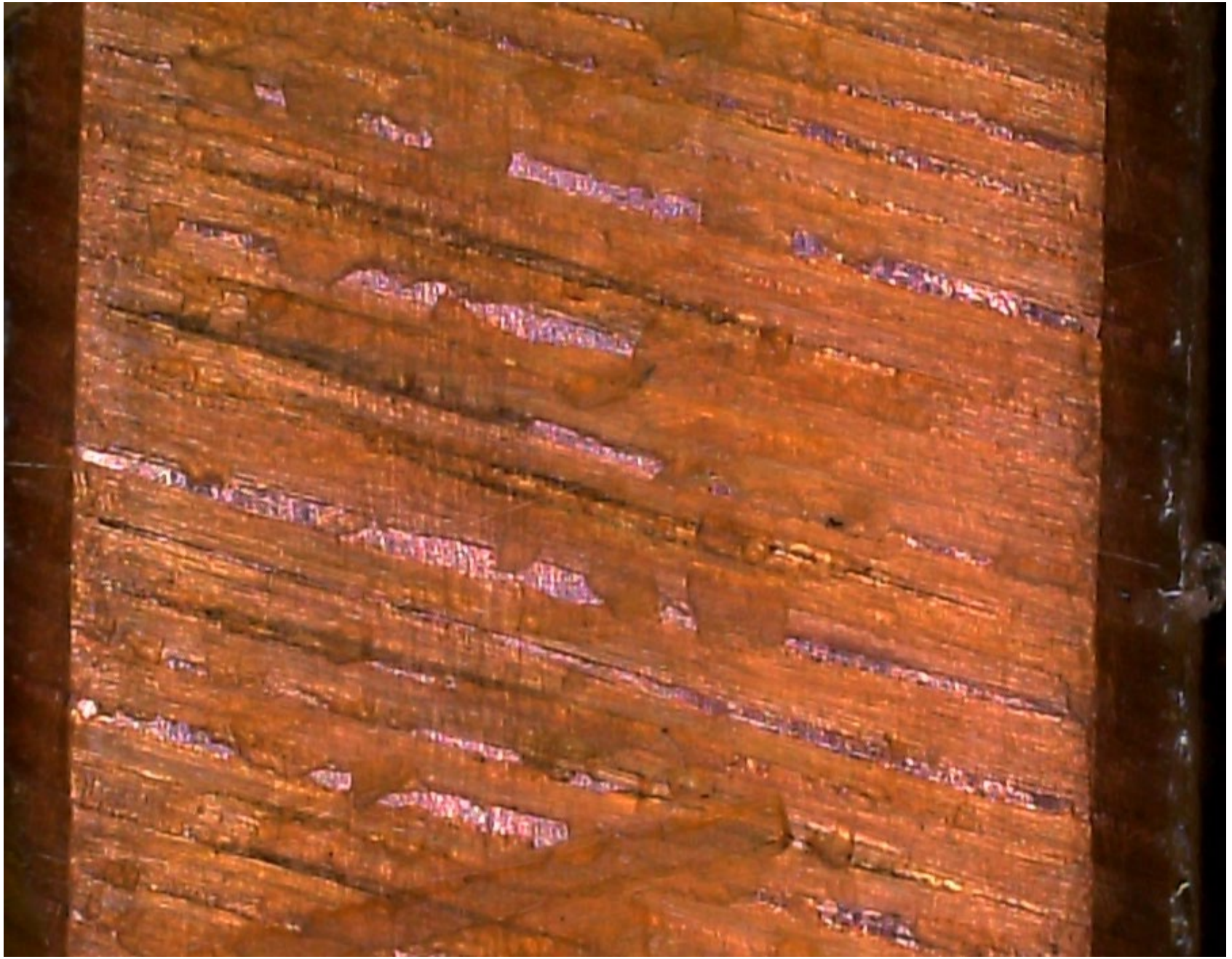
- **No signs of electrical aging** of ground wall or the bar that could have contributed to the failure mechanism.
- Calculation of the failed bar operational voltage is 5.2 kV AC – EE, and 4.5kV AC – TE. The maximum electrical stress did not exceed 35 VPM. Therefore, **Corona activity was not a possible contributor**, given low electrical stress (voltage) and the pressurized hydrogen environment.
- Extreme overheating of the bar on the TE from the series connection to approximately 48” into the core.

Dissection & Analysis Plan

- Failed Bar #63 was carefully dissected into coupons
- Ground wall and strand insulation carefully analyzed.
  - Strand insulation was completely gone area of failure
  - Strand coupons harvested from non- heat effected area for analysis



Failure Root Cause



Representative sample of strand coupons harvested from non-heat affected areas of failed bar #63

Analysis Conclusions

Root Cause – Shorted Strands:

- Compromised strand insulation of top bar #63
- Compromised strand insulation progressively shorted to adjacent strands, creating severe overheating
- The severe overheating damaged the bar ground wall insulation from the inside adjacent to the shorted strands outward to the bar surface.
- Eventually, ground wall deterioration allowed the ground fault failure.

Actions To Support At Site Repair

Manufacture replacement bar for failed bar #63

- Improved strand insulation
- Maintain loss characteristics of original bar design
- Ensure bar geometry to match winding at site
  - Strip an adjacent bar to aid in mechanical verification of the new bar

Qualify stripped adjacent bar for re-insulation, and process along with the new bar

- Autoclave processed single coil VPI

Two remaining adjacent bars utilized to calibrate final mechanical verification

Stator Bar Shorted Strands

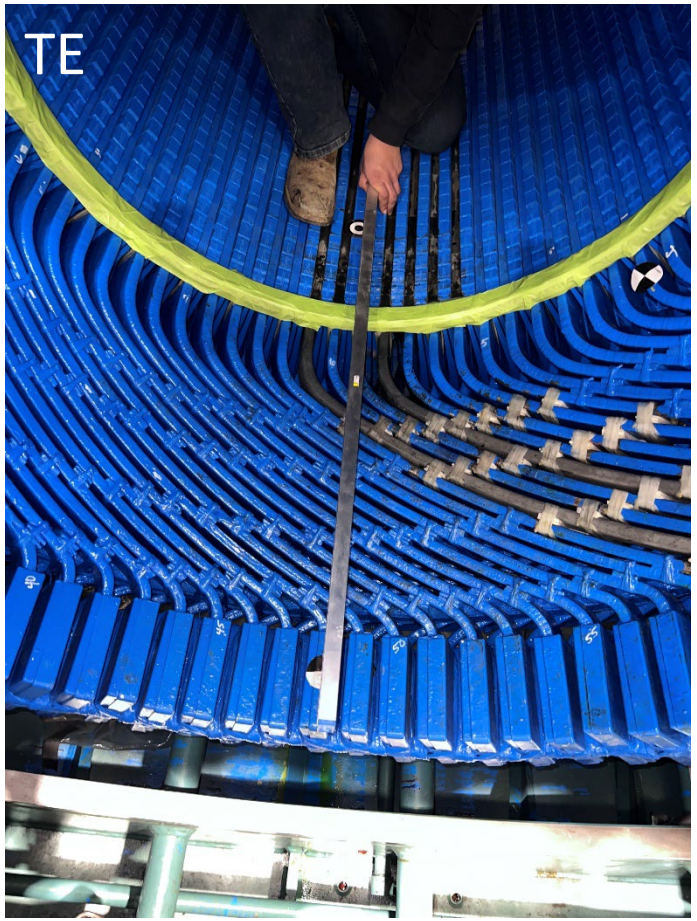
- Magnified Failed Strand
  - Single serving Dacron glass
  - Thin serving, no crosshatching
  - Exposed conductor

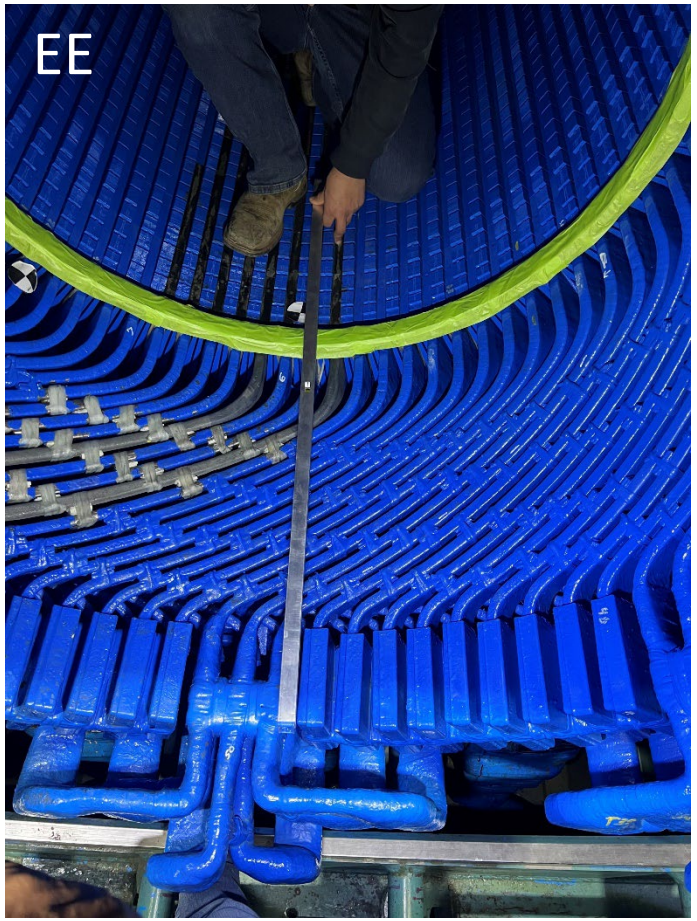
- Magnified Replacement Strand
  - Double serving Dacron glass
  - Crosshatched – increased coverage
  - No exposed conductor

Replacement Bar Manufacturing & Bar Reinsulation

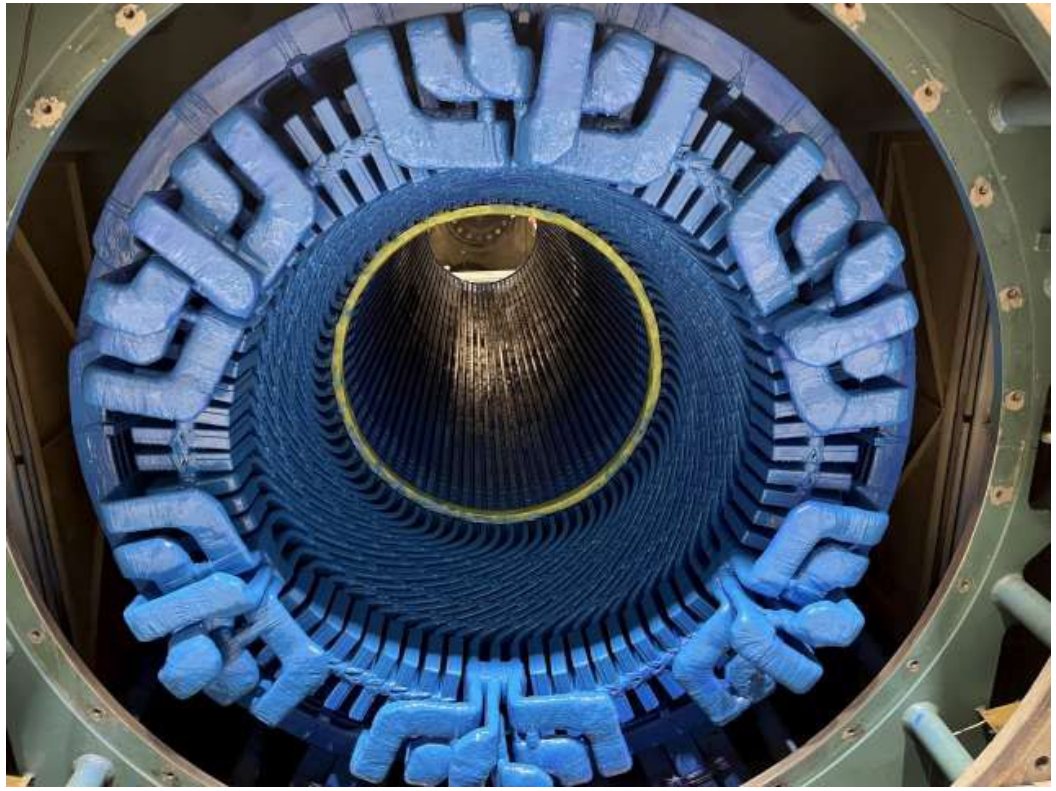
- Replacement bar losses matched original design
- Reinsulated & replacement bar utilized qualified materials and processes
- All bars (replacement, reinsulated, and both adjacent) successfully completed 100% final factory electrical testing and mechanical verification

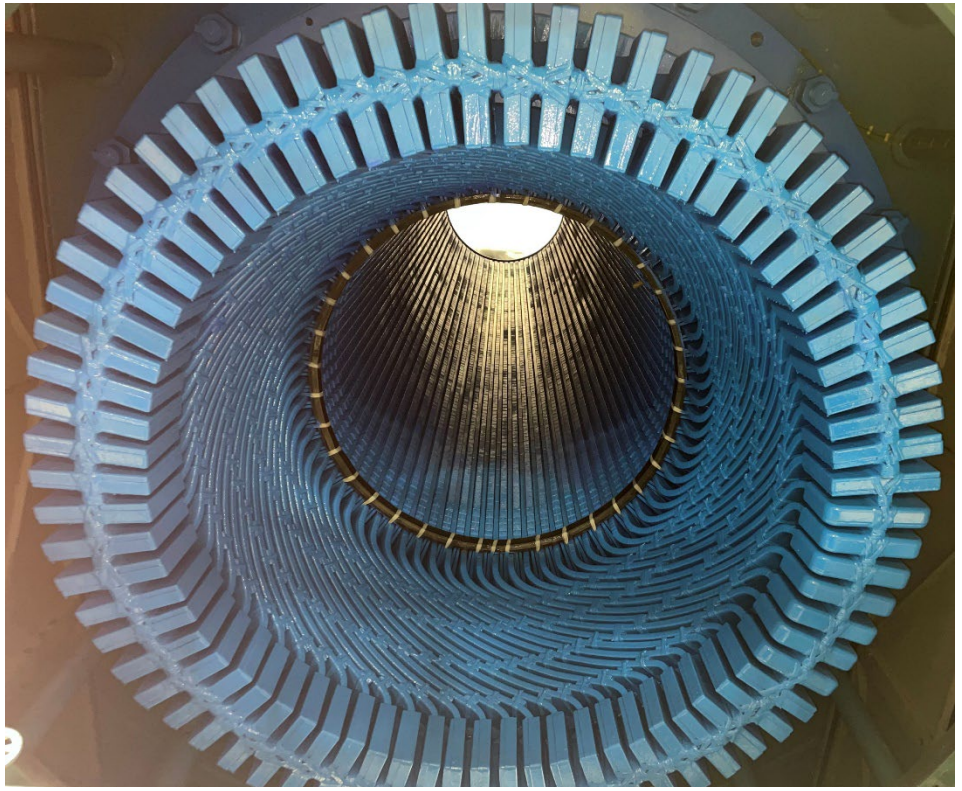
New Replacement Coil, Reinsulated Coil, & Cleaned Up Coils, Installed





Repairs Complete





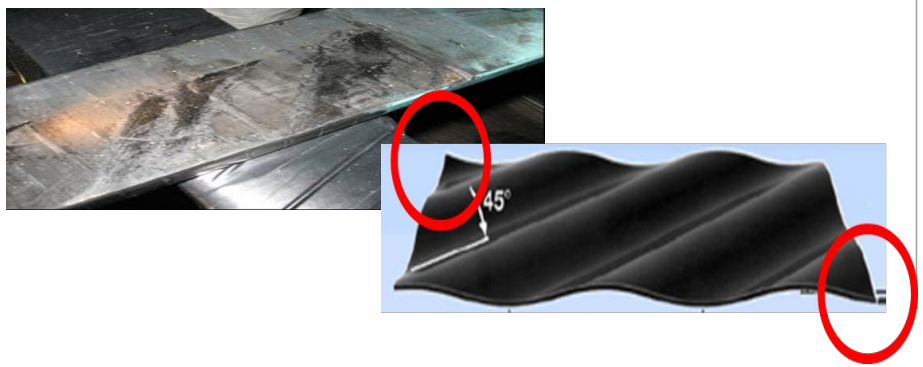
Future Considerations & Concerns

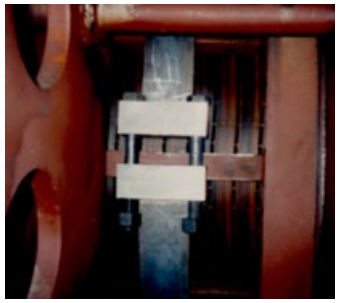
- Strand insulation discovery brings into question integrity of both top and bottom remaining bars.
  - Upgraded strand insulation and optimized losses should be part of future rewinds
- Side ripple filler discoveries present risk for ground wall insulation failure of untouched stator slots.

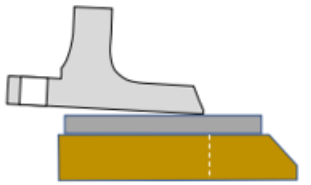


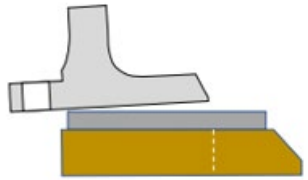

Known 324 Stator Issue Review

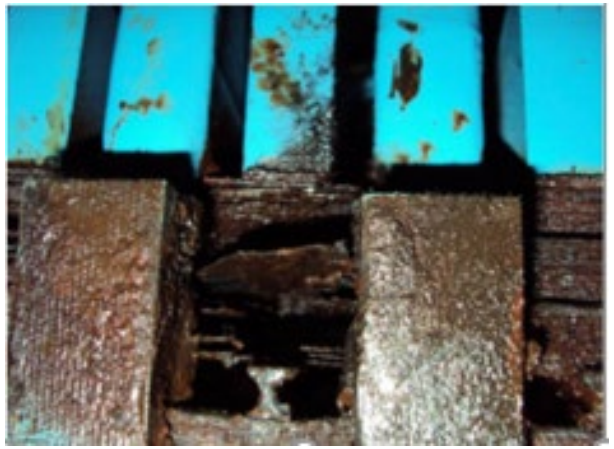
- End Winding Material Concern – Dry Tie Replacement – TIL 1764
- End Winding – Looseness, Resonance, Component Cracking, & Failure
  - TIL's – 1965, 1966, & 2417
- Core Compression Band Looseness, Cracking, & Key Bar Rattle
- Core Compression, Looseness, Lamination Movement & Fracture
- Slot Ripple Filler - Bar Abrasion
- Bar – Strand Insulation Failure





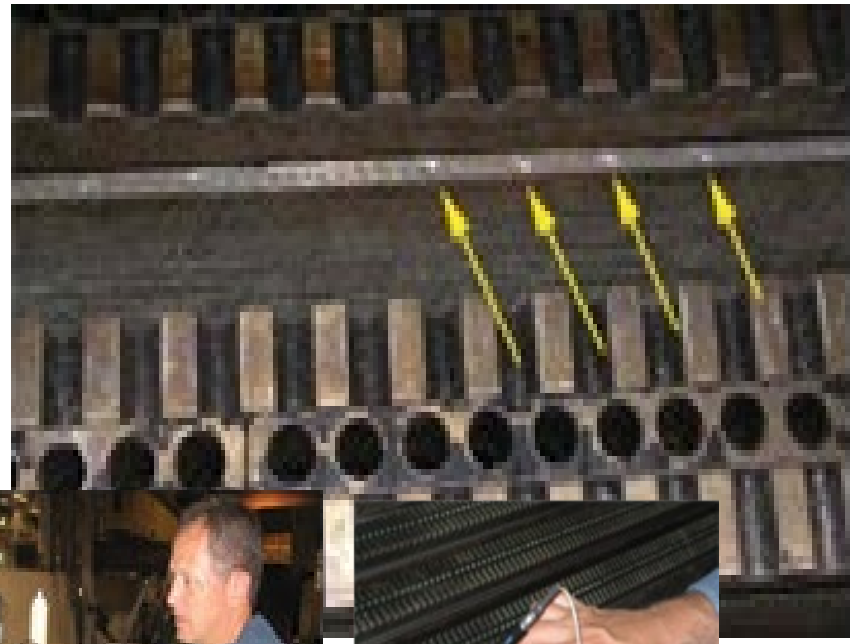


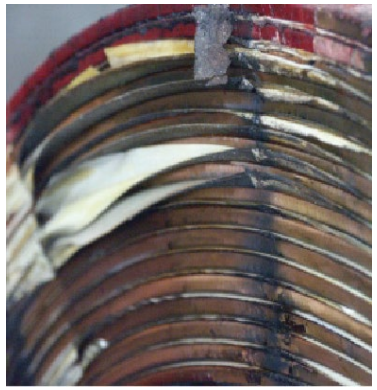




Known 324 Rotor Issue Review

- Rotor Forging Dovetail Cracking (TIL 1292)
- Rotor Amortisseur Migration
- Rotor Radial Lead Cracking & Failure
- Rotor Turn Insulation Migration





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QUESTIONS

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