



Mechanical *Instability* of Cables

[302.2.03 Cable Fabrication]

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Outline

- Popped-strand Cable Status
- High-level cabling process overview
- Issue Discovery
 - During cabling at LBNL
 - During cable handling at coiling and at braiding
- Corrective & Preventative Actions
- Summary

Popped-Strand Cable Status

- Cable mechanical instability ↔ Strands popping out of position
- Excessive popped strands raised cable quality concerns
 - Manifests when cable placed under tension
 - Resource heavy to place popped strands back into position, if many
- Six cables on hold for excessive popped strands at coiling
 - ~60% of allotted yield loss for the project (i.e., 6 of 10 cables)
 - Five quarantined at FNAL (post-braid)
 - Found at cable respooling step of coil winding operation
 - One quarantined at braiding/insulation vendor (pre-braid)**
 - Cables: #1139, #1147, #1151, #1257, #1259, #1260**

Cabling Process Overview

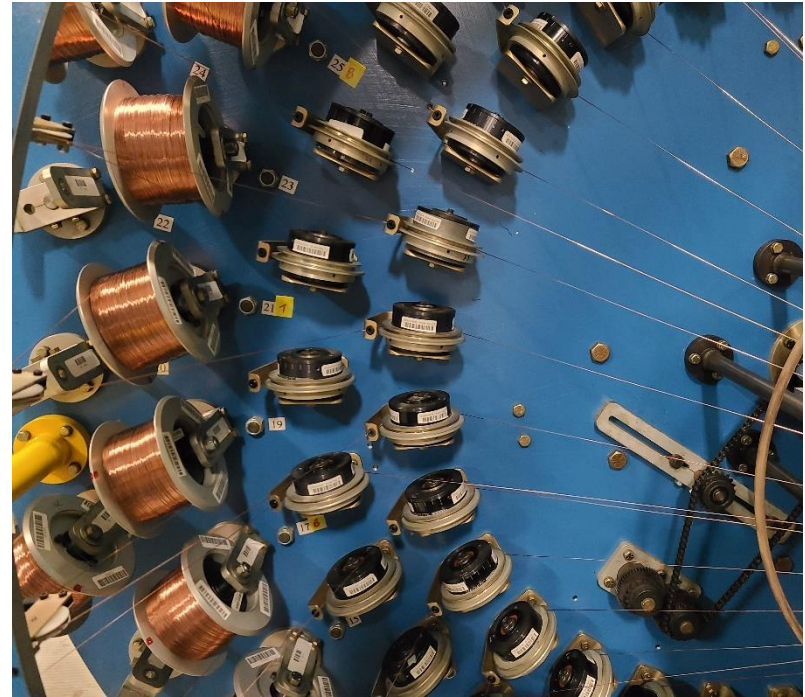
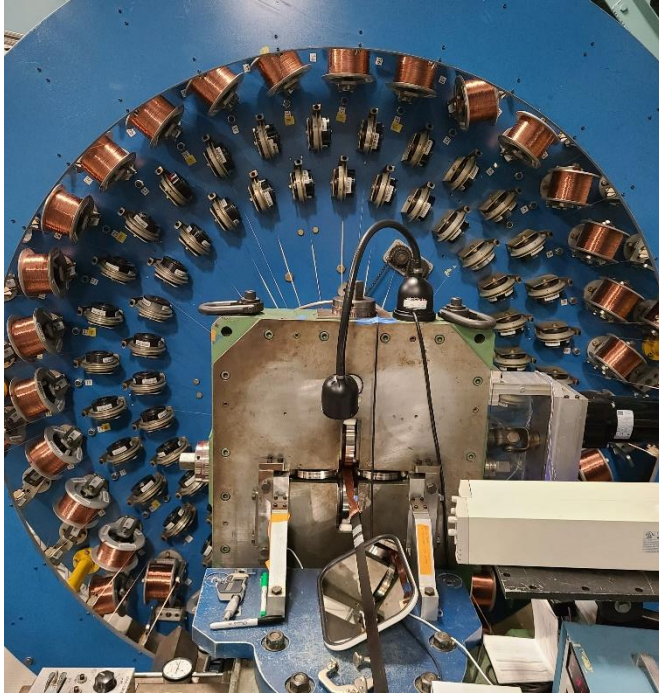
1. Receive up to ~9250 m (~50 kg) of wire from vendor per spool
 - Each billet might be delivered on more than one spool
2. Wire from vendor spools mapped into future cables
3. Wire is wound onto smaller spools in ~500 m unit lengths



Rack of 40 respools ready for mounting

Cabling Process Overview

4. 40 respools loaded onto the cabling machine



5. Initial 'start-up' cables produced to dial-in manufacturing parameters and confirm cable quality parameters meet specs
6. Full cable produced (~470 m)
7. Leftover individual wire strands archived

History: Issue Discovered, January 2021

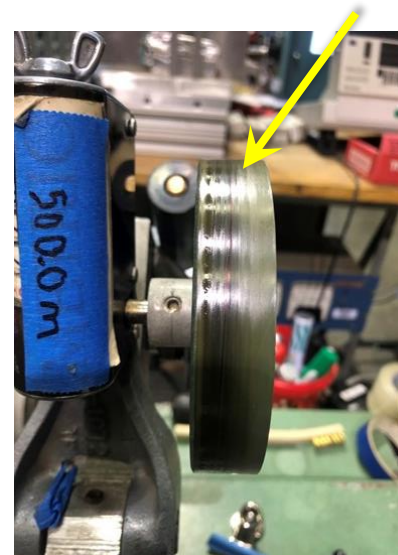
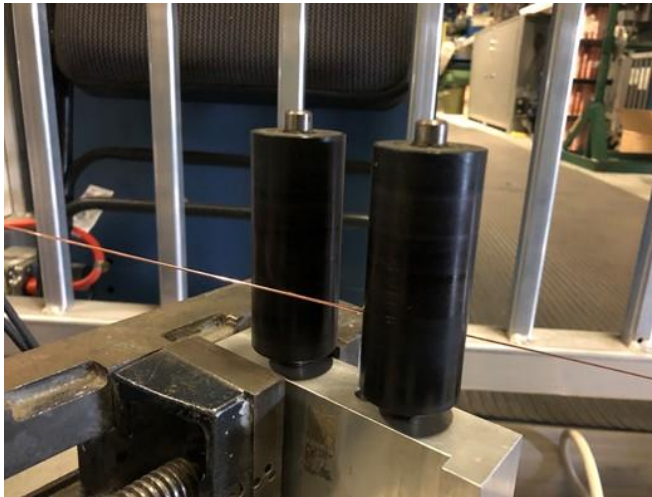
- During wire stringing (#1156), one strand was unusually slippery and difficult to string onto cabling machine
 - Post-cabling, an excess amount of residual wire was found at this fork same position (~25 m. Typically just a few meters)



One respool showing excessive residual strand

History: Issue Discovered, January 2021

- For next cable (#1157), post-startup short cable samples for 10-stack thickness were unusually unstable.
- Also, during respooling of #1157, one vendor spool was 'missing' ~500 m of length (one unit respool length)
 - Correspondingly, many respools were found to be ~10% overweight
→ Too much length onto the respools
- Respooling equipment & pulleys found to be oily



History: Issue Discovered, January 2021

- Most Likely Cause: *Oily wires caused footage counter slippage and cable short-sample instability*
 - Oil transferred to equipment, cross-contaminating other strands
- Immediate (concurrent) actions:
 - ‘Stop Work’ order initiated
 - Concern about future cable stability during coil winding
 - Meeting called with wire vendor
 - Kudos to our wire procurement counterparts for fast action (302.2.02)
 - Notification of L2 & QA managers

History: Vendor Findings

- List of good vs bad spools generated and sent to vendor
 - LBNL inventory inspected for slippery wire by touch
 - Commonality found with vendor's special wire cleaning process
 - 'Asgard' process: Removes surface stains, as needed
 - Includes adding a subsequent lubrication coat to inhibit oxide growth
 - *Mobil 1* erroneously used as lubrication coat.
 - Subsequent eddy current scans left excess oil on the wire
 - Use of drawing oil was not specified, but was used by technician
 - Discovered in June 2021
- Possibly two 'non-standard' lubricants left on wire:
- Mobil 1
 - *Excess drawing oil* (small amount is normal)

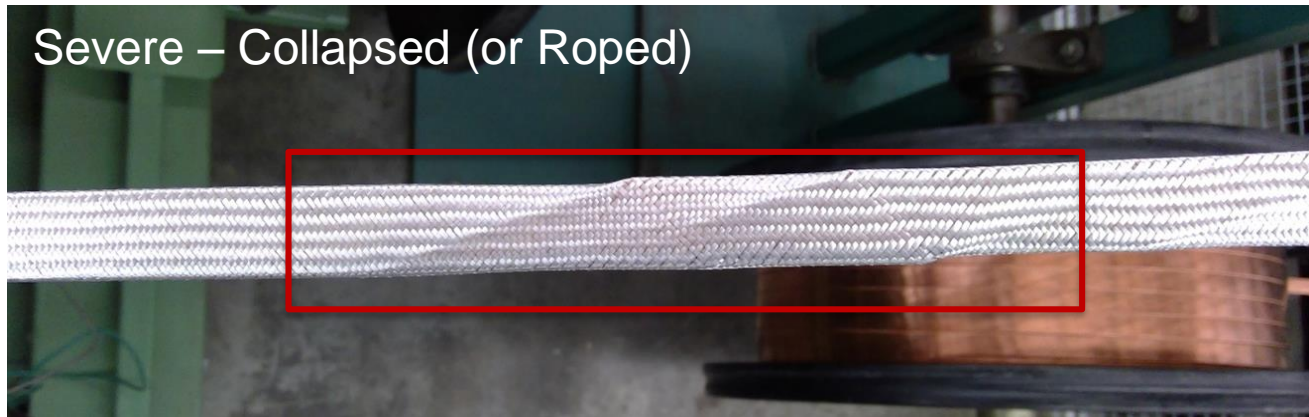
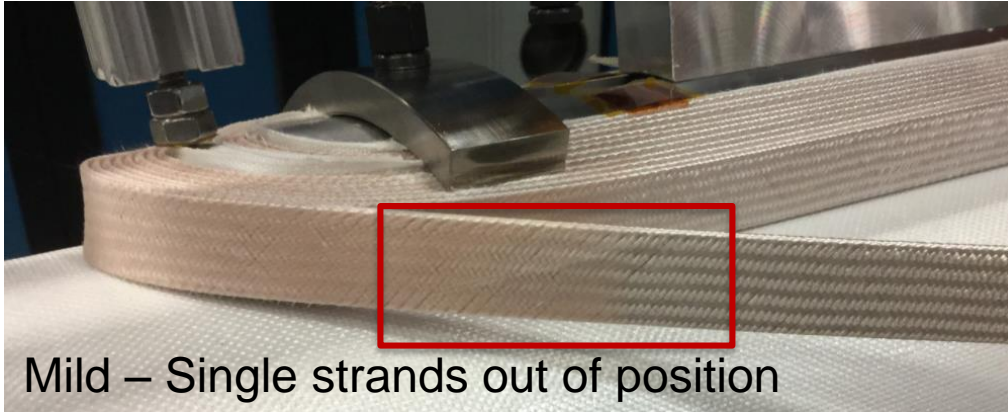
Corrective Actions Taken

- Known affected wire sent back to vendor for recleaning and/or exchange
- Equipment and spools cleaned
- Cables not yet made, but with Asgard strands in their strand maps, were cancelled
 - New cable strand maps created using new, clean wire
 - Example: Cable AUP 057: Cable #1157 → Cable #1257

Cable Instability at FNAL, April 2021

- FNAL reported two cables in close succession that had too many popped strands for effective respooling
 - Cables #1147 & #1151. Put on hold.
 - #1153 & #1154 were reported difficult to use, but coiling completed
- Subsequently found that #1147 & #1151 had some overly long residual strand lengths in post-cabling archive.
 - #1151 used one Asgard wire. #1147 used zero Asgard wires.

Popped Strand Examples



Cable Instability at Braider, Late April 2021

- Insulation vendor had popped strands *with remapped cables*
 - #1259: Able to finish insulation & shipped to FNAL → On Hold
 - Some bobbin tension drift noted during braiding
 - #1260: Unable to insulate → On Hold
 - Other popped strands noted, but ok: 1144, 1153, 1154, 1156, 1162
 - All coiled successfully
- Failure of remapped cables indicates cross-contamination
 - Similarly, FNAL had popped strands with remapped cable #1257 during coiling (June 2021)
 - Cabling equipment had been cleaned then recleaned when issue was discovered

Other Possible Correlations Investigated

- No correlation with cabling physical parameters
 - Thickness, width, pitch length, keystone angle, facet sizes
- No changes to cabling procedures or personnel
- No changes to braiding procedures or personnel
- No correlation to in-process braiding parameters or bobbin tension
 - Tight braid can cause instability by squeezing on edges
- All failed coils occurred at FNAL; None at BNL
 - Sites have stated their processes are reasonably matched
 - No notable differences in cables sent to each site

Current Status

- Popped-strand cables quarantined:
 - @ FNAL (insulated): #1139*, #1147, #1151, #1257, #1259
 - *1139: Presently included due to similar failure mode. A couple residual strands were moderately longer than baseline level.
 - @ NEWT (non-insulated): #1260
- No cables made after #1260 have had popped strands
 - #1163, #1164, #1165, #1166, #1168 used thus far
 - #1163 through #1174 have been qualified
 - All pre- #1260 cables have been coiled or quarantined
- Other cables made in the same time frame as quarantined cables were successfully coiled, some with known ASGARD strands
 - Oily strand increases probability of popping, but not a guarantee

1130	1131	1132	1133	1134	1135	1136	1137	1138	1139	1140	1141	1142	1143	1144	1145	1146	1147	1148	1149	1150	1151	1152	1153	1154	1155	1156	1158	1161	1162	1257	1259	1260	1163	1164	1165	1166	1167	1168	1169	1170
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Corrective and Preventative Actions

- Affected strands returned to wire vendor
- Equipment cleaned (and later cleaned again)
- @Wire Vendor: Procedure updated to specify drawing oil must be off when using loose-fitting guide dies
- Incoming spools to LBNL inspected for surface lubricity (touch)
- Post-cabling residual strand lengths more closely monitored
- Document created to define actions when popped strands found during coil winding
 - Actions based on severity and frequency of popped strands →
 - Disposition of Nonconforming Cables, Sect 3.4 (DocDB #4172)

Corrective Action: Cable Cleaning

- Cable cleaning being investigated to save quarantined cables
 - Submersion into ultrasonic solvent bath
 - Test run successful on short, heavily contaminated cable pieces
 - Might require cable debraiding for effective cleaning
 - Process development underway at FNAL
 - All extra handling degrades cable stability
 - Risk of trading one problem for another
 - Submersion of entire cable spool to minimize handling
 - The target cleaning vendor is located very close to FNAL
 - FNAL could easily monitor process firsthand

Summary

- Overly lubricated wire discovered at LBNL - January 2021
- Cabling team (302.2.03) immediately:
 - Created a Stop-Work order
 - Notified AUP L2 & QA managers
 - Partnered with wire procurement (302.2.02) to resolve with vendor
- Commonality to wire vendor's cleaning and eddy current testing
 - Mobil 1 and/or excess drawing oil
- Unstable cables found at FNAL & braiding vendor - April 2021
 - Cables put into quarantine
- Root Cause: Excess lubricant causing overly lubricious strands
 - Affected cables made in time period when wire oils found
 - No other correlations to cable parameters
- Cable cleaning is being investigated to recover cables

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Back-up Slides Below



Popped Strand Disposition Table

Popped Strand Disposition Table

Frequency	Severity Level	Disposition
<10 mild instances <3 severe instances	Low	Repair
	Medium	Complete respooling and quarantine for L2 determination
>50 mild instances >10 severe instances	High	Wind back and quarantine for L2 determination
Roping	High	Repair, wind back, and quarantine for L2 determination

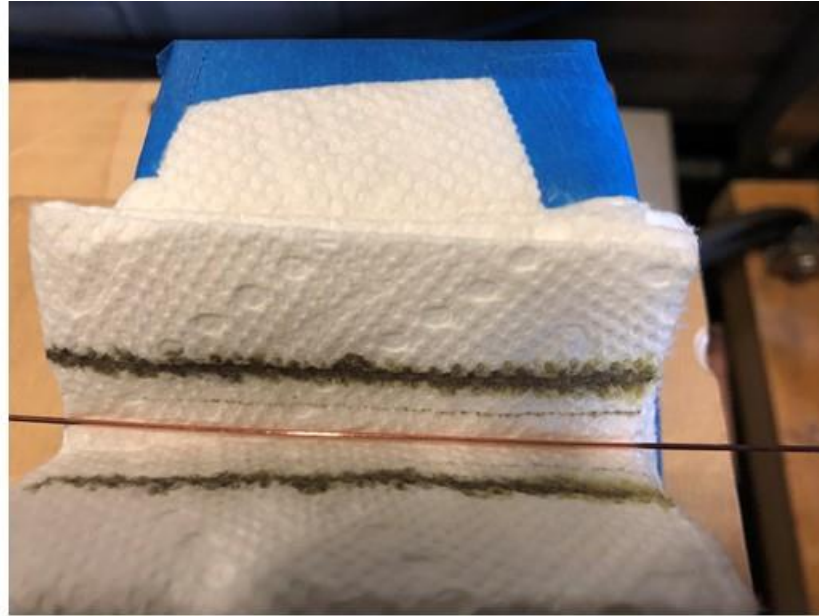
Mild: Popped strands can be pushed & seated under the braid by finger pressure.

Severe: Popped strands cannot be pushed & seated under the braid by finger pressure, requiring use of tools. Cable tension may or may not need to be reduced. Removal of insulation shall not be required.

Roped: Cable collapse. Repair can only be done with insulation removed.



Lubrication Wiped from Strand



- Wire passes through paper towel during respooling
- The above after < 500 m of wire