MQXF RRP® Strand for Q1/Q3

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CERN

Outline

- Introduction
- RRP® Strand
- RRP® 108/127 Strand for MQXFS1
  - Design change for RRR Control
- RRP® 132/169 MQXF strand
- Present status of wire performance
  - Comparison of vendor and LARP data on Ic
  - Ic and RRR optimization
- Strand Magnetization
- Cable and Insulation
- RRR of Extracted strand
- Summary

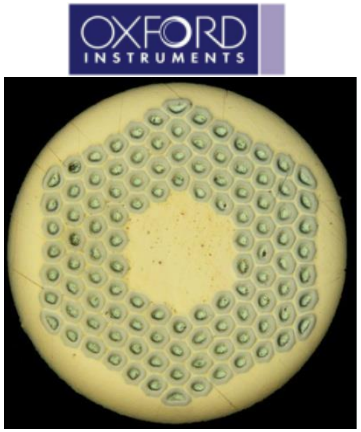
Introduction

For the MQXF Q1/Q3 Magnets we will most likely use RRP® wire from Oxford Superconducting Technology

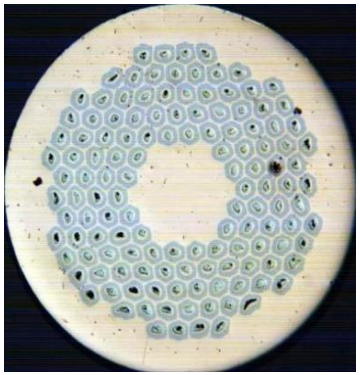
Strand diameter 0.85 mm

- Ti-Ternary Nb_3Sn

Cable is a 40- strand Rutherford Cable with stainless steel core

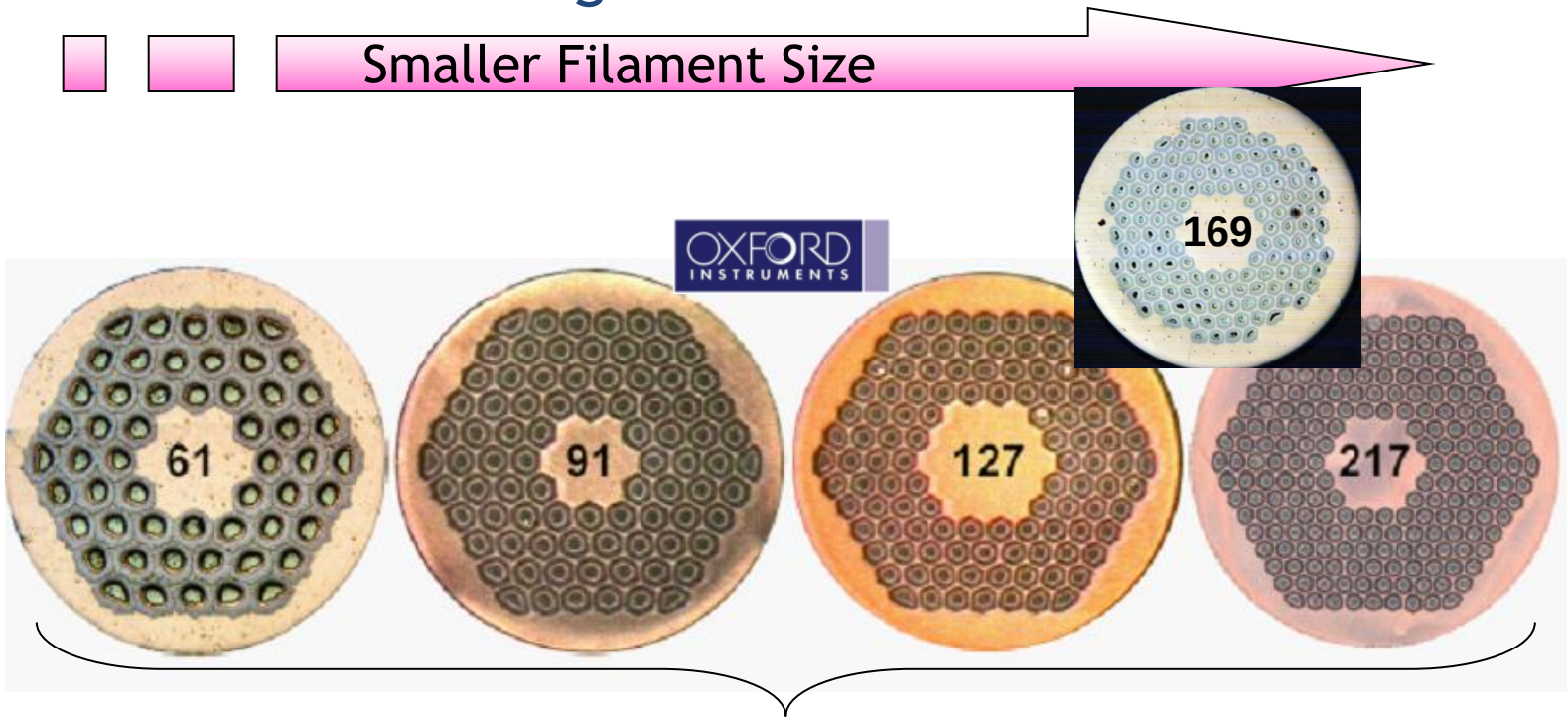


- The 1st Short model MQXFS1 magnet is using coils made with 108/127 strand.
- Subsequent Short model and Long prototype MQXF magnets will use 132/169 design wire (smaller filament diameter)



RRP® strands with smaller filaments

- Smaller sub-elements can minimize flux jumps and improve stability.
- Filament Magnetization decreases



Courtesy of Jeff Parrell (OST)

Sub-element (Filament) diameter D_s

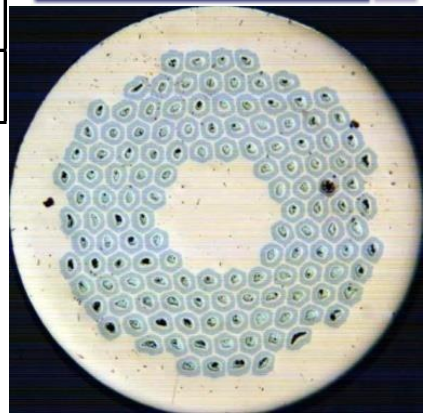
$$D_s = \frac{D_w}{\sqrt{N(1+R)}}$$

— R=Cu/Non-Cu=1.2 , 45.5% SC, 54.5 % Cu

Table of Sub-element diameter in μm

Strand Design	54/61	84/91	108/127	132/169	192/217
			# of Sub-elements		
D_w, mm	**54**	**84**	**108**	**132**	**192**
0.9	83	66	58	53	44
0.85	78	63	55	50	41
0.778	71	57	50	46	38
0.7	64	52	45	41	34

OXFORD INSTRUMENTS



➢ 0.85 mm strand with132 filaments *has the same sub-element size* as the 0.778 mm wire with 108 filaments that is used in HQ

Ti-Ternary 108/127 Strand Production

- From prior experience we found that RRR is not well controlled in the "standard" RRP-wire. (details in a later presentation by A. Ghosh and D. Dietderich)
- For the LARP order of 410 Kg which used 12 billets, OST introduced a small design change in the sub-element
  - This production was used to resolve RRR control
  - 6 billets use standard Tin content (Nb/Sn ratio=3.4)
  - 6 billets use 5%-Reduced Tin content (Nb/Sn ratio=3.6)
- Reduced Tin has significant impact on the RRR of the copper.
    - Side-effect: Marginal decrease in J_c.
- Piece lengths have been very good; some billets drew down in a single piece.

MQXF Strand Specification

Process	RRP® or PIT Nb3Sn
Strand Diameter, mm	0.850 ± .003
Ic(15 T) at 4.2 K, A	> 361
n-value	> 30
Ic(12 T) at 4.2 K, A (Reference Only)	(> 632)
Ds, µm (sub-element diameter)	< 50
Cu : Non-Cu volume Ratio	1.2 ± 0.1
RRR (after full reaction)	≥ 150
Twist Pitch, mm	19 ± 2
Twist Direction	Right-hand screw
Strand Spring Back, deg.	< 720
Magnetization Width at 3 T, 4.2 K, mT	< 300
Minimum Piece length, m	TBD for Q1/Q2/Q3

Specification for MQXF Strand LARP-M-8007 Rev.0

Process	Ti-Ternary RRP® Nb_3Sn
Strand Diameter, mm	0.850 ± .003
Ic(15 T) at 4.2 K, A	> 361
n-value	> 30
Ds, µm (sub-element diameter)	< 50
Cu : Non-Cu volume Ratio	1.2 ± 0.1
RRR (after full reaction)	≥ 150
Twist Pitch, mm	19 ± 2
Twist Direction	Right-hand screw
Strand Spring Back, deg.	< 720
Magnetization Width at 3 T, 4.2 K, mT	< 300
Minimum Piece length, m	550
High temperature HT duration, h	≥ 48

$J_c(15\ T) > 1400\ A/mm^2$

132/169

Nb/Sn ratio > 3.4 to meet RRR

RRP 132/169 strand for MQXF short model magnets

- LARP had an existing PO of 255 Kg (~55 km) for 108/127 under specification LARP-M-8004-Rev. B
- (

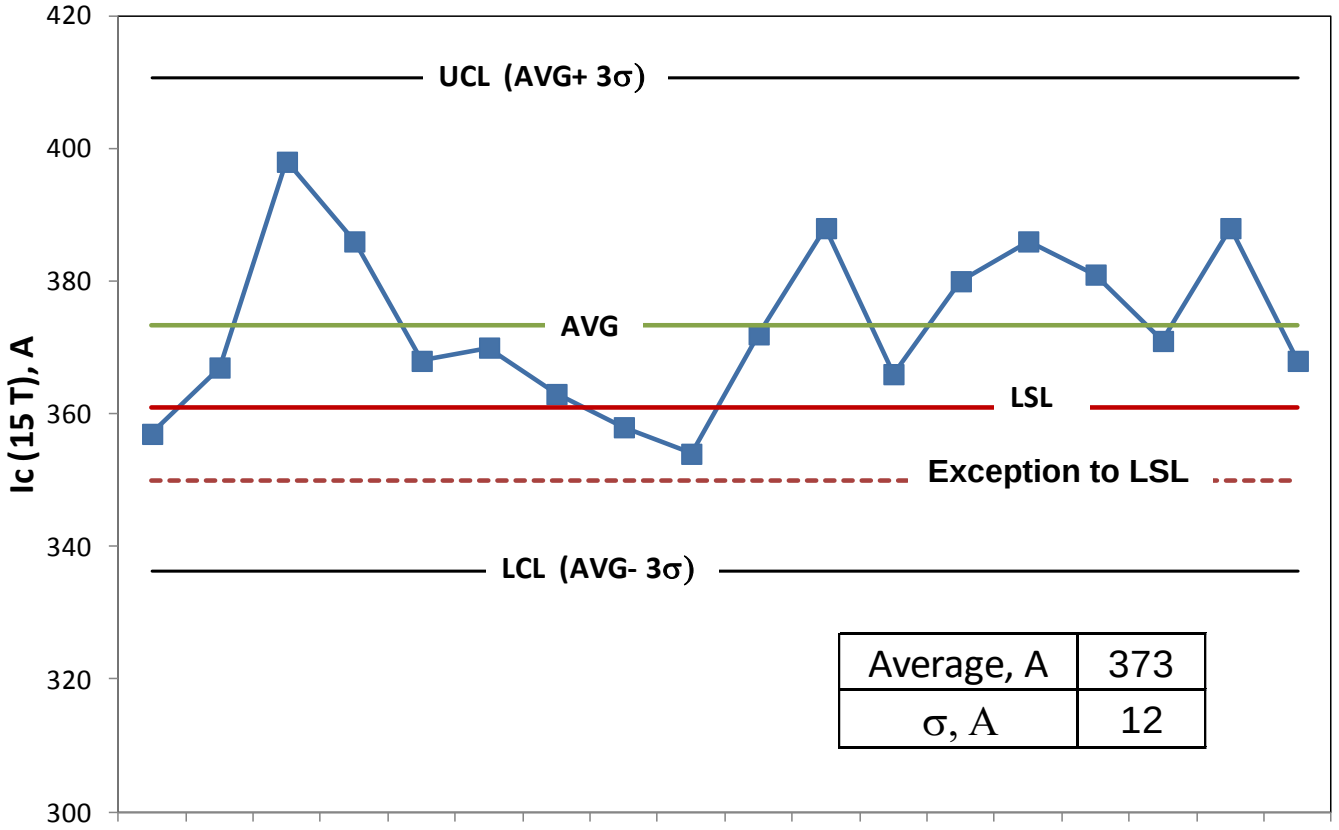
Process	Ti-Ternary RRP® Nb_3Sn
Strand Diameter, mm	0.85 ± .003
Ic(15 T) at 4.2 K, A	> 361
Ic(12 T) at 4.2 K, A	> 684
n-value	> 30
Ds, µm (sub-element diameter)	< 60
Cu : Non-Cu volume Ratio	> 1.1
RRR (after full reaction)	≥ 150
Twist Pitch, mm	14 ± 2
Twist Direction	Right-hand screw
Minimum Piece length, m	750
High temperature HT duration, h	≥ 48

Exception: I_c(15 T) > 350 A

RRP 132/169 strand for MQXF model magnets

- LARP had an existing PO of 255 Kg (~55 km) for 108/127 under specification LARP-M-8004-Rev. B
  - This was converted to 132/169- strand with “reduced-Sn”, using Nb Type-1.
  - Exception to I_c (15 T) specification: 350 A (compared to 361 A)
  - Strand qualified using HT schedule: 210C/48h + 400C/48h + 665C/50h
  - 9 billets were made
  - I_c, RRR and Cu/non-Cu measurements made at OST for samples taken from the front-end and back-end of each billet.
  - I_c and RRR measurements made at BNL using samples reacted with the same nominal HT schedule

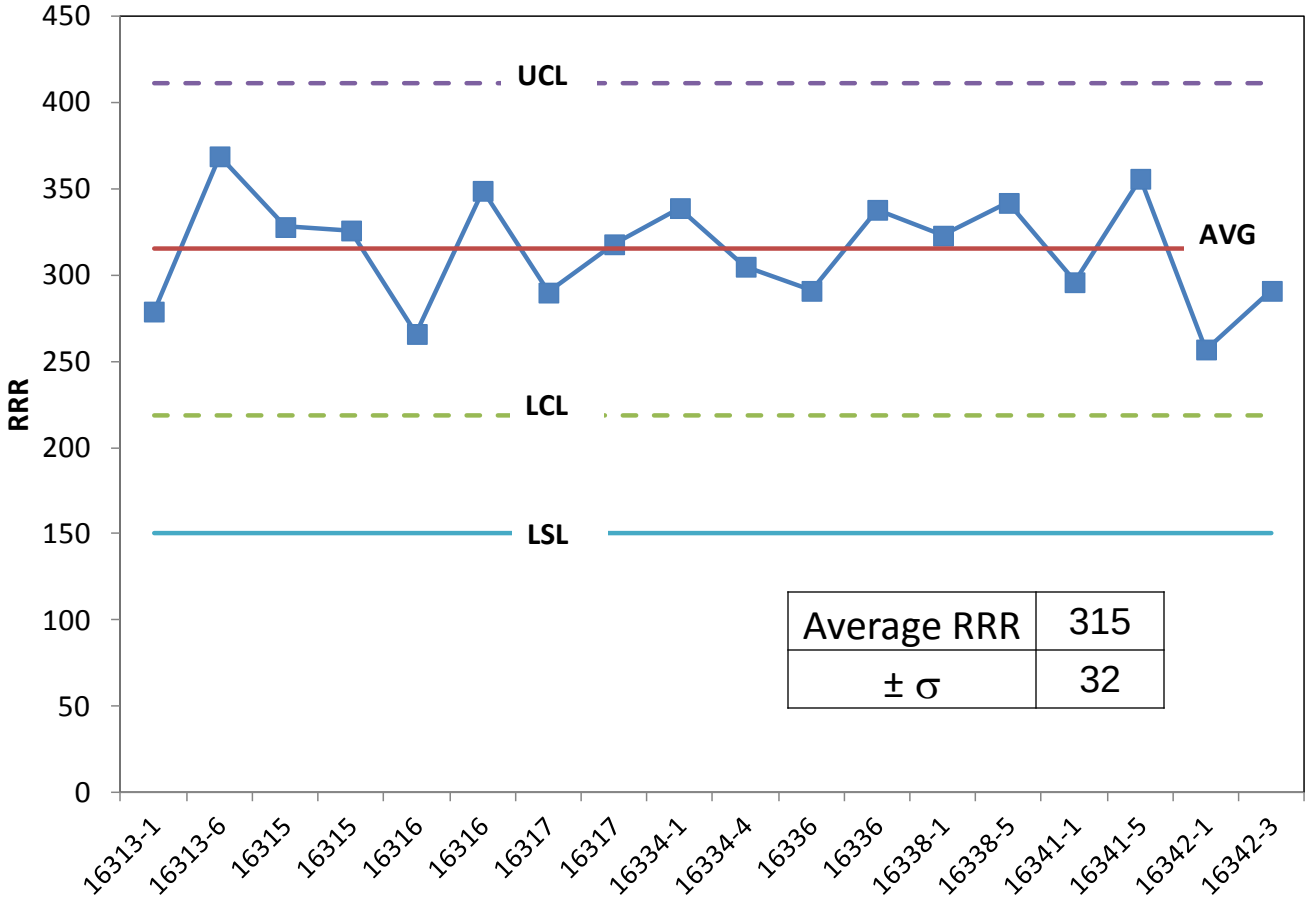
MQXF strand 132/169, “reduced-Sn”, OST data 210C/48h + 400C/48h + 665C/50h



UCL-Upper Control Limit
LCL – Lower control limit
LSL – Lower specification limit
AVG – Average
σ – Std. Dev

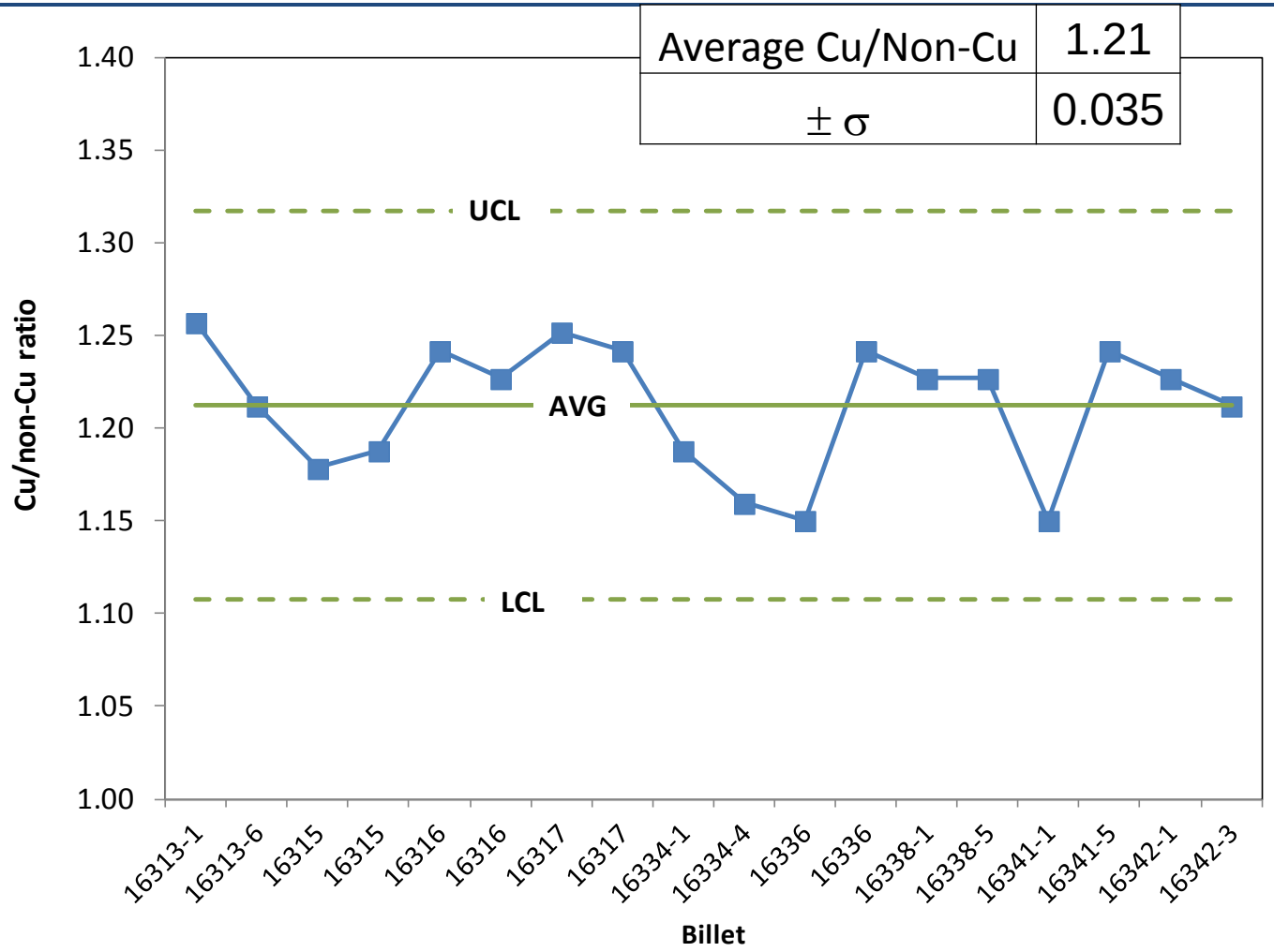
Ic-AVG needs to be increased in production to meet LSL of 361 A

RRR of the billets with the same HT



➢RRR is well above specification minimum of 150

Cu/Non-Cu ratio



Comparison of BNL and OST data

Samples were reacted and measured at each facility

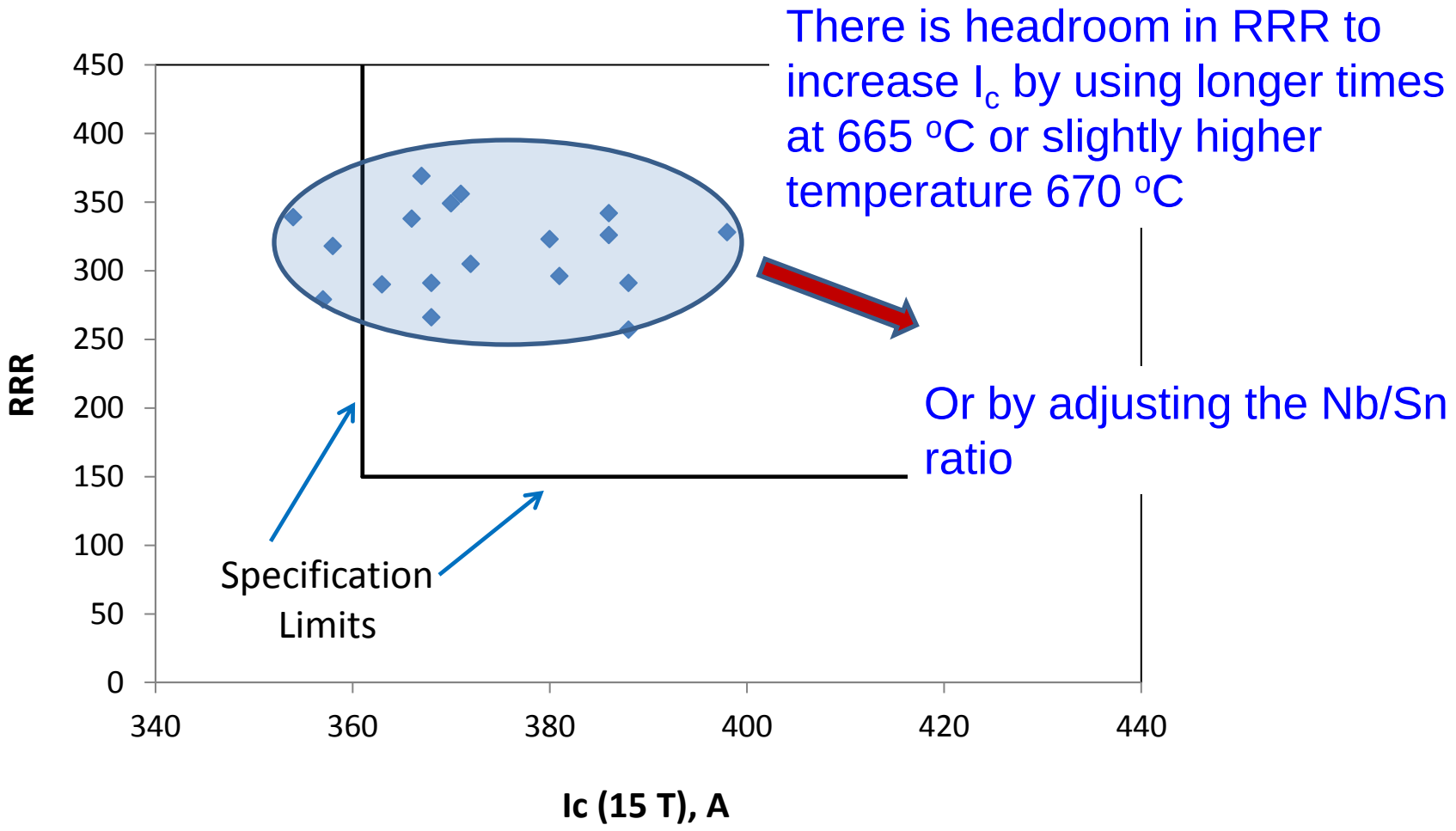
	I_c(15T) BNL	I_c(15T) OST	I_c(12T) BNL	I_c(12T) OST	**I_c(15T)_OST/ I_c(15T)_BNL**	I_c(12T)_OST/ I_c(12T)_BNL	RRR BNL	RRR OST
Average	374	370	692	687	**99.0%**	99.3%	288	315
σ	15	15	19	20	**1.0%**	1.0%	38	32

OST and LARP measurements are very consistent

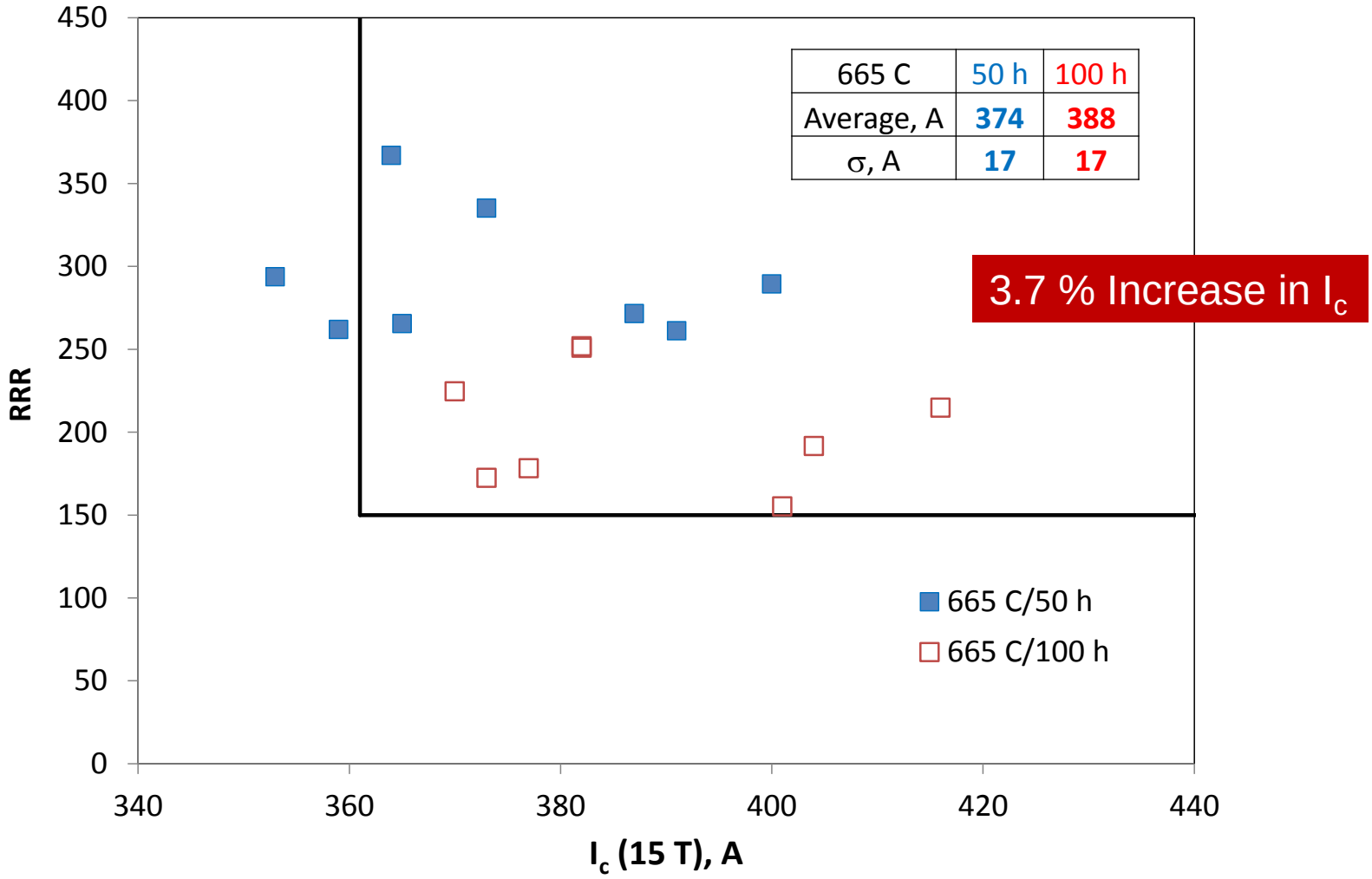
Round Robin Test of samples reacted at BNL

H, T	Ic_OST	Ic_BNL	n_OST	n_BNL
11.0		819		52
12.0	681	678	50	46
13.0	557	558	48	46
14.0	447	450	46	41
15.0	352	355	44	35
16.0	269		34	

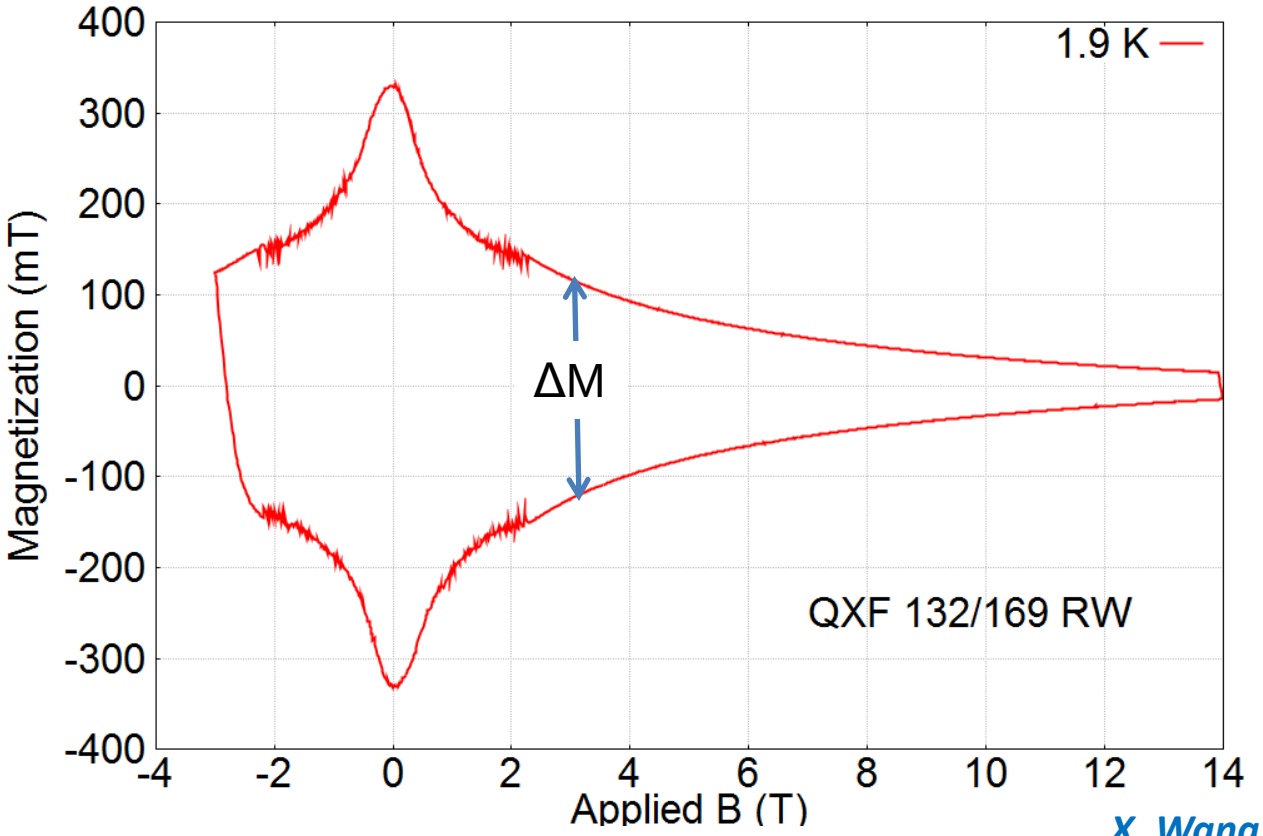
Optimizing 132/169 for MQXF



Longer times at 665 °C



Magnetization of MQXF 132/169



X. Wang

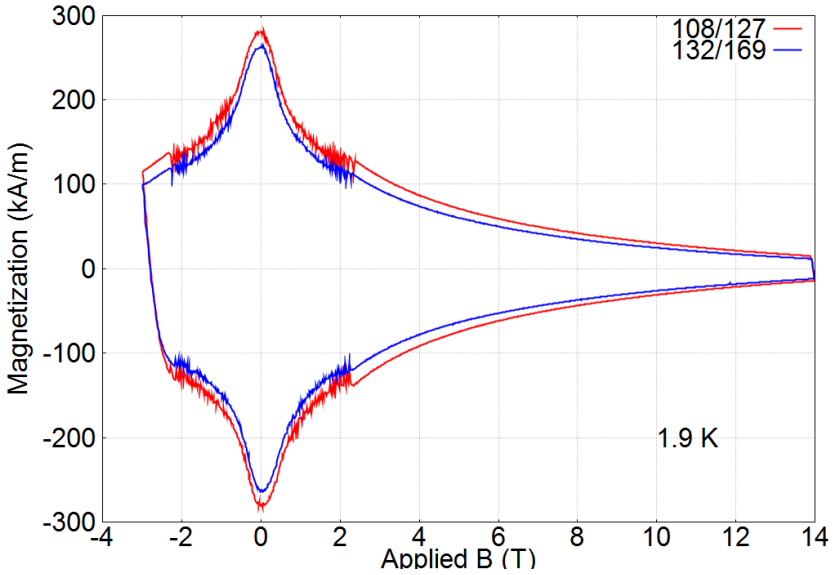
Measurements performed at OSU

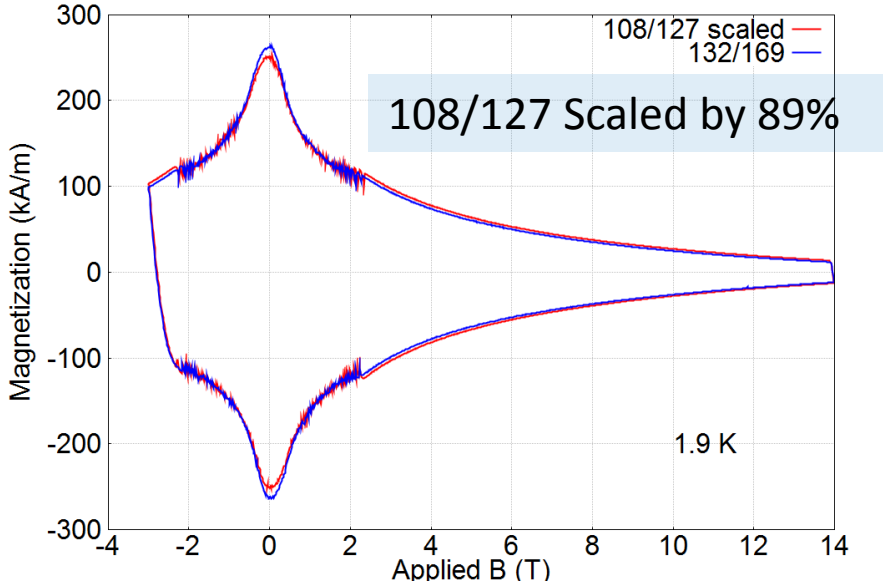
By M. Sumption and X. Xu

- ΔM = 238 mT at 3 T, 1.9 K
- ΔM expected to be ~ 200 mT at 3 T, 4.5 K

Magnetization of 0.85 mm,108/127 and 132/169 at 1.9 K

Strands have same J_c and Cu/Non-Cu ratio





- Magnetization scales with filament diameter

X. Wang

Measurements performed at OSU

By M. Sumption and X. Xu

Cable Insulation at LARP

- Insulation is braided directly on cable
  - New England Wire Technology (NEWT)
- Using S-2® glass (from AGY) with 933 Silane sizing
  - 48 carriers
  - 2 ply yarn, twist pitch 75 mm
- Several lengths of QXF cable has been insulated
  - Using braiding parameters to yield target specification of 0.145 ± 0.005 mm thickness
  - 10-stack measurements at 5 MPa are used to determine insulation thickness

Each Cable length ~ 170 m	Measurement at 5 MPa		
~170 m		mm	
Cable ID	Ist Cycle	2nd Cycle	3rd Cycle
1050Z	0.142	0.140	0.140
1051Z	0.143	0.140	0.138
1053Z	0.154	0.149	0.147
1055Z	0.148	0.145	0.143
1057Z-A	0.149	0.146	0.145
1057Z-B	0.149	0.146	0.145

  - Thickness can be readily adjusted to meet any change to present specification.

Summary

- The "reduced-Sn" design change increases RRR manufacturing margin with minimal loss of J_c.
  - Implemented for all billets in process and future procurements.
- RRP® 132/169 wire can meet strand specs
  - Manufacturing margin in I_c needs to be increased by good control of the Nb/Sn ratio, and by reaction optimization
- LARP plan implements 132/169-strand in MQXFS2 magnet and all MQXFL prototypes.
- Strand procurement has been planned to meet cable manufacture and coil winding schedule. (Later Presentation)
- Specification and Production QA plan and documents is being finalized this fiscal year for pre-production lots and preparing for issuing call for RFP(Request For Proposal) for the production.

End of Presentation