MQXF Cable for Q1/Q3

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MQXF Conductor Review
November 5-6, 2014
CERN

Outline

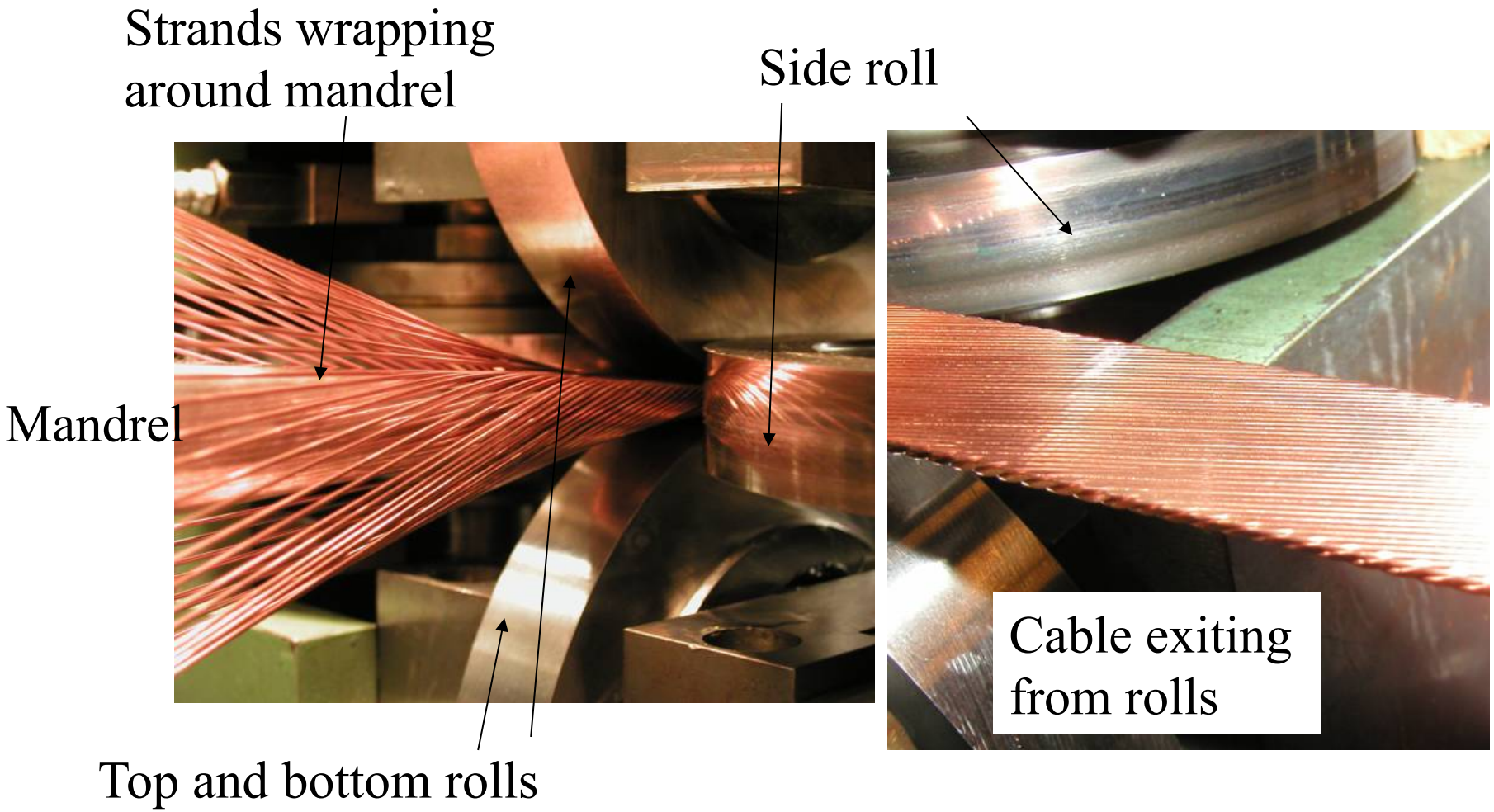
- MQXF parameters in draft specification (LARP-MAG-M-8007)
  - Cable made with these parameters and RRP 132/169 wire
- MQXF-S cable fabrication experience in LARP
  - A sub-set of the R&D to support the parameter selection
  - Cable parameters from the LARP MQXF-S cable runs
- Strand deformation and quality of strands with the MQXF cable parameters
  - Metallographic observations – Quality score
  - Effect on RRR and I_c
- Observation on cables made from annealed vs. un-annealed wire
- Summary

MQXF Cable Parameters

- Mid-thickness = 1.525 mm +/- 0.010 mm
- Width = 18.15 mm +/- 0.050 mm
- K.S. angle = 0.55 deg. +/- 0.10 deg.
- Pitch Length = 109 mm +/- 3 mm
- S.S. core = 12.0 mm wide
  - 0.025 mm thick
  - bias towards thick edge
- Anneal wire at 170C for 15 hrs.

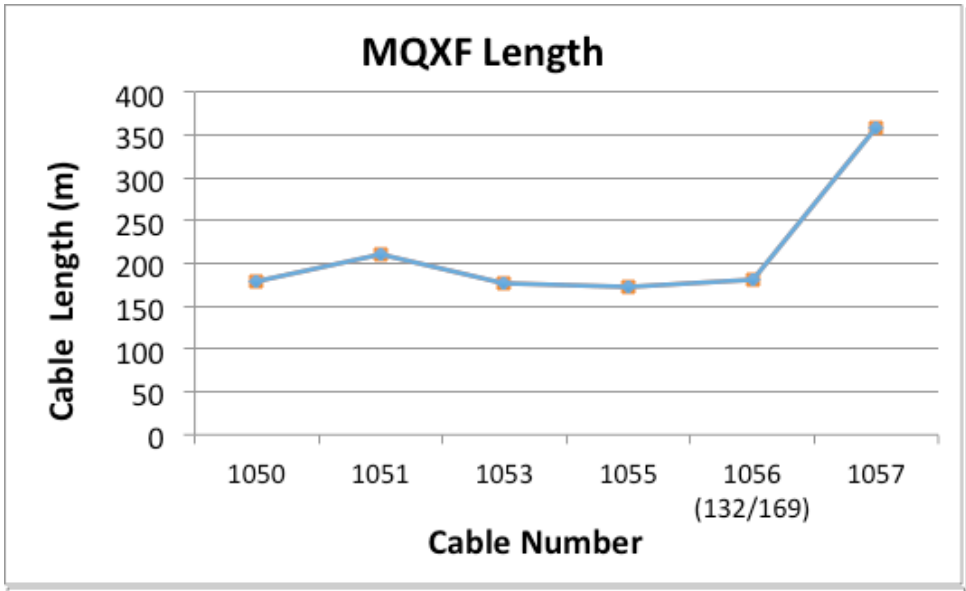
- Before reviewing some of the R&D that lead to the above specification I will evaluate a cable made with RRP132/169

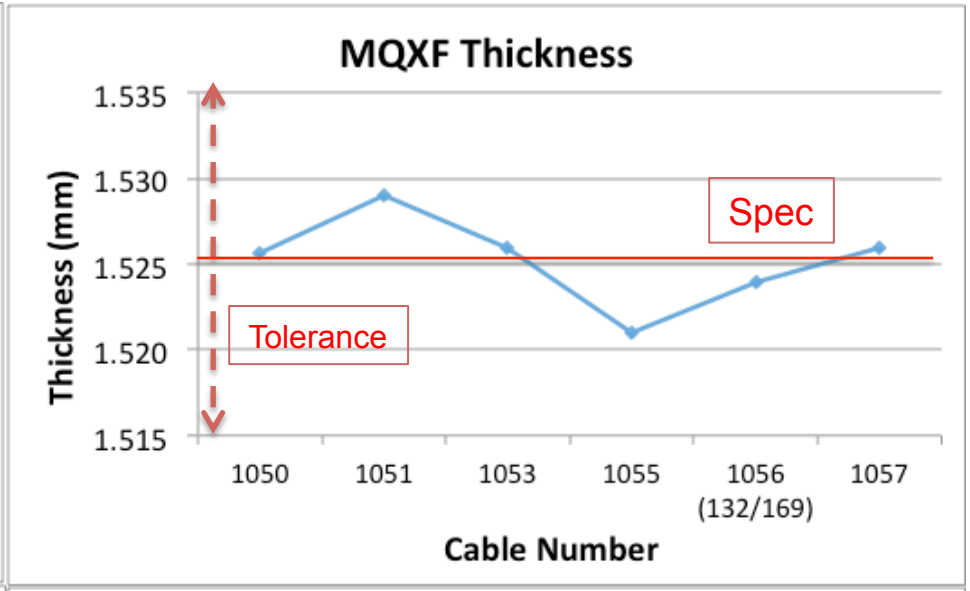
Cable Machine Hardware at LBNL

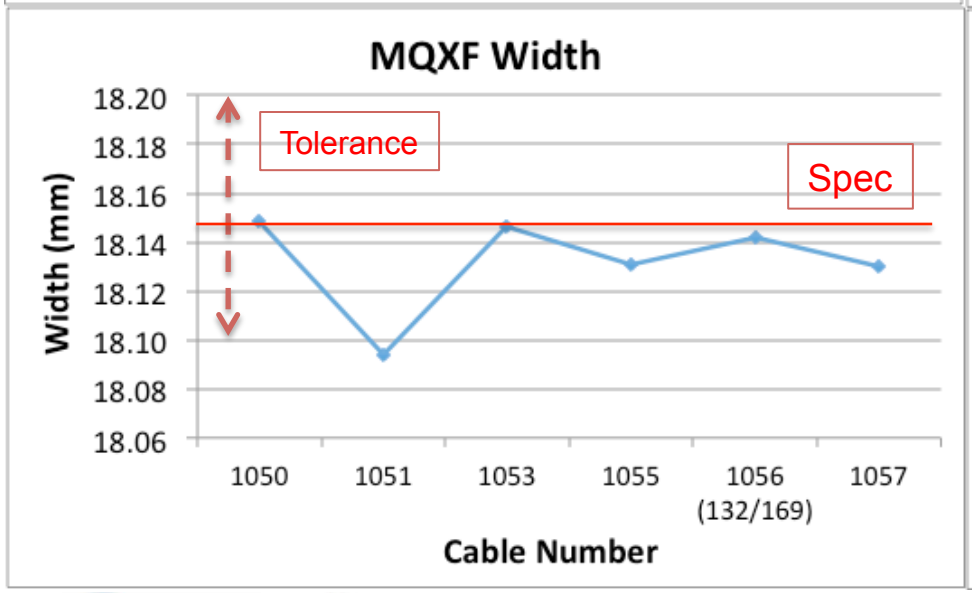


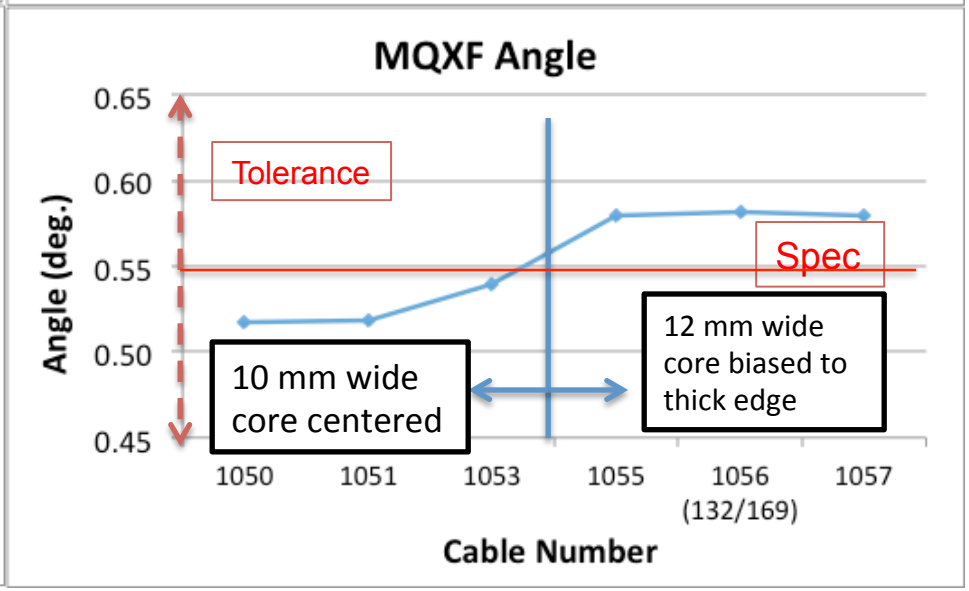
Fabricating Cable at LBNL

MQXF Production Cable Parameters









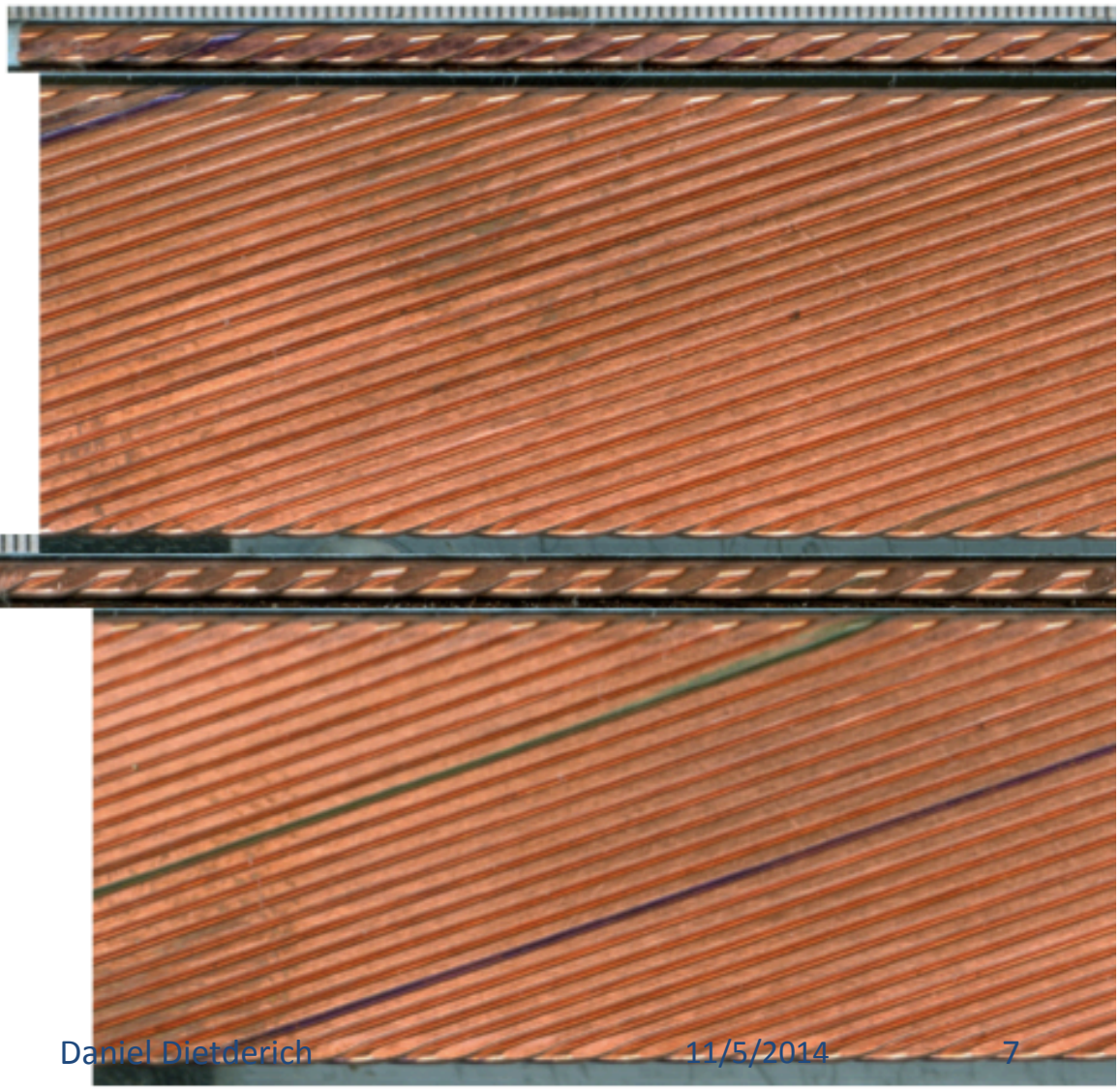
MQXF Cable 1056Z with 132/169

Bottom

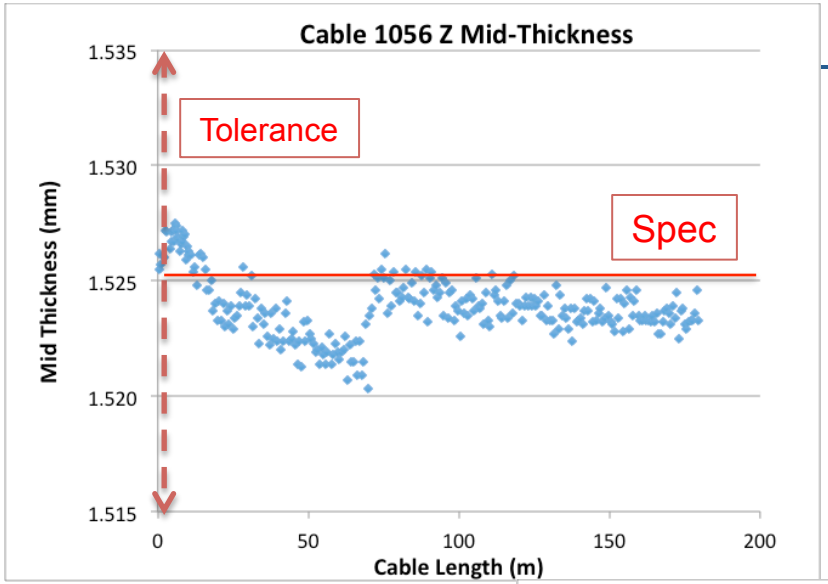
- Facet are uniform and not too large
- All surfaces show uniform wire spacing

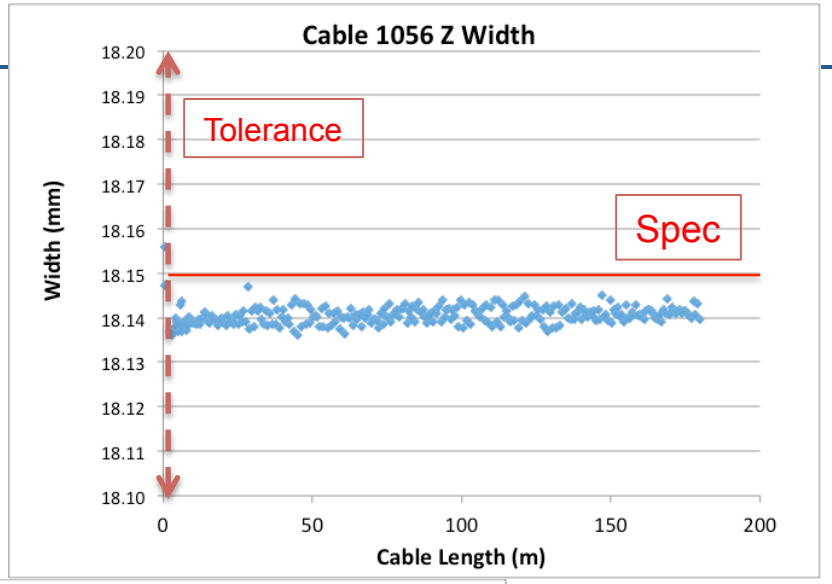
QXF-1056z-C_Tail End
-Major Edge

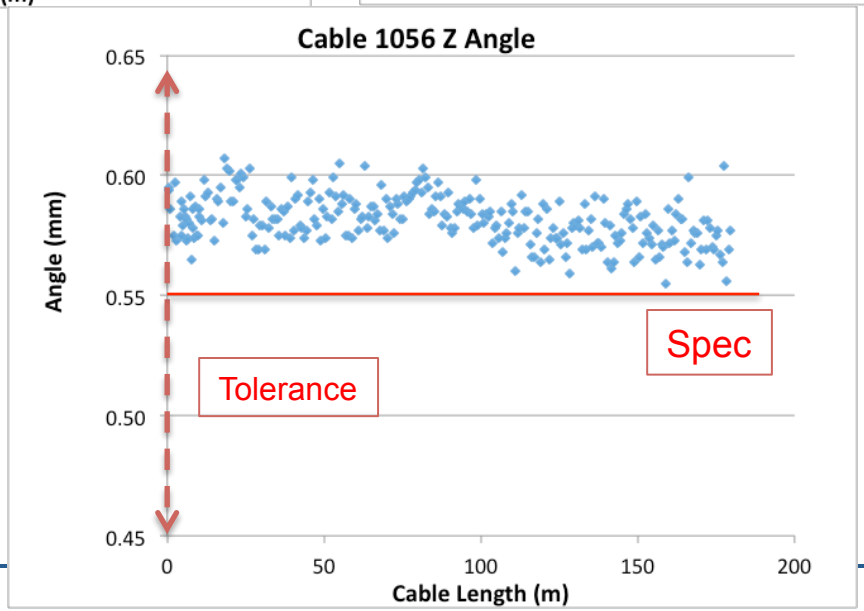
Minor Edge



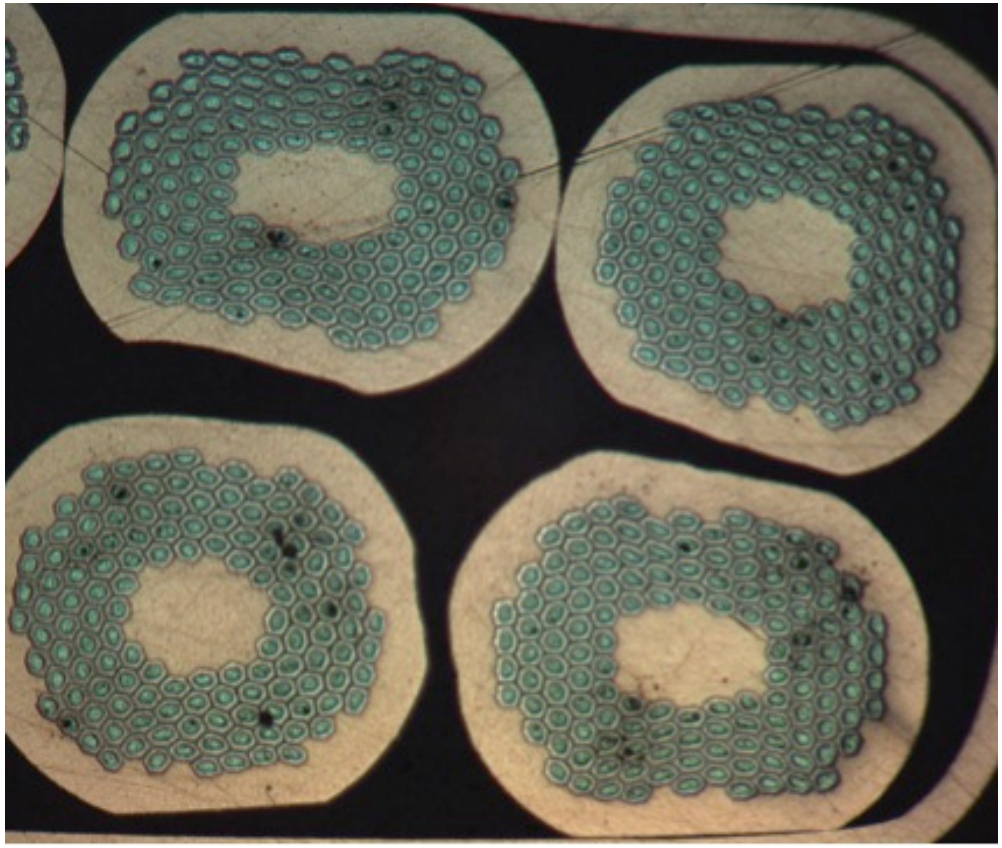
MQXF Cable with RRP 132/169 Wire and Draft Parameters





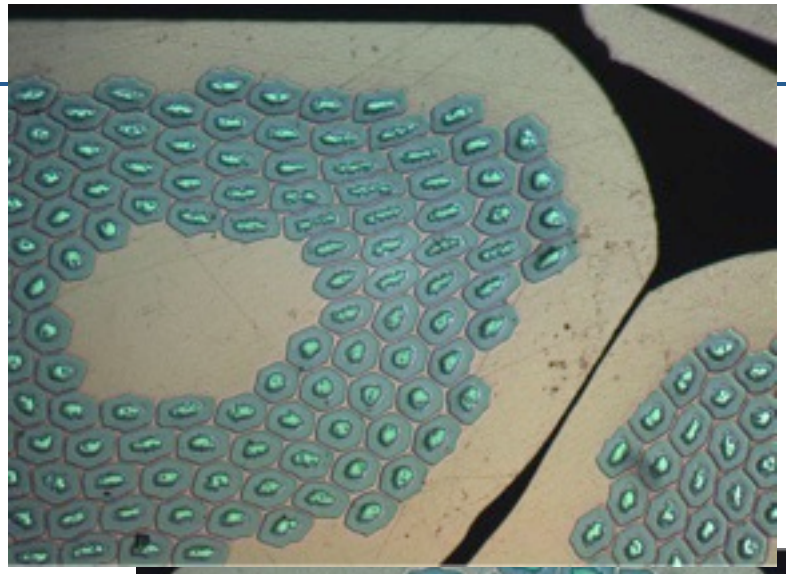


1056Z – Rectangular Configuration

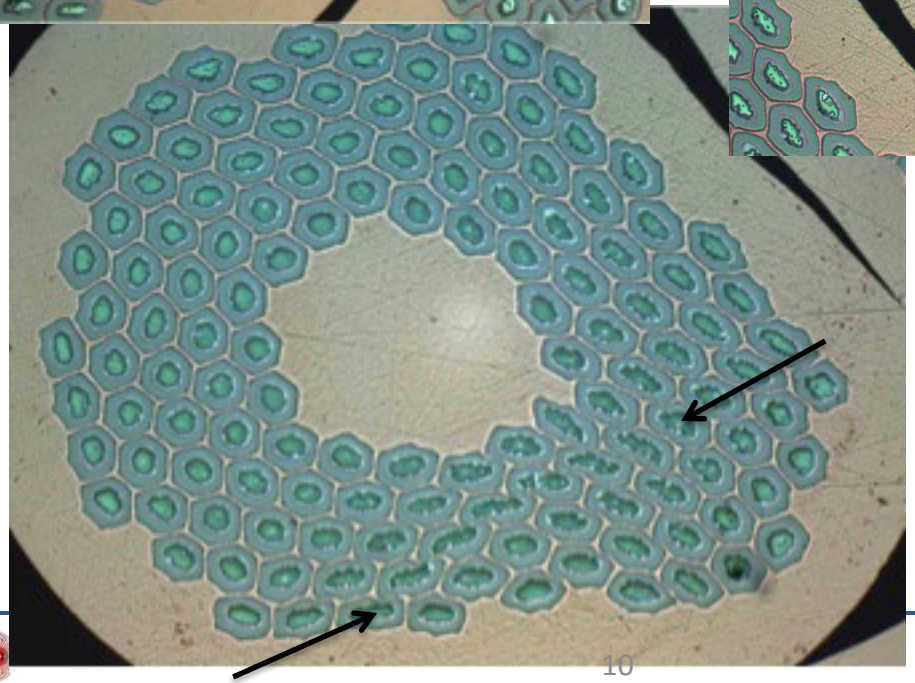


Orientation when polishing started

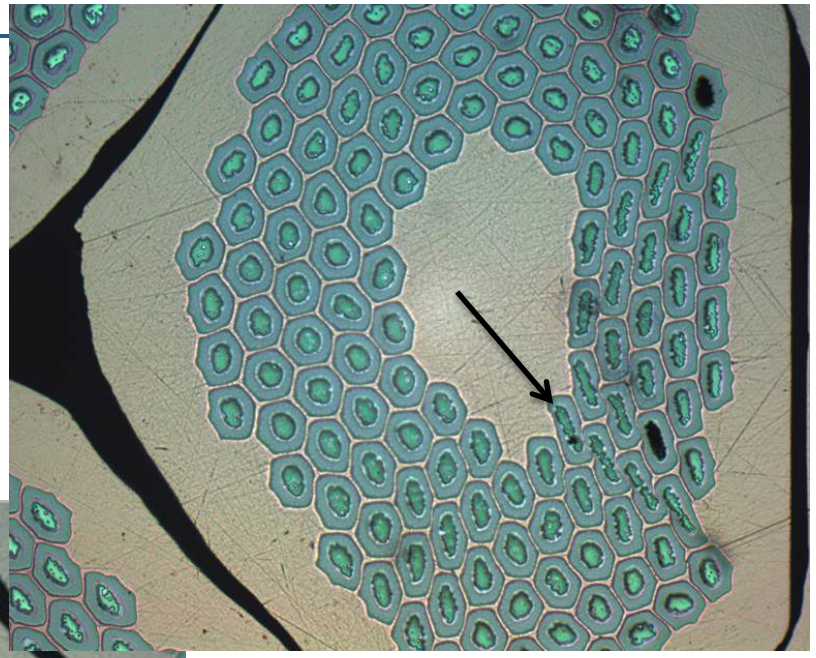
1056Z – Triplett Configuration at



Top



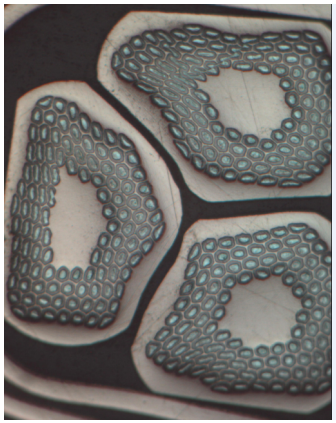
Bottom

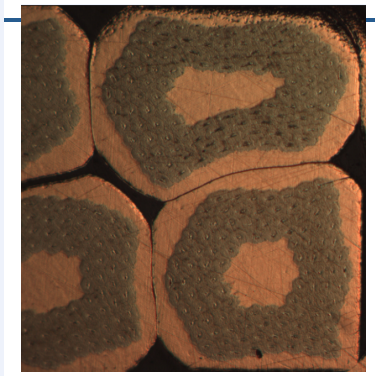


Apex

- Worse case for 8 cables sections:
- One strand has 6-8 broken sub-elements
- Typical:
- 0-3 broken sub-elements

Strand Quality Score





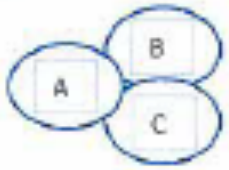
Sample ID:

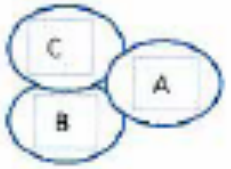
Date/ Initials

T

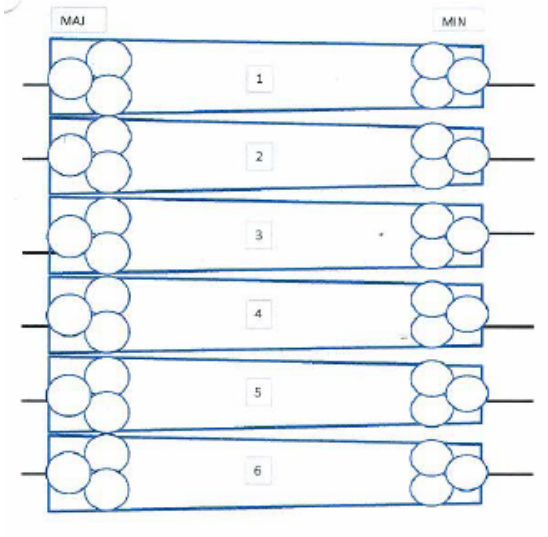
Q

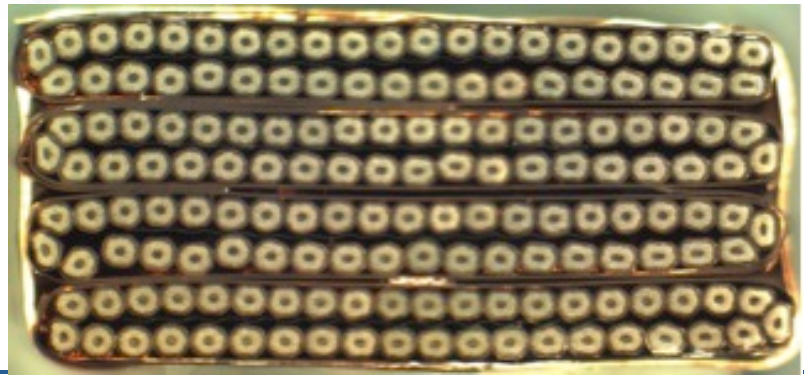
R





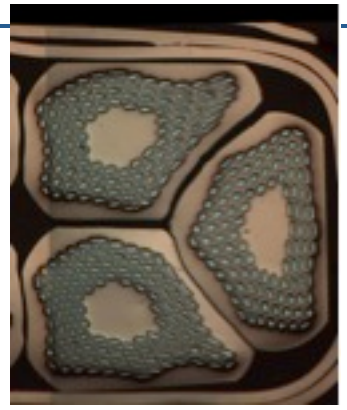
	MAJ				MIN		
Triplet	A	B	C	Triplet	A	B	C
1							
2							
3							
4							
5							
6							

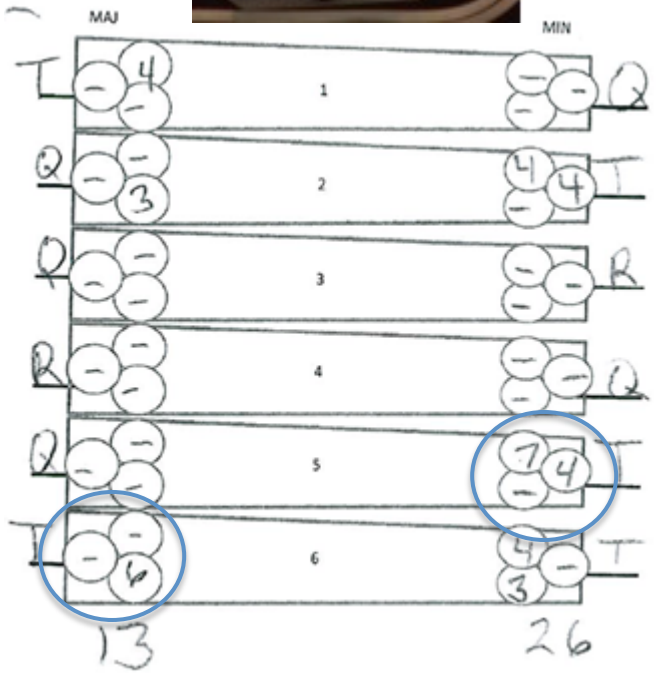




Quality Score Method for Cable 1048Z (Un-annealed)

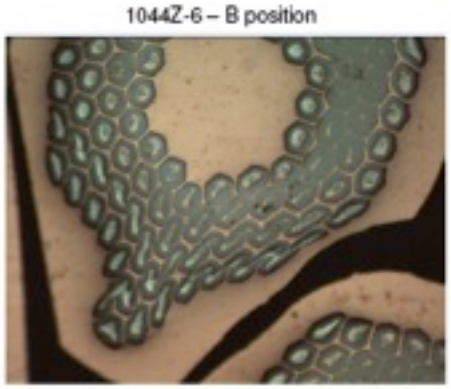
- **How is the "Quality Score" determined?**
- The number of sheared sub-elements in the wires at the **each** edge of the **each** cable is determined.
- One method is to average the number of sheared sub-elements at each edge of the cable.
- The other assumes that the stability performance of the cable in a magnet is going to be limited by the highest score (i.e. lower local RRR) not the average at each edge.
- A "Quality Score" is determined by one of these methods.
  - Highest value in any one wire , i.e. 7 for the minor edge and 6 for the major edge
  - However the average method would give a values of (0+2.66+0+0+3.66+2.33)/6 cables = 2.88

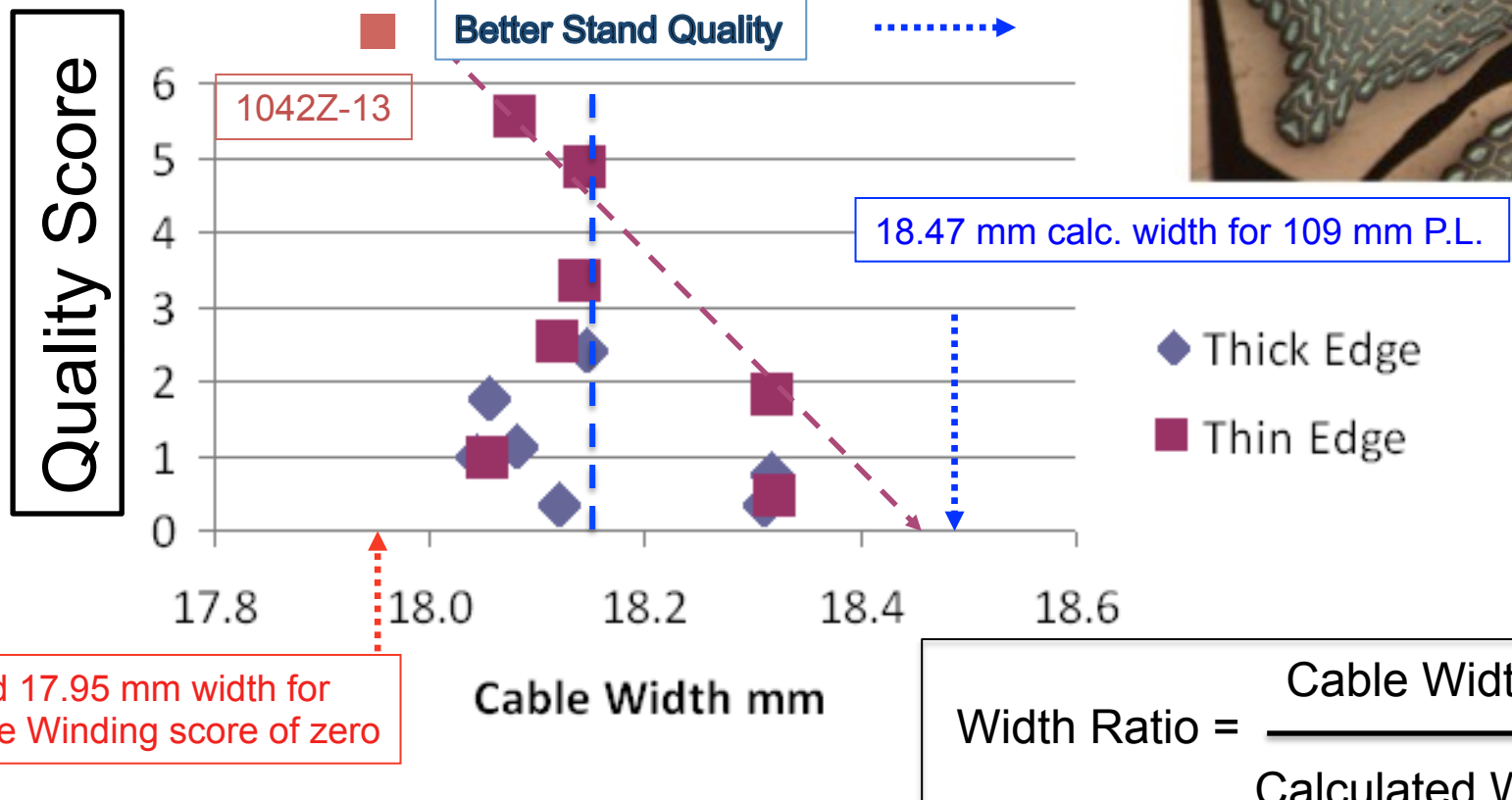




Trade-off Between Cable Mechanical Stability vs. Strand Quality

RRP 108/127, ~1.50 mm thick





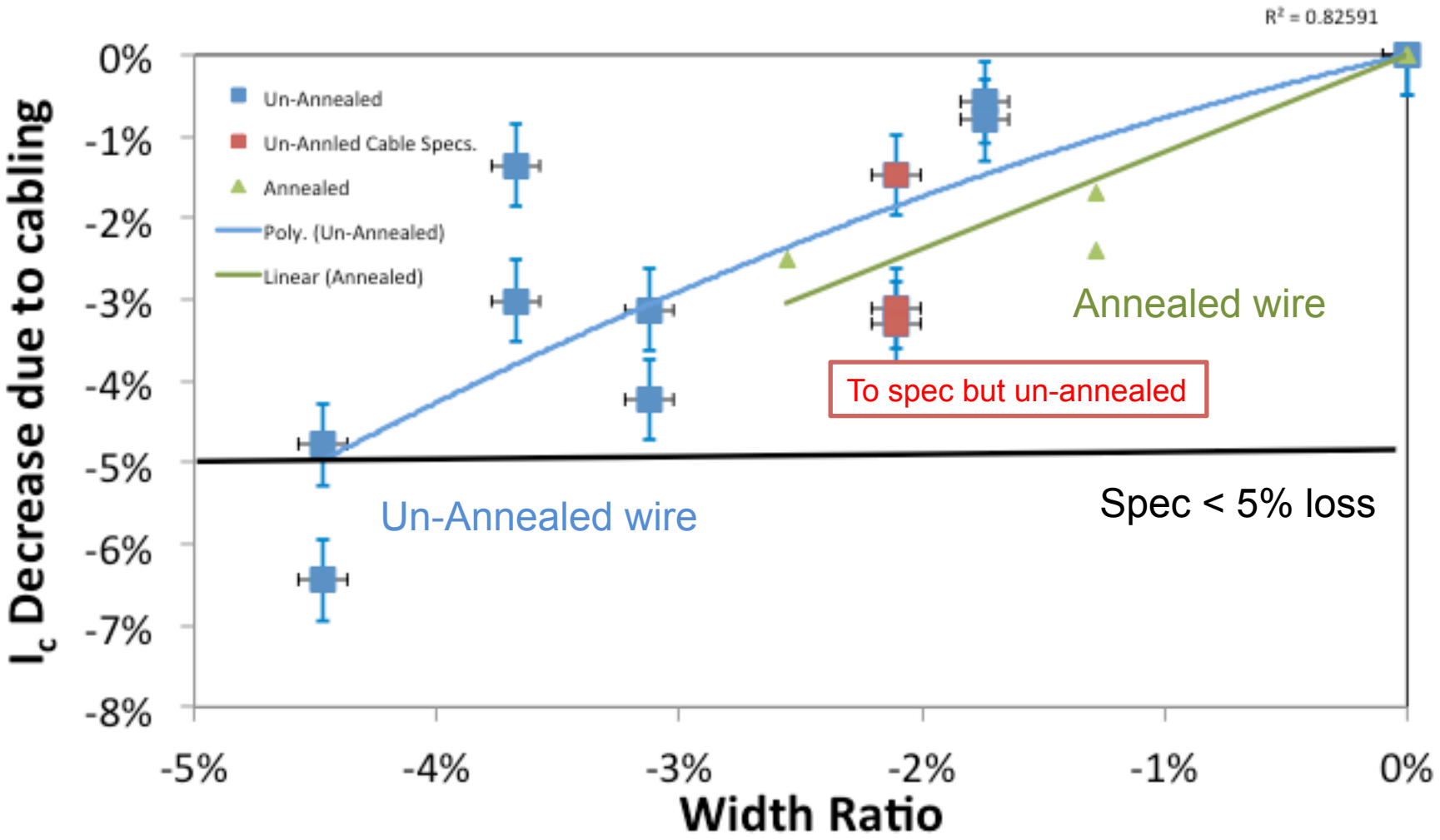
$$\text{Width Ratio} = \frac{\text{Cable Width}}{\text{Calculated Width}}$$

Cable Parameters from R&D Effort with Reduced Sn

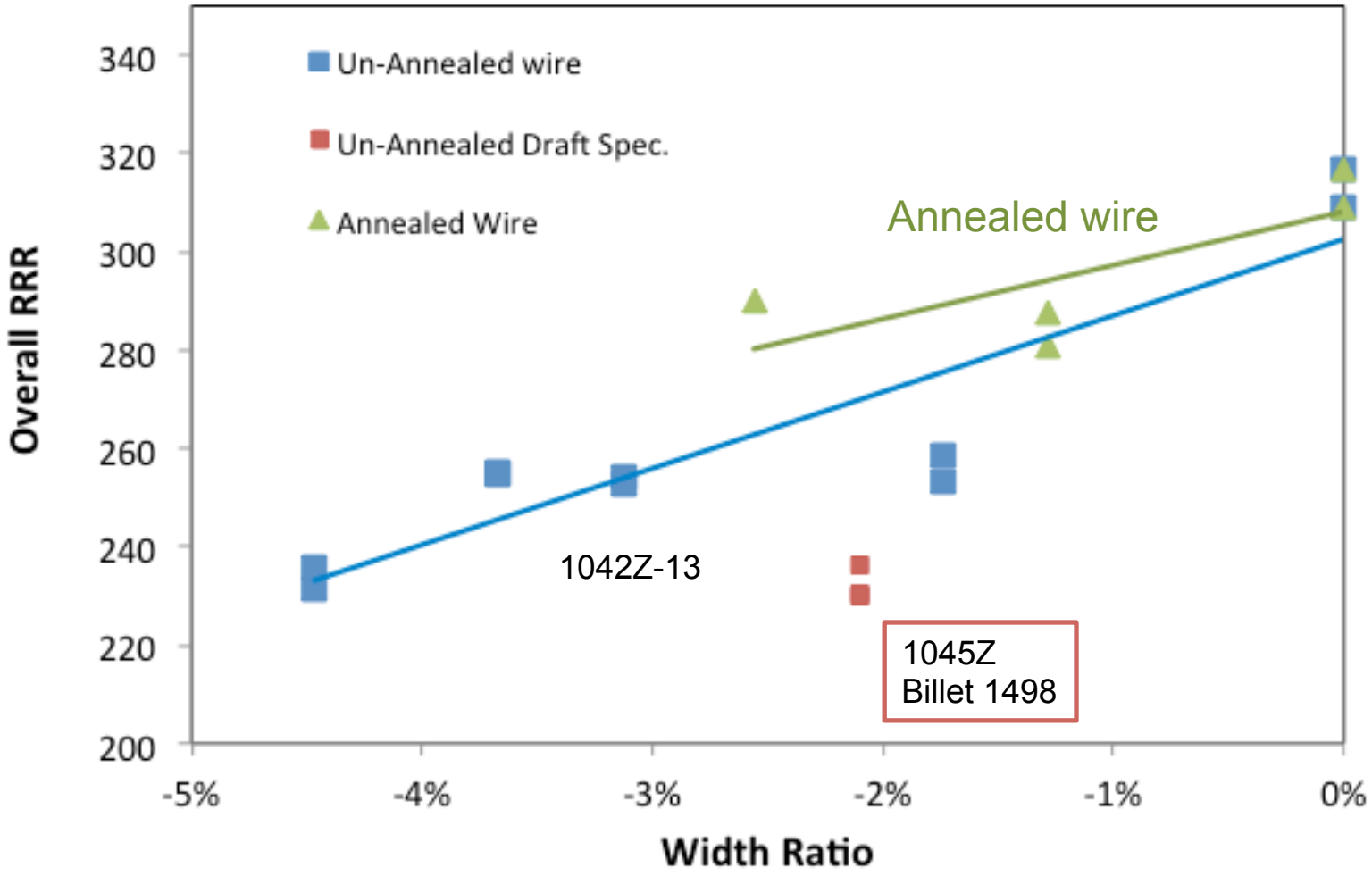
Cable Section	Billet No.	Width, mm	Mid-Thickness, mm	Keystone Angle, deg.	Pitch Lp, mm	Anneal Condition	Ic loss
1042Z-01	14735	18.09	1.502	0.67	117.5	None	-0.7%
1042Z-10	14735	18.11	1.501	0.62	95.5	None	-2.2%
1042Z-11	14735	17.94	1.499	0.62	95.5	None	-5.6%
1042Z-13	14735	17.94	1.490	0.64	109	None	-3.7%
1041Z-2	14735	17.93	1.499	0.66	118	Yes	-2.5%
1041Z-10	14735	18.32	1.512	0.63	109	Yes	-2.0%
1045Z-8	14982	18.15	1.520	0.54	109	None	-2.6%

1045Z-8 was made to specifications but with un-annealed wire

I_c(11T, 4.2K) Decrease due to Cabling

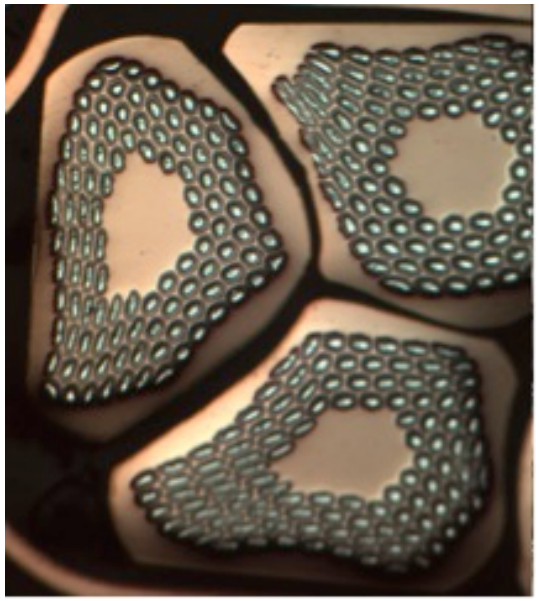


RRR of Extracted Strands for Annealed and Un-Annealed Wire

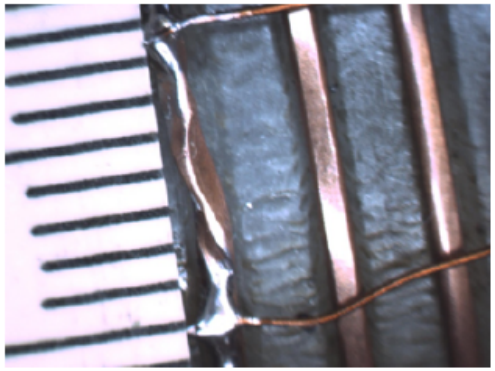


RRR of Edges of MQXF Strands Extracted from Cable

- For heat treatment of 650C for 48 hr.
- Round strand has RRR of 317
- RRR of kink (edge of cable) is 150-160 for Voltage Tap spacing ~7 mm
- Cable width 17.94 mm, R&D cable
- Wire RRR specification is >150.



1042Z -13



Round wire
RRR = 317

RRP 14735

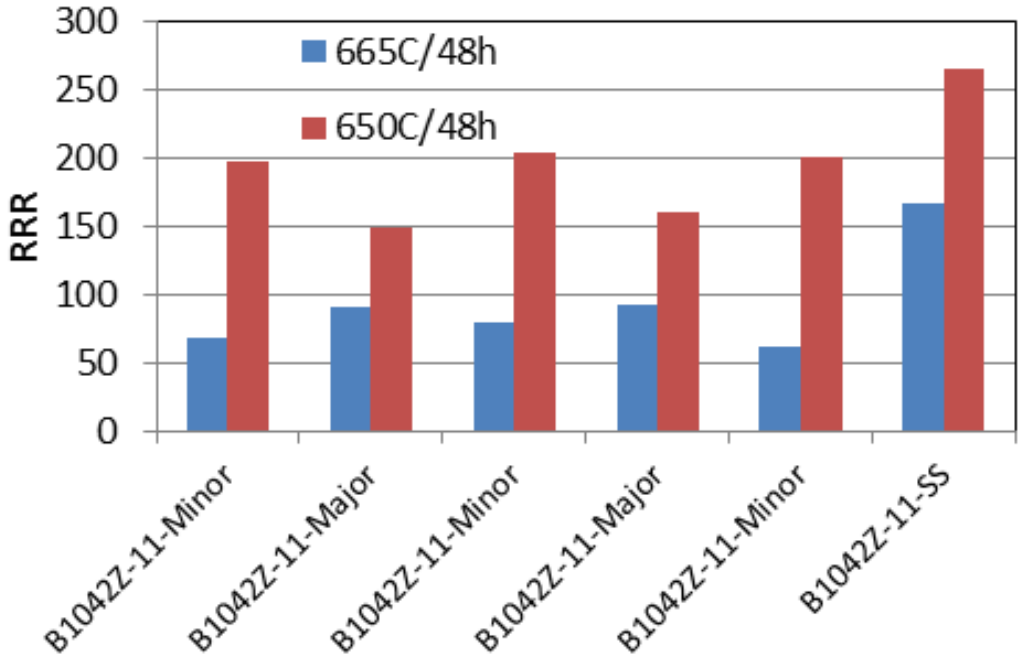
Tap configuration for measuring local RRR at the Minor and Major ends

Wire ID	RRR
B1042Z-13-ES-Minor	162
B1042Z-13-ES-Major	188
B1042Z-13-ES-Minor	163
B1042Z-13-ES-Major	179
B1042Z-13-ES-Minor	149
B1042Z-13-ES-SS	270

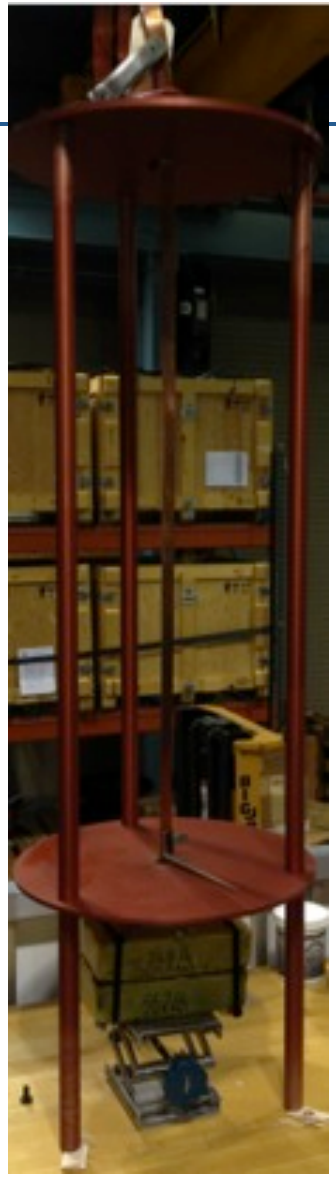
Control of RRR with Heat Treatment

- R&D cable is narrower and thinner than spec
  - Plus shorter pitch length and larger keystone angle
- RRP 108/127 with reduced Sn
- 7 mm voltage tap spacing

Cable Section	Billet No.	Width, mm	Mid-Thickness, mm	Keystone Angle, deg.	Pitch Lp, mm
1042Z-11	14735	17.94	1.499	0.62	95.5



Cable Residual Twist



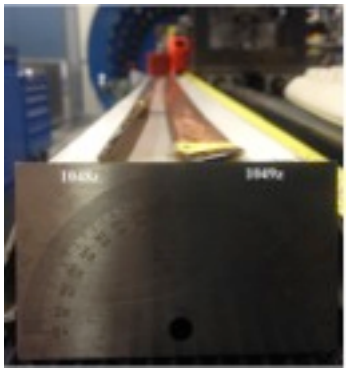
Residual Twist Measurements In Deg./m

Three loads were used 0, 12.2 & 24 kg

- -Deg. cable loosens when straightened "unfavorable"
- +Deg. (CW) cable tightens when straightened "favorable"

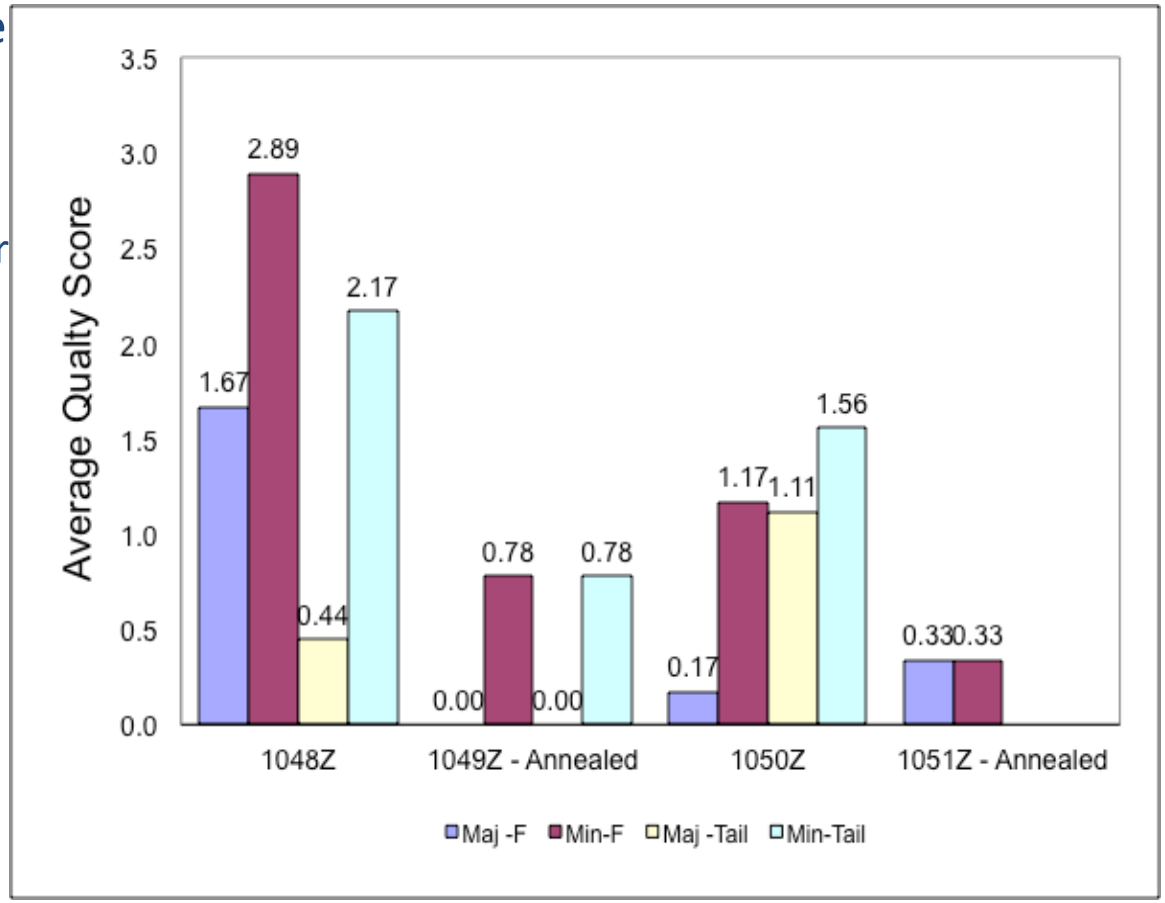
VERTICAL	Rotation (deg.)			Horizontal
Load (Kg)	0 kg	12.2 kg	24 kg	0 .
1048z (Un-annealed)	+40°	+60°	+80°	+50° (CW to 0°)
1049z (Annealed)	-10	5°	+25°	0°

Both seem to be acceptable for coil winding



Reasons to Anneal Wire

- LARP has prior experience with annealing cable and wire
- Cables with annealed wire appears to have less strand damage during cabling
  - Lower Quality Score (i.e. fewer sheared sub-elements)
- May provide a higher RRR at the edges of a cable
  - This has yet to be confirmed
- Cable is flatter
- Has less residual twist
- Could reduce dimensional changes of coil during heat treatment (HT)
- Permits smaller gaps in coil pole pieces prior to HT



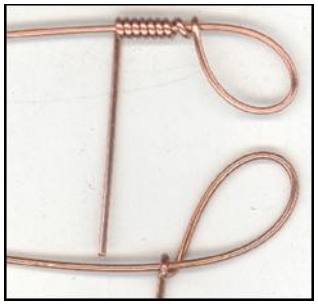
Summary

- For LARP no changes to cabling parameters are expected
  - Mid-thickness = 1.525 mm +/- 0.010 mm
  - Width = 18.15 mm +/- 0.050 mm
  - K.S. angle = 0.55 deg. +/- 0.10 deg.
  - Pitch Length = 109 mm +/- 3 mm
  - S.S. core = 12.0 mm nominal width
    - 0.025 mm thick
    - bias towards thick edge
  - Anneal wire at 170C for 15 hrs.
- Baseline cabling process uses annealed wire
- Extracted strands have good "quality" with the cable parameters listed above
- For RRP® 108/127 strand the RRR and I_c reduction measured in extracted strands is acceptable with these cable parameters
- LARP is still investigating the local RRR of extracted strands of RRP 132/169

The End

Risk of annealing wire

- Risk of annealing wire – It may become brittle
  - If temperature is too high or too long
- Strain in self bend test is 4 times greater than during cabling



RRP 108/127