Technology Quadrupole Series (TQ)

LARPAC Review

May 10-12, 2006

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LARP

Outline

1. LARP Magnet R&D plan
2. TQ objectives, FY06 budget
3. Conductor and magnetic design
4. Coil fabrication experience
5. TQS and TQC mechanical designs:
   - *Design concept*
   - *FEA Analysis*
   - *Mechanical models*
6. TQS01 assembly and test
7. Comparison TQ-SQ results
8. Updated TQ plan for FY06-07
9. Summary

LARP Magnet Program Goals

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FY09 Milestone:

Demonstrate viability of Nb_3Sn technology for "Quad-first" option

1. Capability to deliver predictable, reproducible performance:

TQ (Technology Quads, 2005-07) D = 90 mm, L = 1 m, G_{nom} > 200 T/m

2. Capability to scale-up the magnet length:

LQ (Long Quadrupoles, 2008-09) D = 90 mm, L = 4 m, G_{nom} > 200 T/m

3. Capability to reach high gradient (pole tip field) in large aperture:

HQ (High Gradient Quads, 2008-09) D = 90 mm, L = 1 m, G_{nom} > 250 T/m

Magnet R&D Plan

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Oct 25, 2005	Type	Length [m]	Gradient [T/m]	Aperture [mm]	FY05	FY06	FY07	FY08	FY09
MODEL MAGNETS									
Technology Quad (TQ)	cos(2θ)	1	> 200	90		3N+1R	2N+1R		
Long Quad (LQ)	cos(2θ)	4	> 200	90				1N	1N
High Gradient Quad (HQ)	cos(2θ)	1	> 250	90					2N
SUPPORTING R&D			**Peak Field** [T]						
Sub-scale Quad (SQ)	block	0.3	10-11	110	1N+1R	1N+1R	1N+1R	1N	
Short Racetrack (SR)	block	0.3	10-12	N/A		1N	1N	1N	
Long Racetrack (LR)	block	4	10-12	N/A			2N+1R		

N = New magnet

R = Revised magnet using existing coils

FY06 Budget		FNAL	LBNL	Total
Model Magnet R&D	Sabbi	1334	1063	2397
Technology Quad (Shell)	Caspi	210	718	928
Technology Quad (Collar)	Bossert	1087	295	1382
Coil-Structure Exchange	Ferracin	37	50	87

Technology Quads (TQ)

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Objective: develop the technology base, in preparation for LQ & HQ:

- evaluate conductor and cable performance
- develop and select coil fabrication procedures
- compare mechanical design concepts and support structures
- ***demonstrate predictable and reproducible performance***

Implementation: two series, same coil design, different structures:

- TQC models: collar-based structure
- TQS models: shell-based structure

Magnet parameters:

- 1 m length, 90 mm aperture, 11-13 T coil peak field
- Nominal gradient 200 T/m; maximum gradient 215-265 T/m

Magnetic Design

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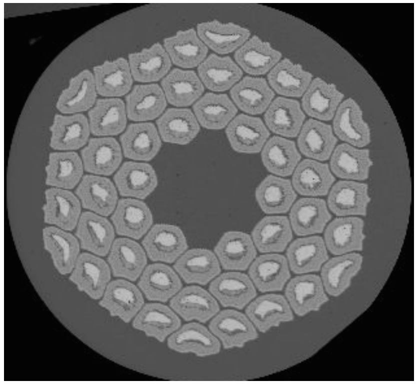
Strand:

- OST-MJR, 0.7 mm diameter
- $J_c = 2$ kA/mm^2 (12 T, 4.2 K)
- $I_s > 1$ kA w/optimized HT



MJR strand:

- same strand for both models
- 70 kg borrowed from FNAL
- extensive characterization
  - HT studies
  - Cabling studies
- validation in SQ02 magnet

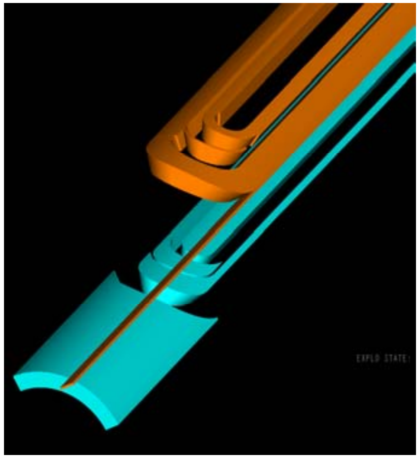
Cable:

- 27-strand, 10.05 mm width
- Mid-thickness: 1.26 mm
- Keystone angle: 1.0 deg
- Insulation: S-2 glass sleeve

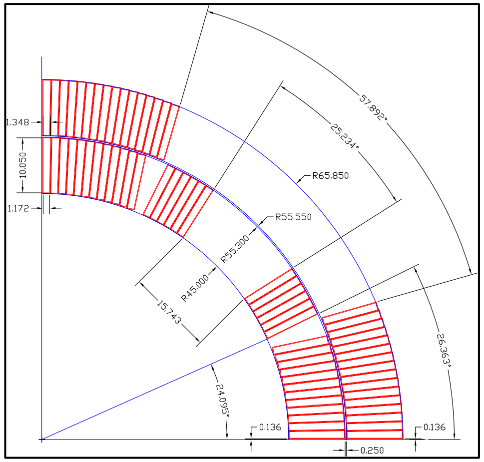
Coil:

- double-layer, shell-type
- one wedge/octant (inner layer)

Coil end (inner layer)



Coil cross-section



Gradient and Coil Field

"MJR" strand

$J_c = 2\ kA/mm^2$ (12 T, 4.2 K)

Magnet	T_{op} [K]	G_{ss} [T/m]	$B_{ss}^{(body)}$ [T]	I_{ss} [kA]
TQS01	4.2	222	11.4	12.5
	1.9	239	12.3	13.6
TQC01	4.2	215	11.2	13.0
	1.9	233	12.1	14.1

"RRP" strand

$J_c = 3\ kA/mm^2$ (12 T, 4.2 K)

Magnet	T_{op} [K]	G_{ss} [T/m]	$B_{ss}^{(body)}$ [T]	I_{ss} [kA]
TQS	4.2	245	12.6	13.9
	1.9	264	13.5	15.1
TQC	4.2	239	12.4	14.4
	1.9	255	13.2	15.5

Coil Production Strategy

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FNAL: Winding and curing of all production coils (TQS & TQC)
LBNL: Reaction and potting of all production coils (TQS & TQC)

Motivations:

1) Efficient use of the **available resources**
2) Ensure **uniformity of coil fabrication** for both magnets
3) **Program and team integration**

Results:

- *Coil production strategy was successful*
- *Coils can be transported without damage*
- *TQ01 plan included 4 practice, 8 production and 2 spare coils*
- *We plan to continue with the next set of 10 coils for TQ02*

Coil tooling was designed by FNAL and optimized w/LBNL feedback
Detailed Coil Production Travelers have been developed and updated

Practice Coil Experience

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Goals:
1. Check/optimize *cable, insulation, end parts, tooling etc.*
2. Check/optimize *fabrication steps*, develop procedures/travelers
3. Used in mechanical models to provide *input for magnet assembly*
4. Used to *assess readiness to proceed* with production coils

Issues encountered during practice coil fabrication:

Area:	Issue:	Response:
Parts	Difficult to insert end spacers	Added central cut to increase flexibility
Winding	Instances of de-cabling	Modified cable path (reel to coil)
Curing	Cable damage at ramp	Designed/procured modified tooling
Reaction	Tin leakage in PC#2	Cable damage; adjust HT schedule

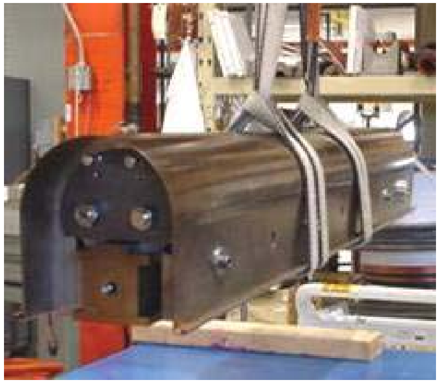
- *Practice coils are a required step for developing new, complex Nb_3Sn coils*
- *Validation goal requires iterations – increased number of practice coils to 4*
- *Spare coils included in TQ model plan provide additional risk mitigation*

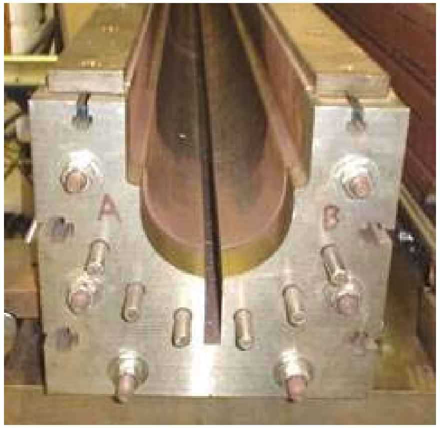
Coil Fabrication: Winding

- Pole cut makes end parts more flexible to facilitate insertion during winding
- Optimized cable tension, tensioner path and added twist to avoid de-cabling

Coil Fabrication: Curing

- Ceramic binder injected after layer winding and cured (150C, 30 min) at ~35 MPa
- Coils are curing after winding first layer, then again with both layers
- Sets the coil size for reaction, facilitates coil winding and handling

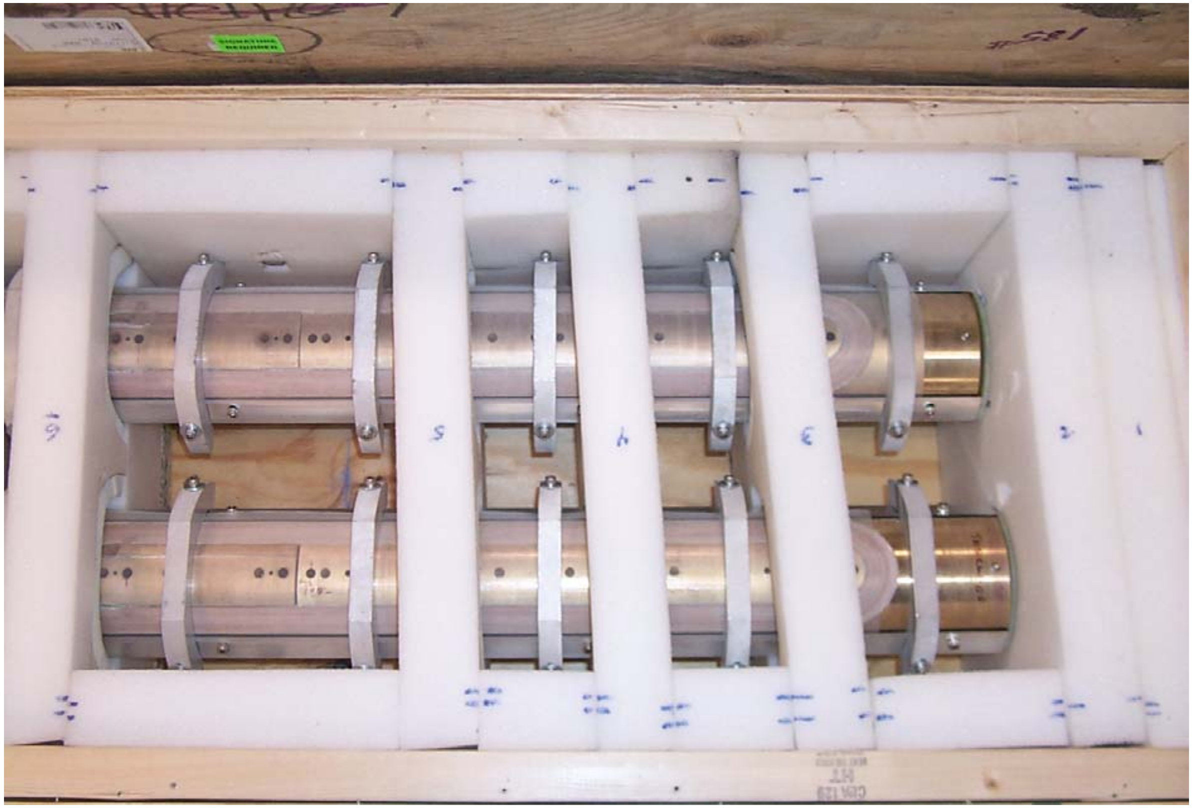




Coil Shipping

Coil shipping was accomplished without damage to the coils:

- 6 pairs of wound/cured coils (12 coils)
- 4 pairs of reacted/potted coils (8 coils)

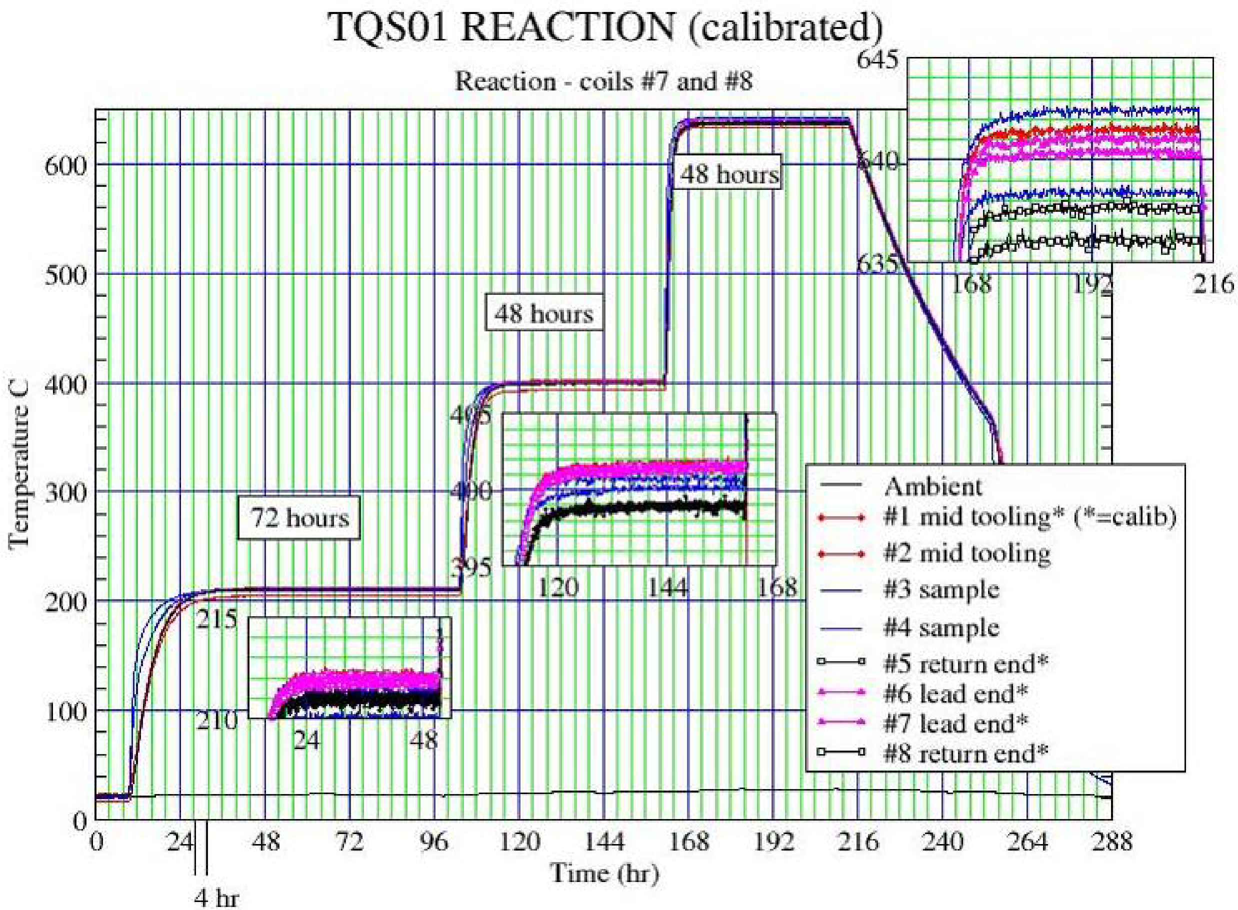


Preparations for Reaction

- Two coils are reacted (and potted) at the same time using modular tooling
- Thermo-couples are placed in the tooling next to the coils

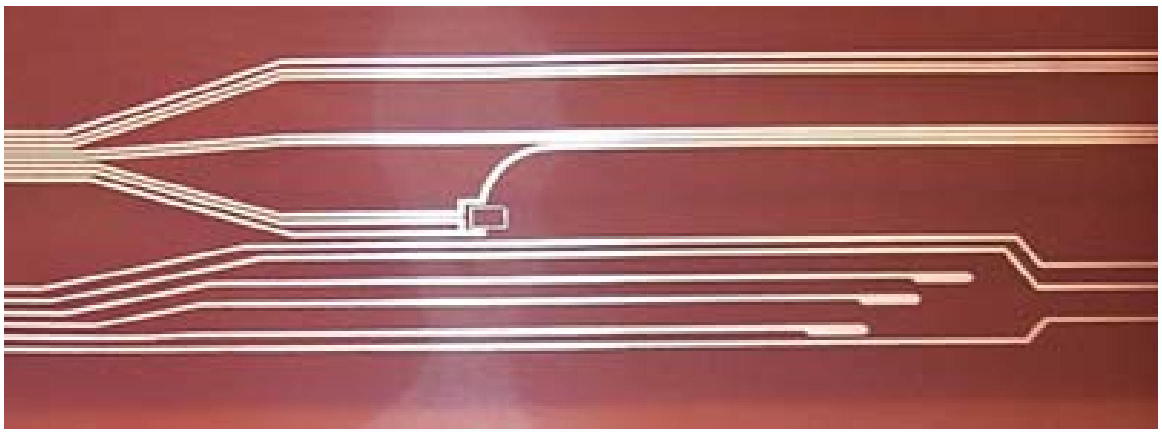
Reaction Cycle

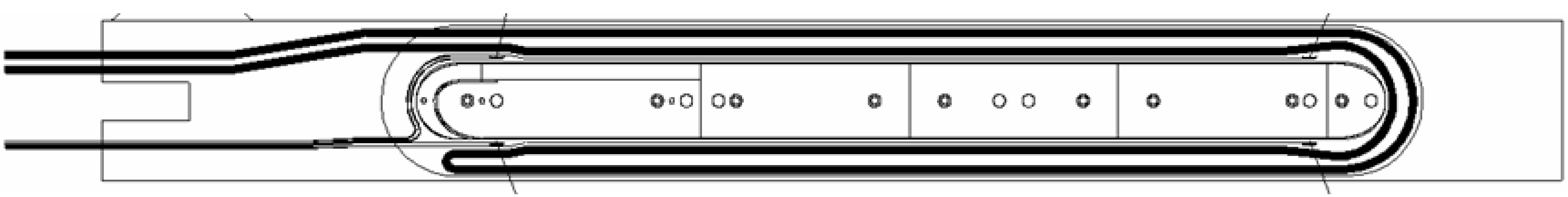
- Reaction cycle was optimized using practice coils to match recommended schedule
- Good homogeneity inside tooling, but different temperatures and times outside



Post-Reaction, Instrumentation Trace

- Traces incorporating heaters, V-taps, strain gauges adopted for both TQS and TQC
- Coil instrumentation is similar for both magnets, but some differences exist



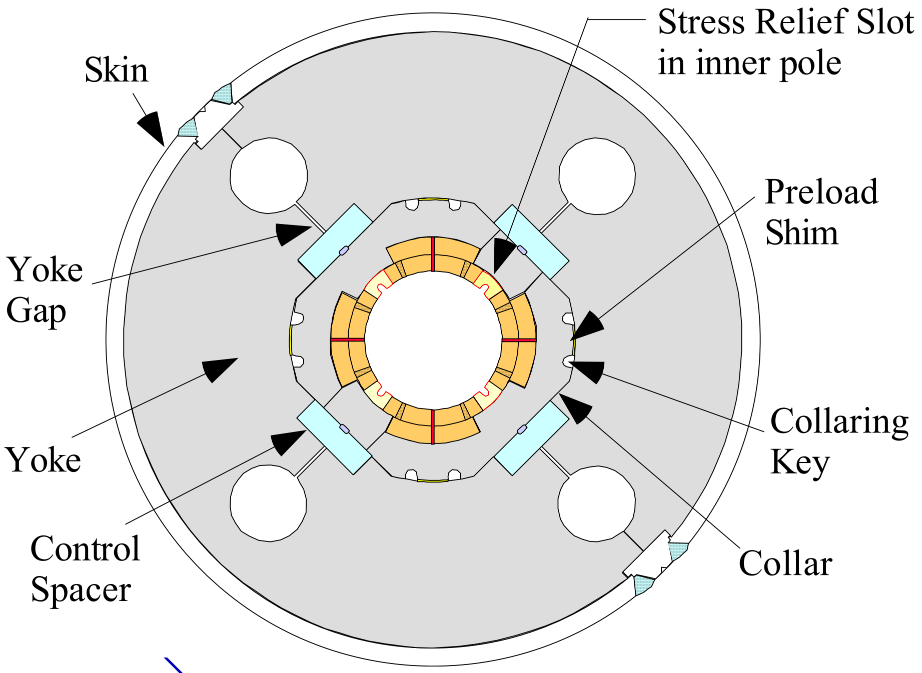


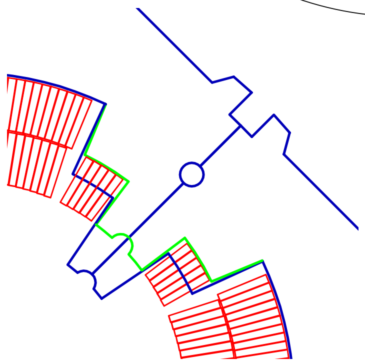
Final Step: Impregnation

- Ceramic ground insulation layers replaced with glass after first pair of coils

"The best looking coils we ever made!"

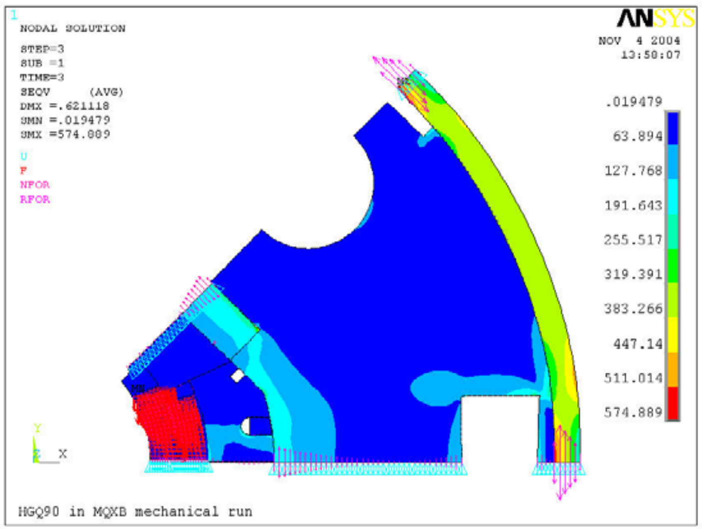
Mechanical Structures: TQC

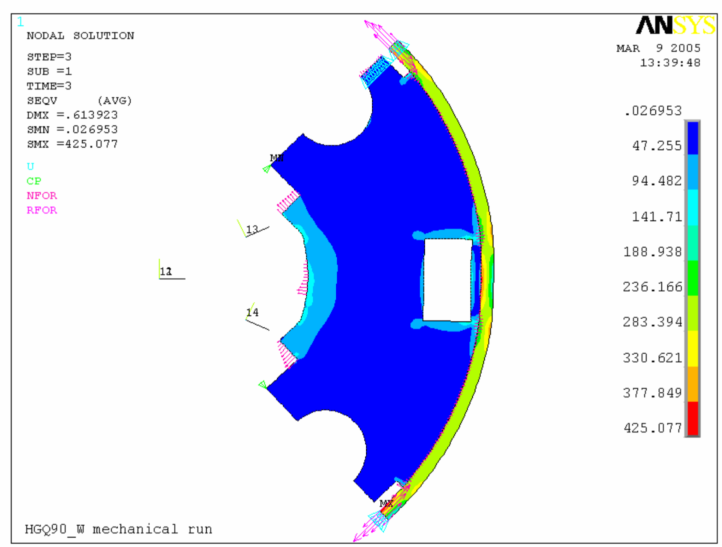


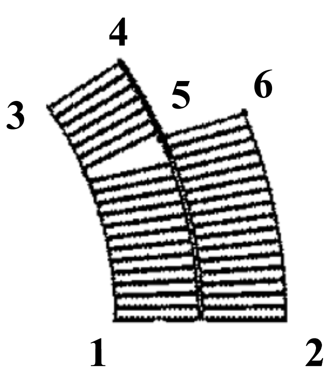


- **A radial cut is made in each yoke quadrant to provide symmetrical loading to the collars.**
- **Control spacers are introduced for collared coil alignment and yoke motion control.**
- **12 mm thick stainless steel skin, increased from 8mm used for MQXB.**
- **Mechanical structure and coil pre-stress is studied and optimized using a series of mechanical models.**

TQC 2D Mechanical Analysis

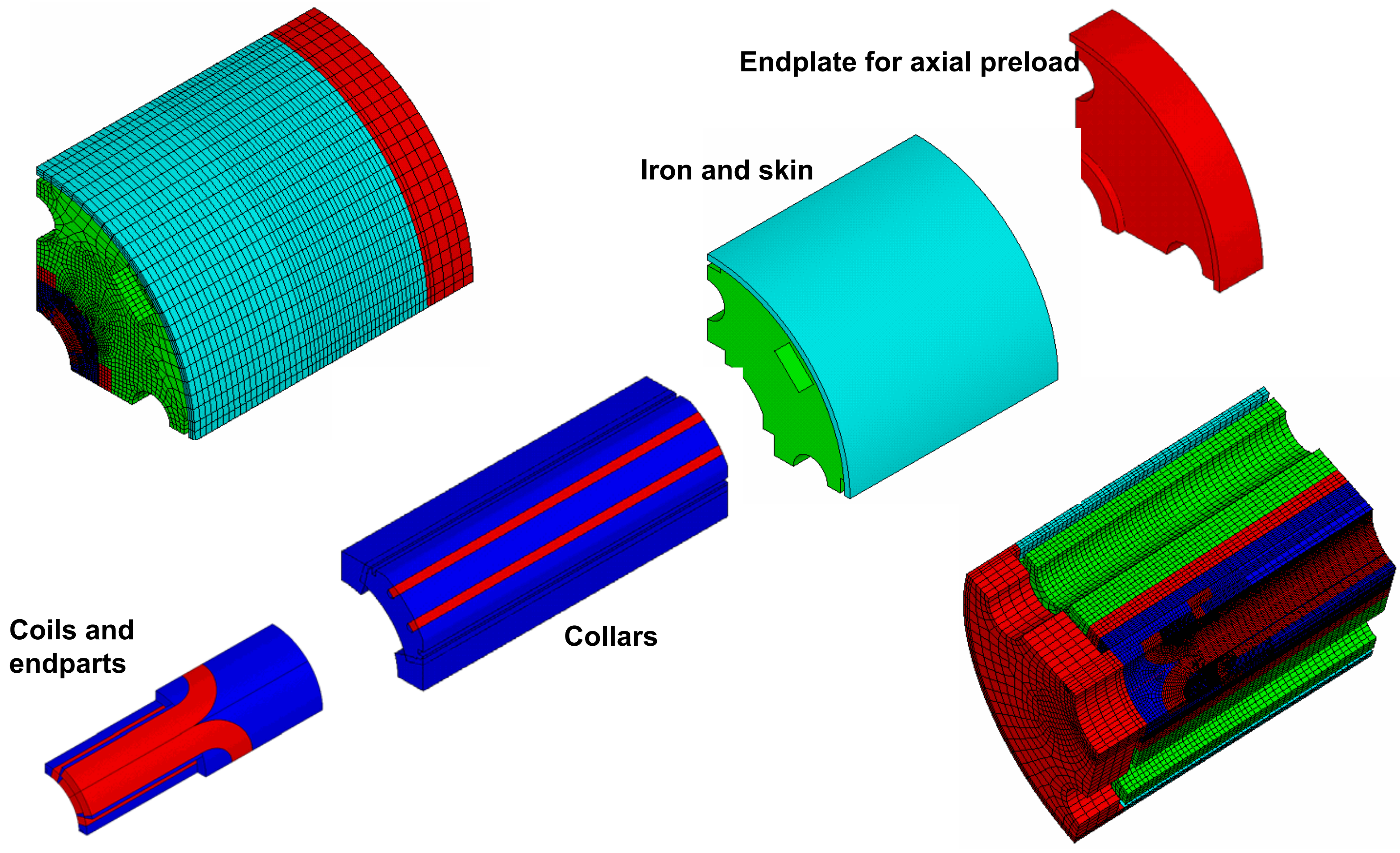






	Max/Min Coil Stress	At Coil Pos. No.	Pole Insert	Control Spacer	Collar	Yoke	Skin 8mm	Skin 12mm
300K	140/65	3/1&2	250	50	420	170	230	150
4.3K	150/80	3/1&2	230	150	470	270	400	270
Bmax	145/20	2/3	50	50	460	280	450	300

TQC 3D Mechanical FEA



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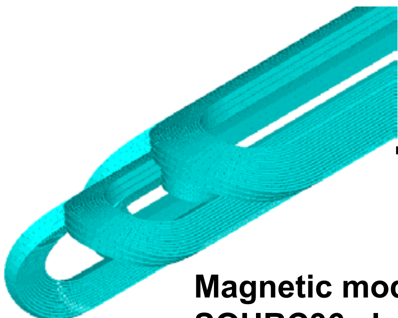
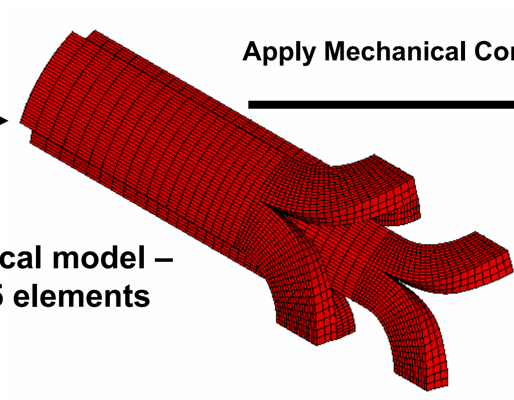
TQC 3D Analysis Techniques

Magnetic forces:



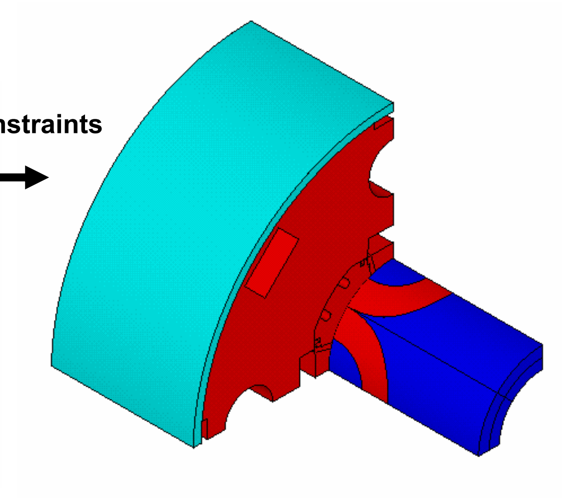
Magnetic model – SOURC36 elements

Calculate Lorentz Forces for structural coil mesh

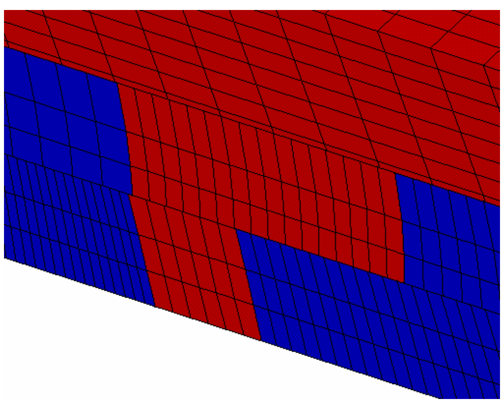


Mechanical model – SOLID45 elements

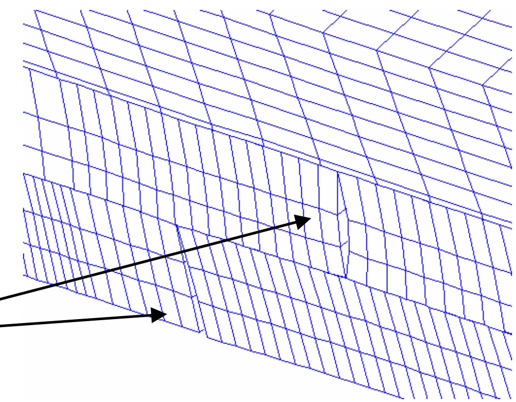
Apply Mechanical Constraints



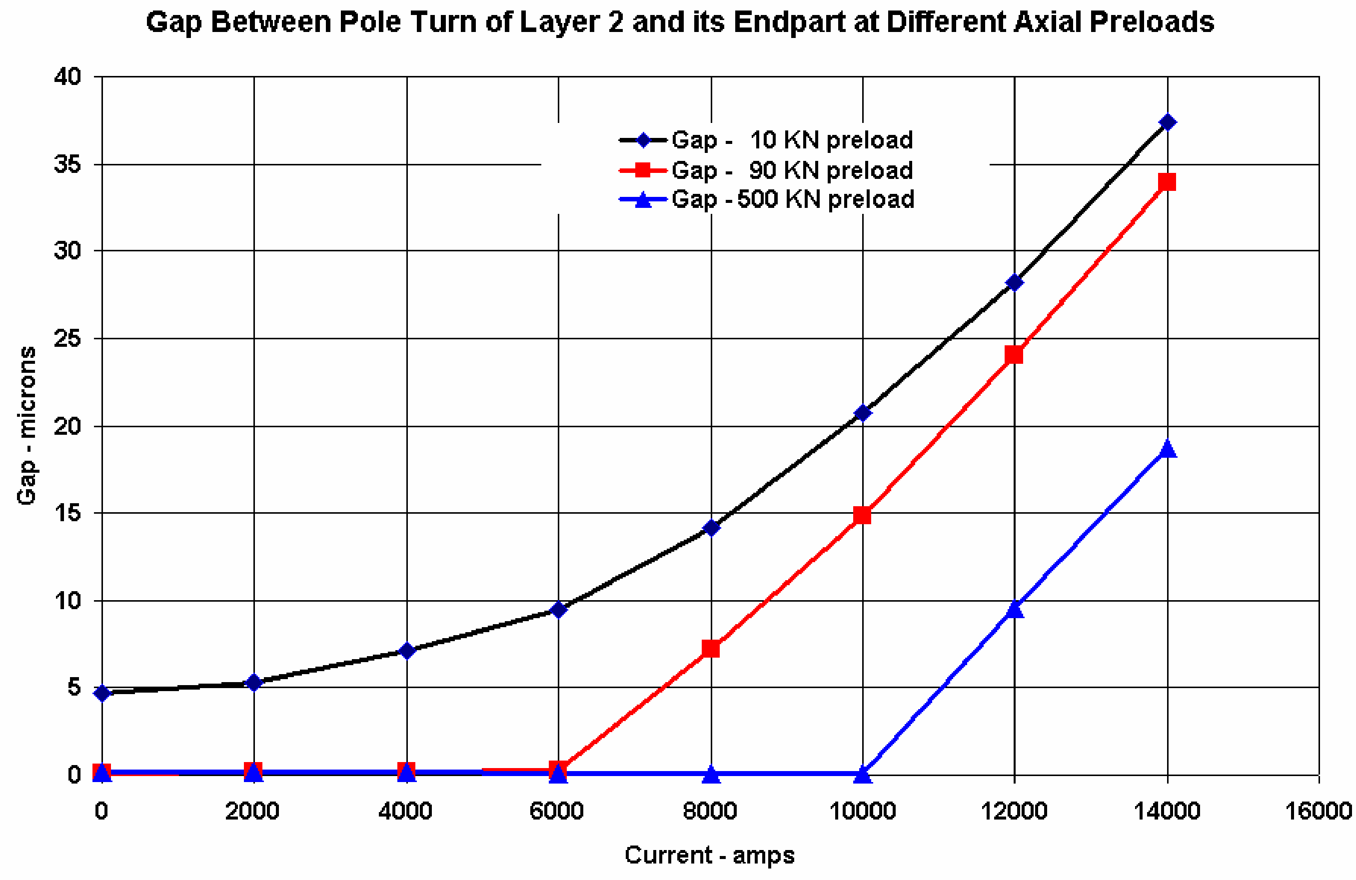
Epoxy bonding:



- The coils and parts are initially bonded
- Bonded interface releases for tensile stress beyond 30 MPa
- Interface elements with stresses above σ_t are removed allowing surfaces to separate



3D Analysis: effect of axial pre-load



Calculated effect is strongly dependent on collar and iron axial stiffness, and slip-or-stick assumptions at collar/iron/skin interfaces

Shell-based Structure (TQS Models)

Concept:

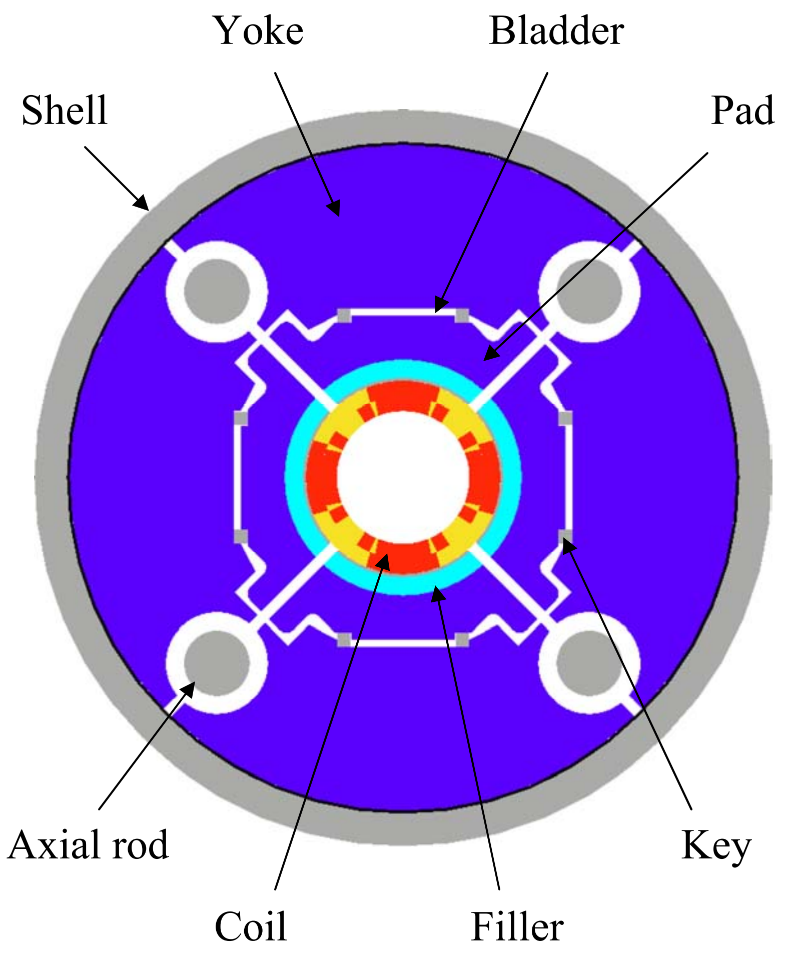
- Aluminum shell over yoke and pads
- Assembly based on bladders and keys

Advantages:

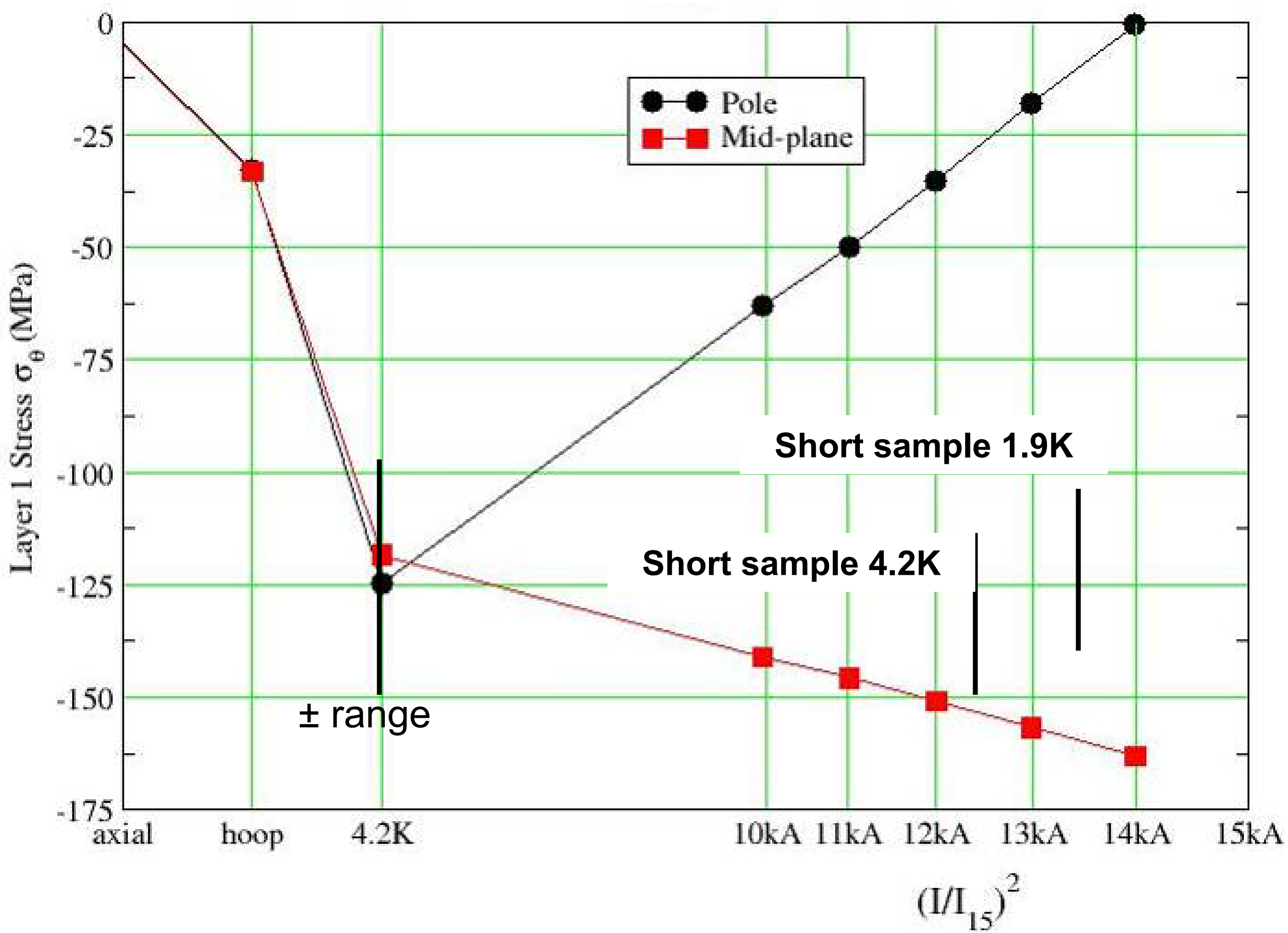
- Can deliver very high pre-stress
- Large pre-stress increase at cool-down
- Easily adjustable

R&D issues:

- Coil alignment accuracy
- Length scale-up



Stress at assembly, cool-down, excitation



TQS 2D FEA

<u>After cool-down</u>:

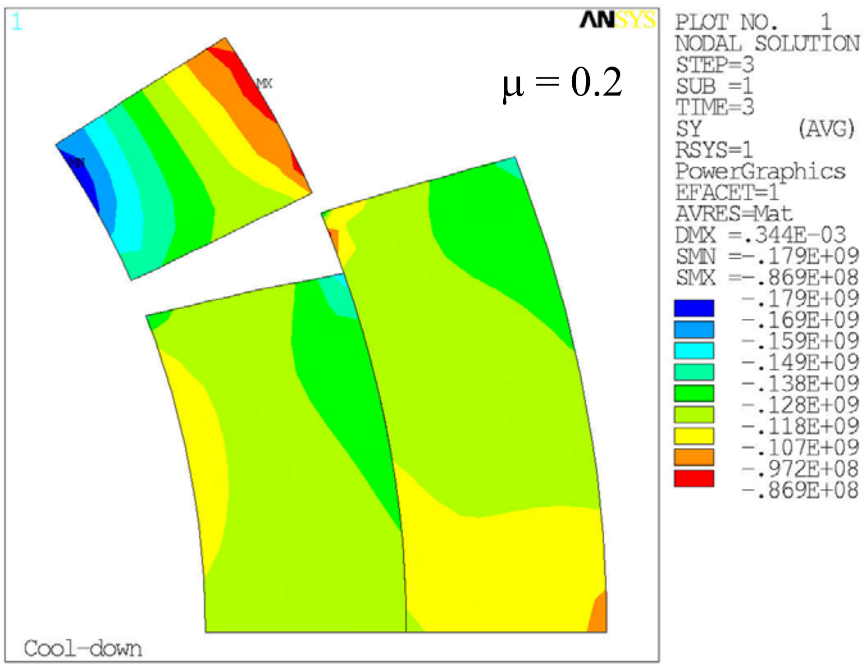
Peak stress: 179 MPa

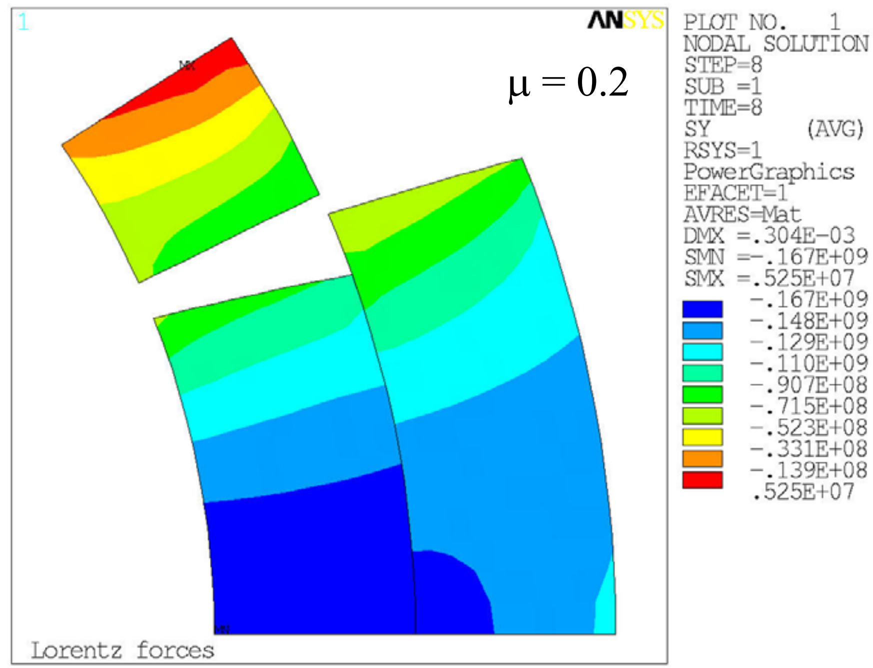
Mid-plane stress: 120-115 MPa

<u>At short sample</u> (1.9K, 13.5 kA):

Peak stress: 167 MPa

Mid-plane stress: 160-145 MPa

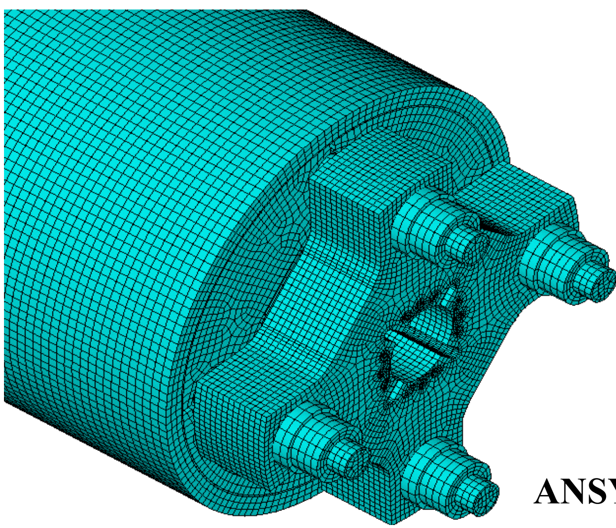




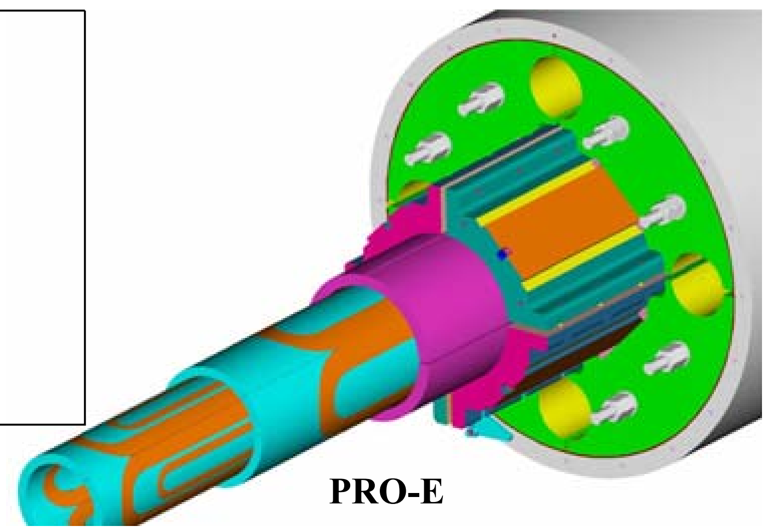
TQS 3D FEA

- Integrated use of CAD, mechanical and electro-magnetic packages
- Studies of the effect of friction among interfaces (coil-pads, yoke-shell) or glued
- Coil models using either "blocked" turns or individual turns

		Layer 1	Layer 2
Lorentz stress (θ)	MPa	- 123 (- 144)	- 83 (- 97)
F_z (aperture)	kN	+ 95 (+ 112)	+ 255 (+ 301)
Lorentz stress (z)	MPa	+ 41 (+ 49)	+ 127 (+ 150)



ANSYS **TOSCA**



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TQS 3D FEA: Lorentz forces

1. ANSYS

    x, y, and *z* coordinates of each coil element center

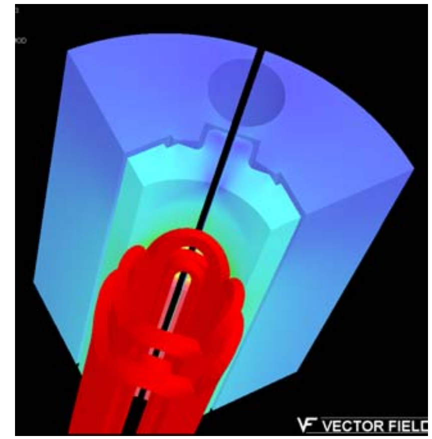
2. OPERA

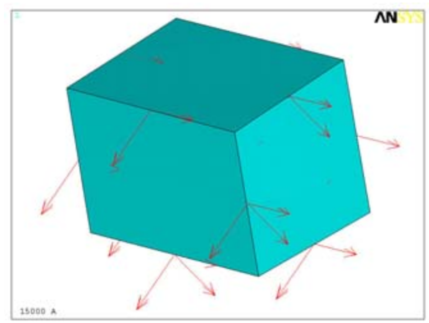
    Computation of J x B (N/mm^3) at each *x, y,* and *z* coordinate

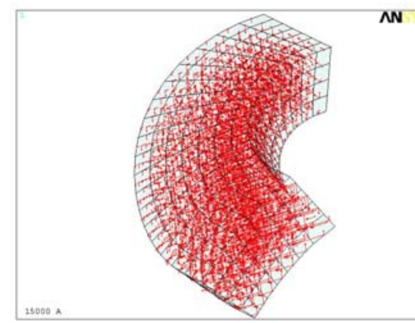
3. ANSYS

    Computation of J x B · V_{el} (N)

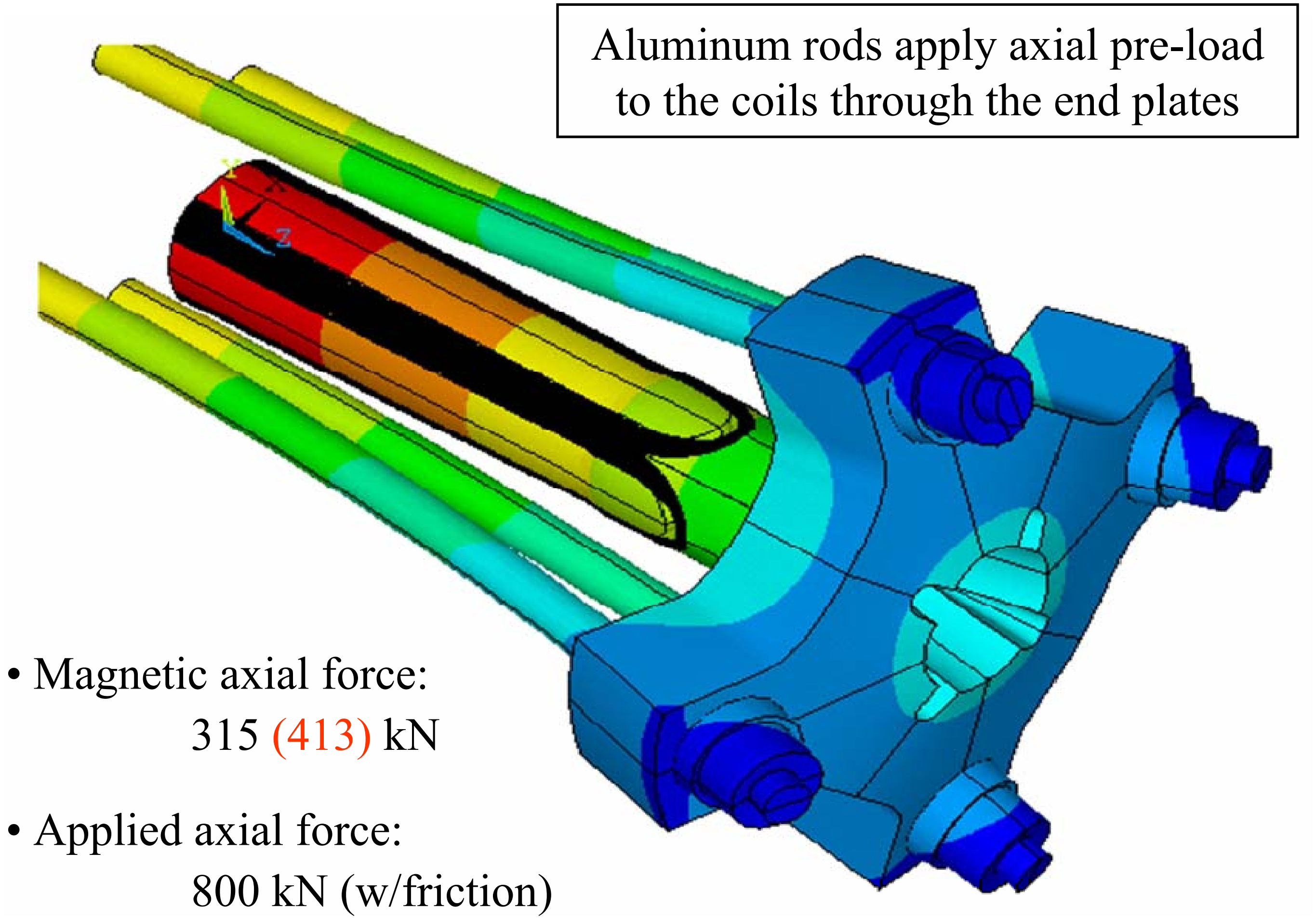
    Final force applied to each coil node







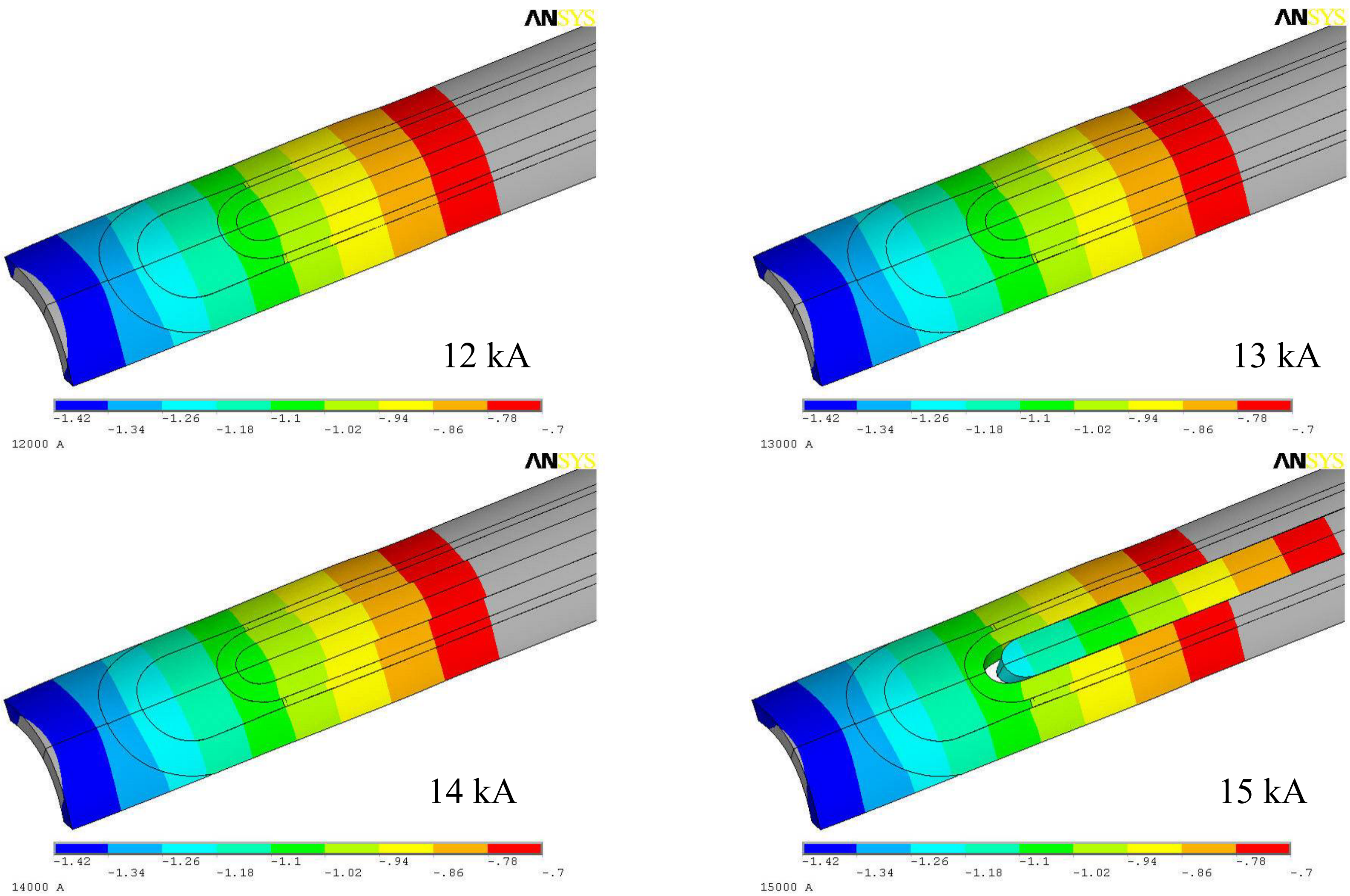
TQS Axial Support



Aluminum rods apply axial pre-load to the coils through the end plates

- Magnetic axial force:
  315 (413) kN
- Applied axial force:
  800 kN (w/friction)

3D Analysis of Pole Area



Material Properties Comparison

TQS	Elastic modulus @ 293 K (GPa)	Elastic modulus @ 4.3 K (GPa)	$\alpha \cdot \Delta T$ (293 K – 4.3 K)
Aluminum bronze	110	120	$3.12 \cdot 10^{-3}$
Stainless steel	193	210	$2.84 \cdot 10^{-3}$
Iron	213	224	$1.97 \cdot 10^{-3}$
Aluminum	70	79	$4.19 \cdot 10^{-3}$
Coil (3D, r, z, ϑ)	45	45	$3.35 \cdot 10^{-3}$

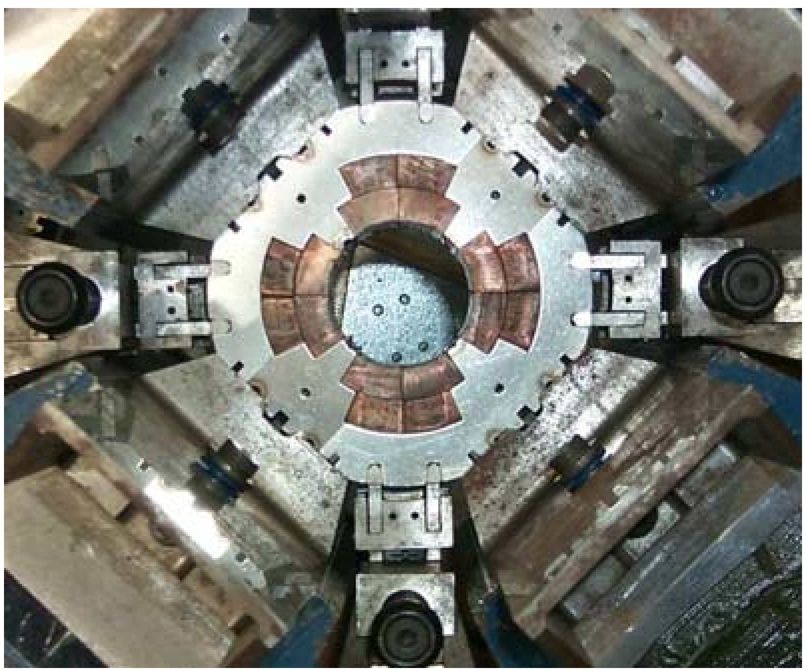
TQC	Young's Modulus – Gpa @293k (@4.3K)	Integrated Thermal Contraction from 293K to 4.3K, DL/L (x 10^{-3})
Radial	44 (55)	2.6
Azimuthal	44 (44)	3.5
Axial	44 (44)	2.3

Some differences in coil properties still need to be resolved

TQC Assembly Procedure

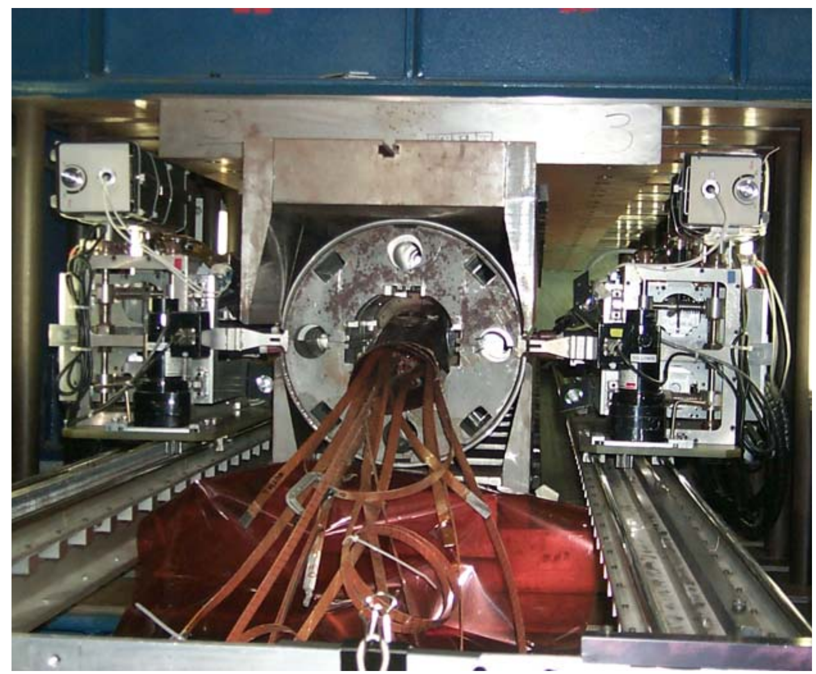
Collaring:

• Collars keyed in 8 cm. longitudinal sections
• Coil pre-load: 70MPa after keying complete
• Key depth is incrementally increased
• Pressure increases in ~15 MPa steps



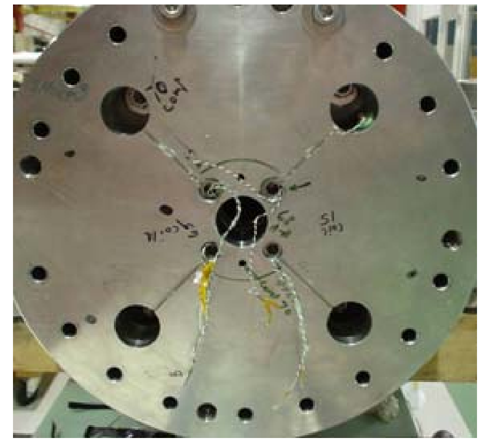
Yoke and skin:

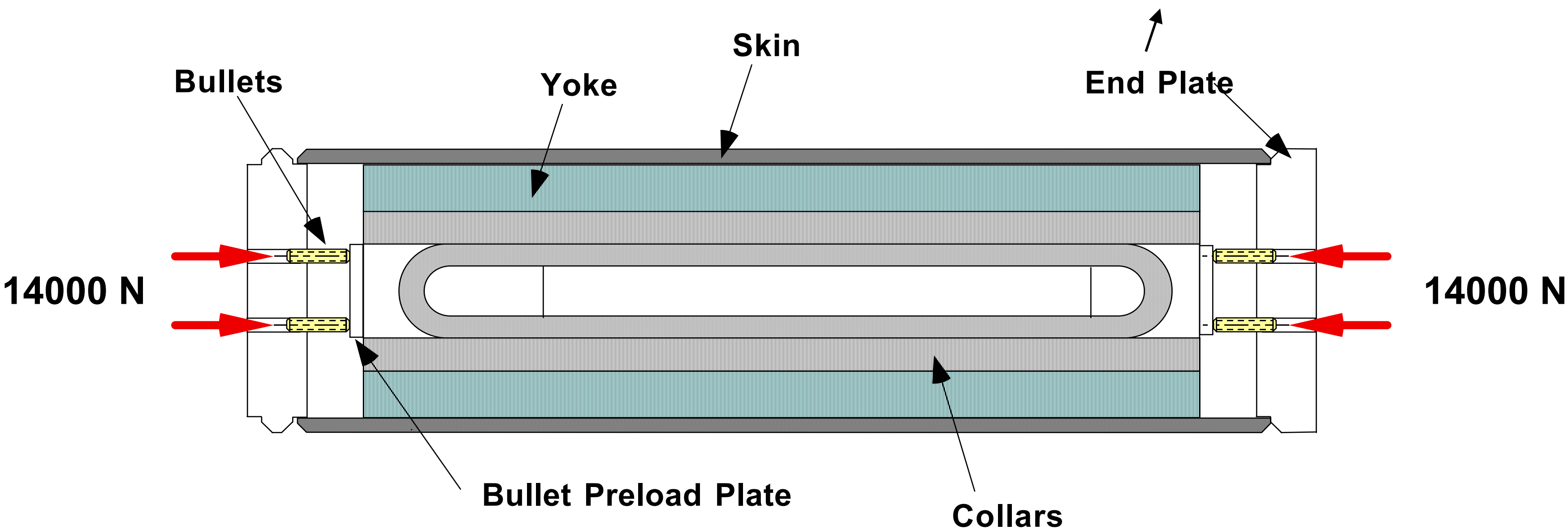
• 140 MPa coil pre-load after skin welding
• Pre-load tuned using collar-yoke shims
• Warm pre-load limited by control spacers
• Coil pre-load ~150 MPa after cool-down



TQC End Loading

- TQC end support system is similar to Fermilab Nb_3Sn dipoles and MQXB Quads
- End force of 14 kN applied by bullets through 50 mm thick end plates
- Magnet ends are in contact with bullets during cool-down and operation
- Confirmed by test results of HFD dipoles





Mechanical Model #1 ("Dummy Coil")

Goals:

- Determine coil size, mid-plane & collar-yoke shims
- Compare measured and calculated preloads
- Optimize collaring process for TQ coils.
- Understand and verify yoke welding process

Mechanical Model #1:

- Instrumented aluminum tube in collar structure
- Strain in the aluminum tube was measured while the collaring keys were inserted, incrementally, in small steps until they were fully inserted.
- Key depth could be controlled during the keying operation to about 1mm; the corresponding incremental stress between keyed sections is ~15 MPa.

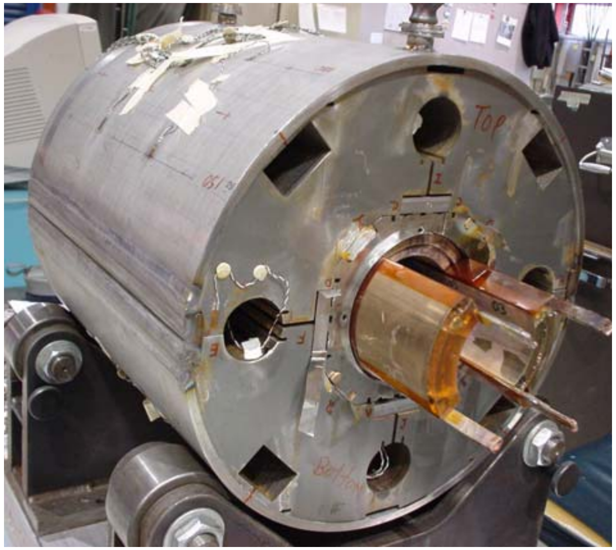
Mechanical Model #2 ("Coil ends")

<u>Mechanical Model #2:</u>

- Used practice coils 1 and 3; end areas collared with "full round" collars
- Purpose: understand collaring process over ends
- Some straight section was also collared with full round collars

<u>Results</u>:

- Mid-plane shims of 125 μm yield preloads within the acceptable range.
- Yoke welding alignment gap and weld pass numbers were established
- Yoke closes onto control spacers to provide the 140 MPa to coils necessary for completed magnet .



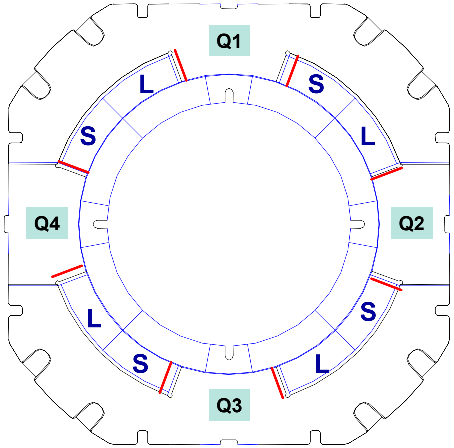
Mechanical Model #3 (“straight section”)

TQC Mechanical Model #3

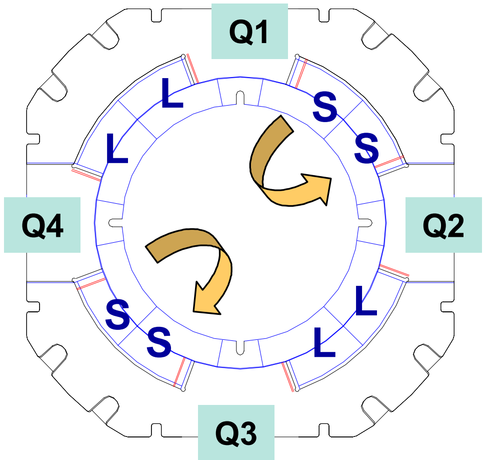
- Used practice coils #1 and #3
- Purpose: understand collaring process over straight section with “tabbed” collars, and differences between inner and outer preload
- Findings: collar deflections and mid-plane gauge readings after keying showed large differences in size and preload between quadrant
- Cause: side-to-side size variations between coils

Response:

A “full round” configuration will be adopted for TQC01, until precision and placement of components within the coil cross section is completely understood



Normal TQ configuration



Mechanical Model #3

Current Status & Near-term Plan

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Mechanical Model #4:

- Re-collared practice coils 1 and 3 using full round collars
- Large variations in collar deflections were eliminated, as expected
- Gauges still indicate large preload variations between coil quadrants
- Conclusion: practice coil 1 and/or 3 may been damaged from handling
- MM4 is not being used to determine mid-plane shims
- MM4 can be used to verify weld processes and collar-yoke shim size

Mechanical Model #5:

- Practice coils 2 and 4 have been collared with full round collars, using a range of shims from 0 to 125 μm, and Fuji film at the mid-planes.
- Based on this data, preload shims of 50 μm will be placed at each mid-plane when coils are assembled.

Final assembly of TQC01 has started; the test is expected to start in June

TQS Assembly Procedure

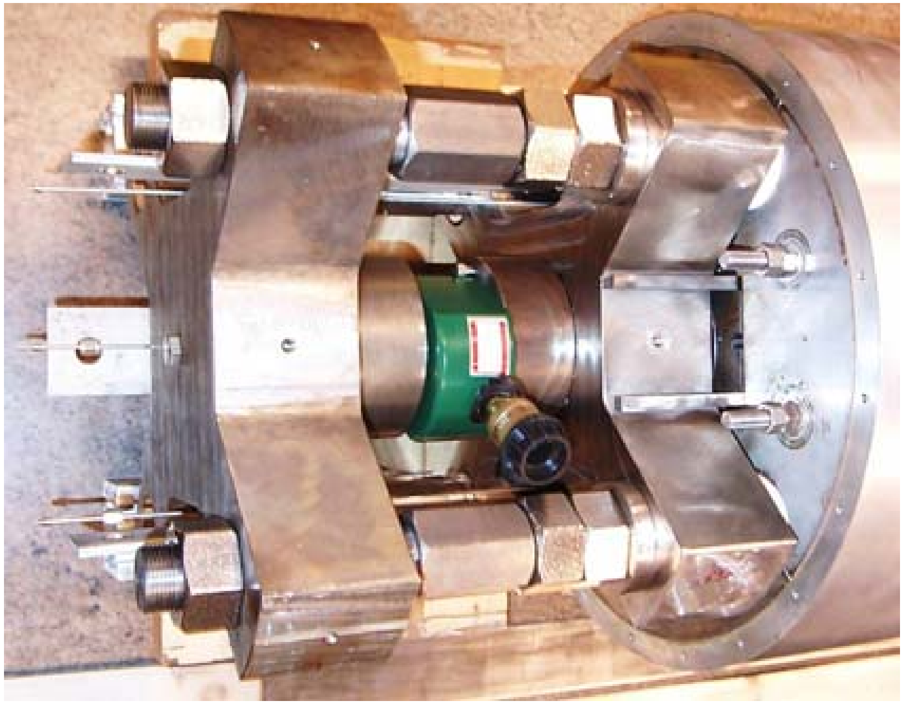
Insertion of coil-pad sub-assembly in yoke-shell sub-assembly

Axial rods

TQS Axial Loading

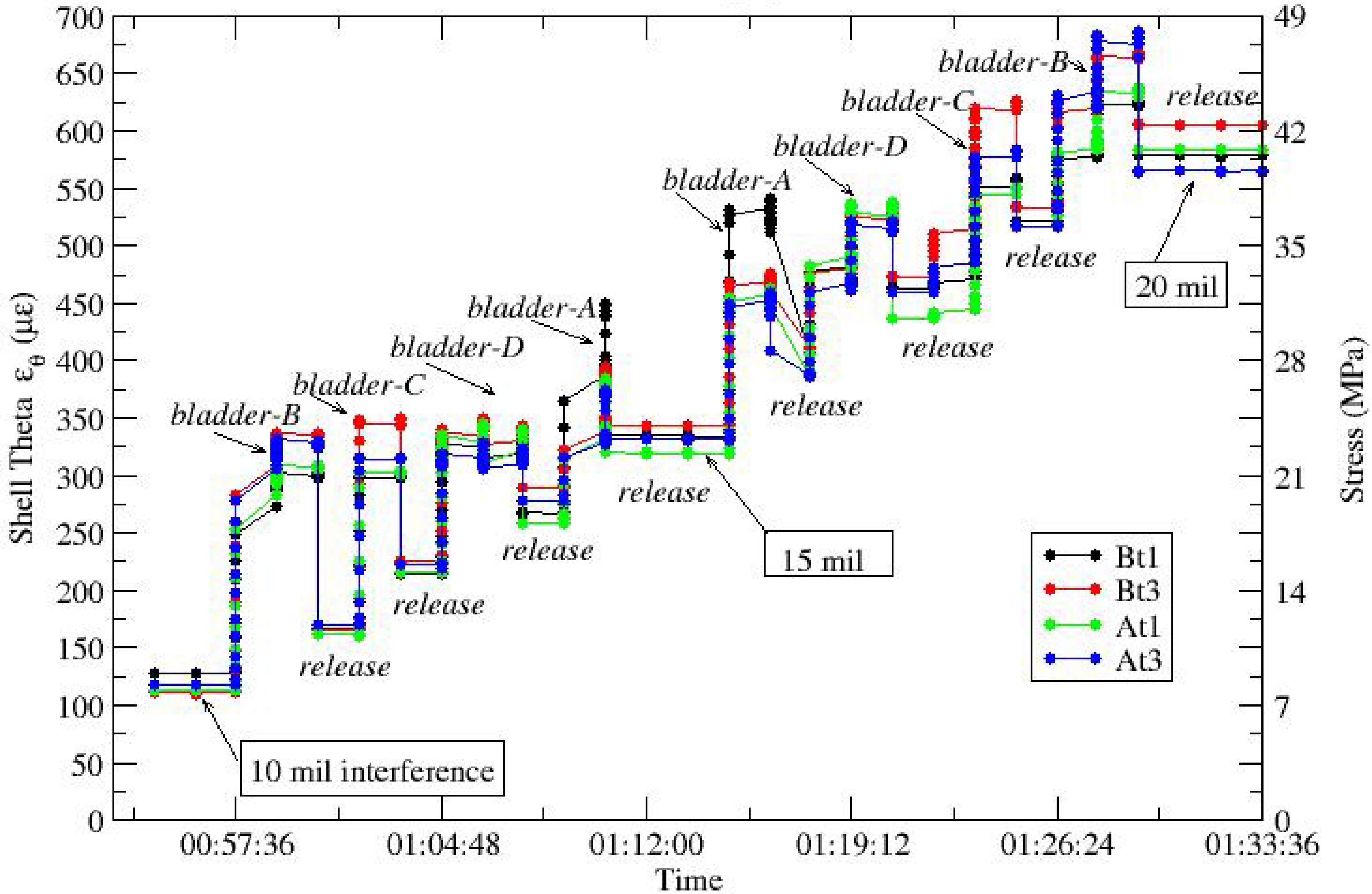
End plate installation

Axial rods pre-tensioning system



TQS Transverse Loading

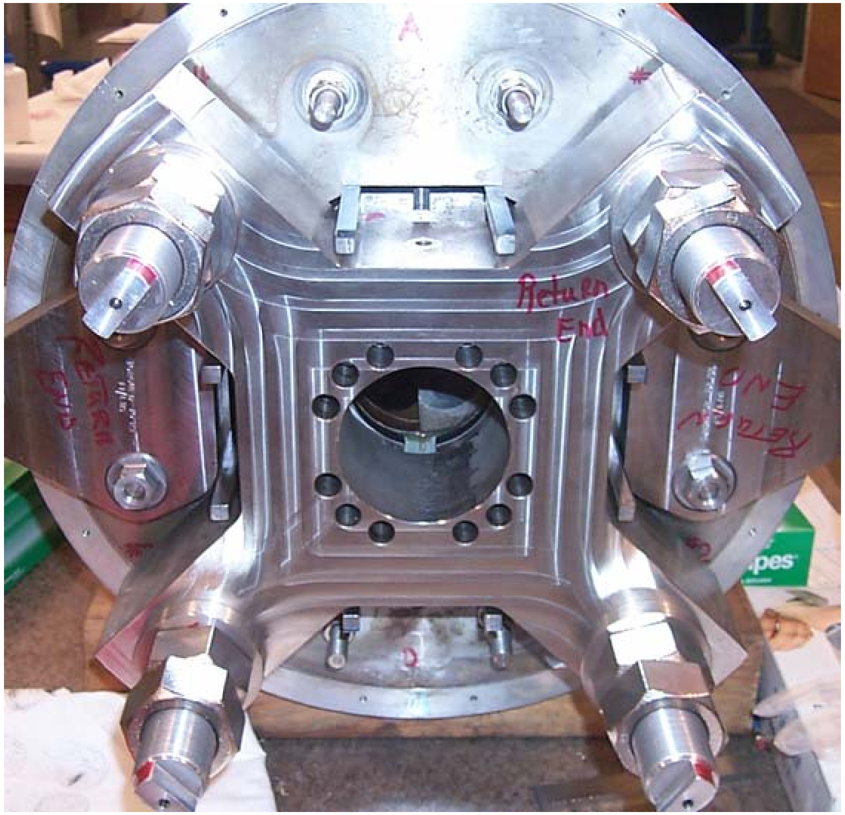
Transverse Loading Operation



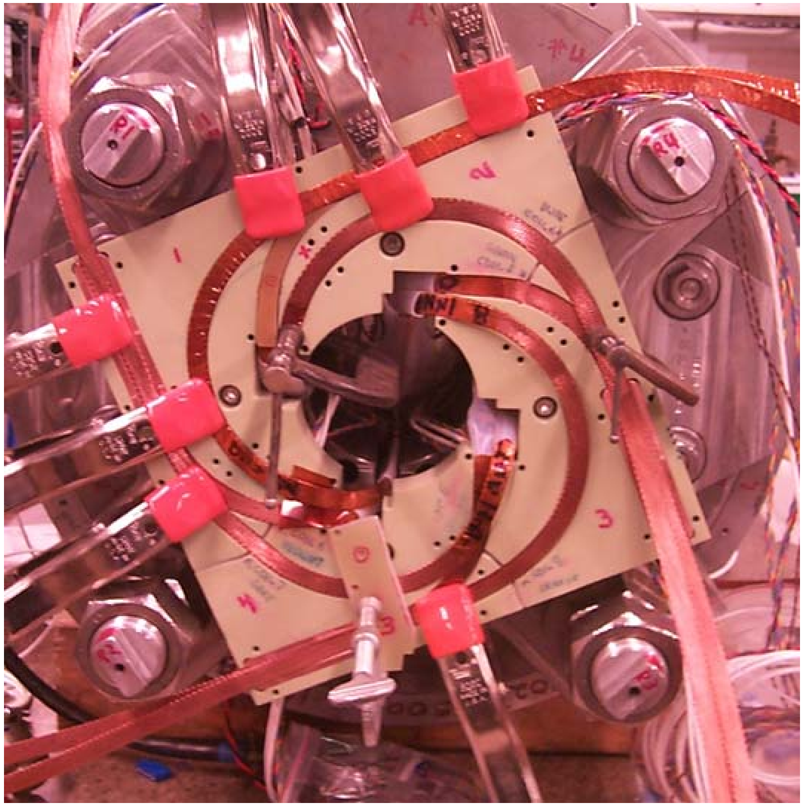
LARP

TQS Final Assembly

Return end view

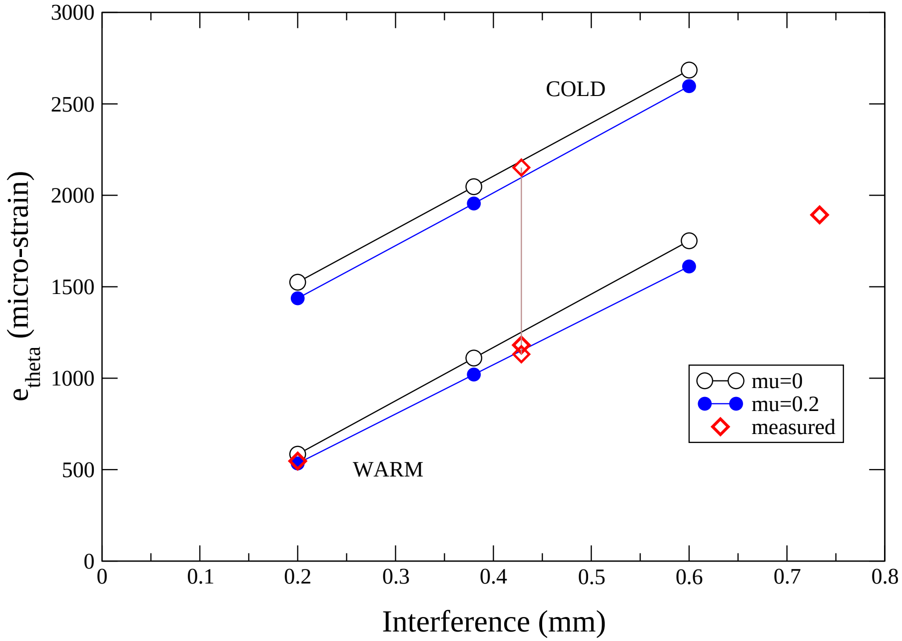


Lead end view with splice block



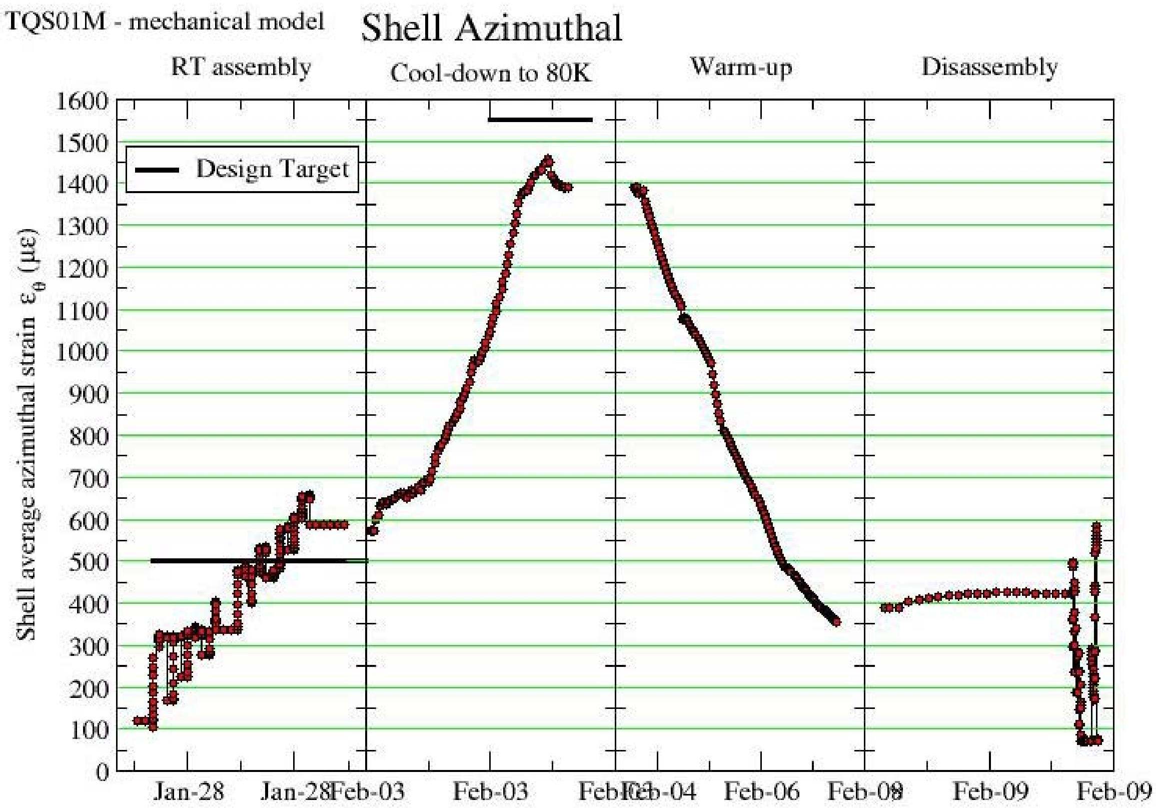
Mechanical Model #1 ("Dummy Coil")

- Dummy aluminum cylinder used in place of coils
- Compared measurements with calculations:
  - *Correlation between shim size and shell stress*
  - *Cool-down effects*
- No axial load



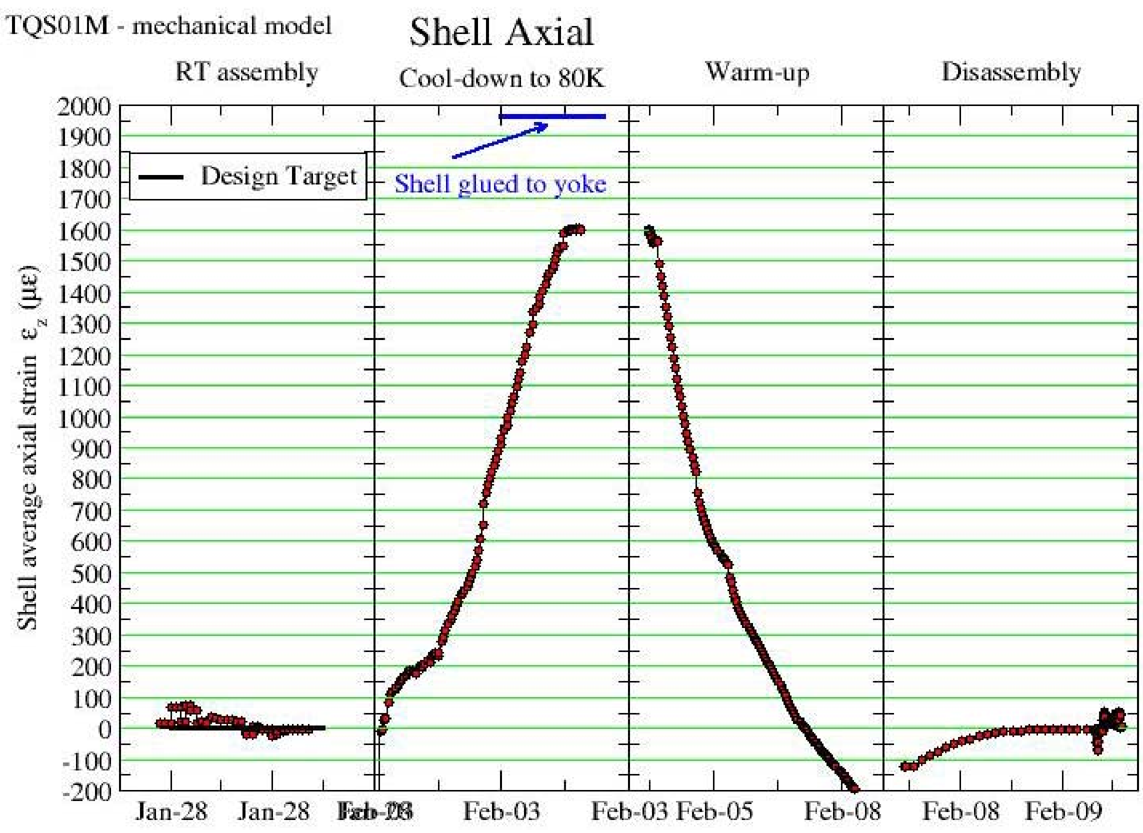
Mechanical Model #2 (“Practice Coils”)

- Practice coils 1-4 were assembled and cooled to LN
- “Dry-run” for the complete assembly procedure
- Only shell and axial rods measurements (schedule driven)



Feedback from Mechanical Model #2

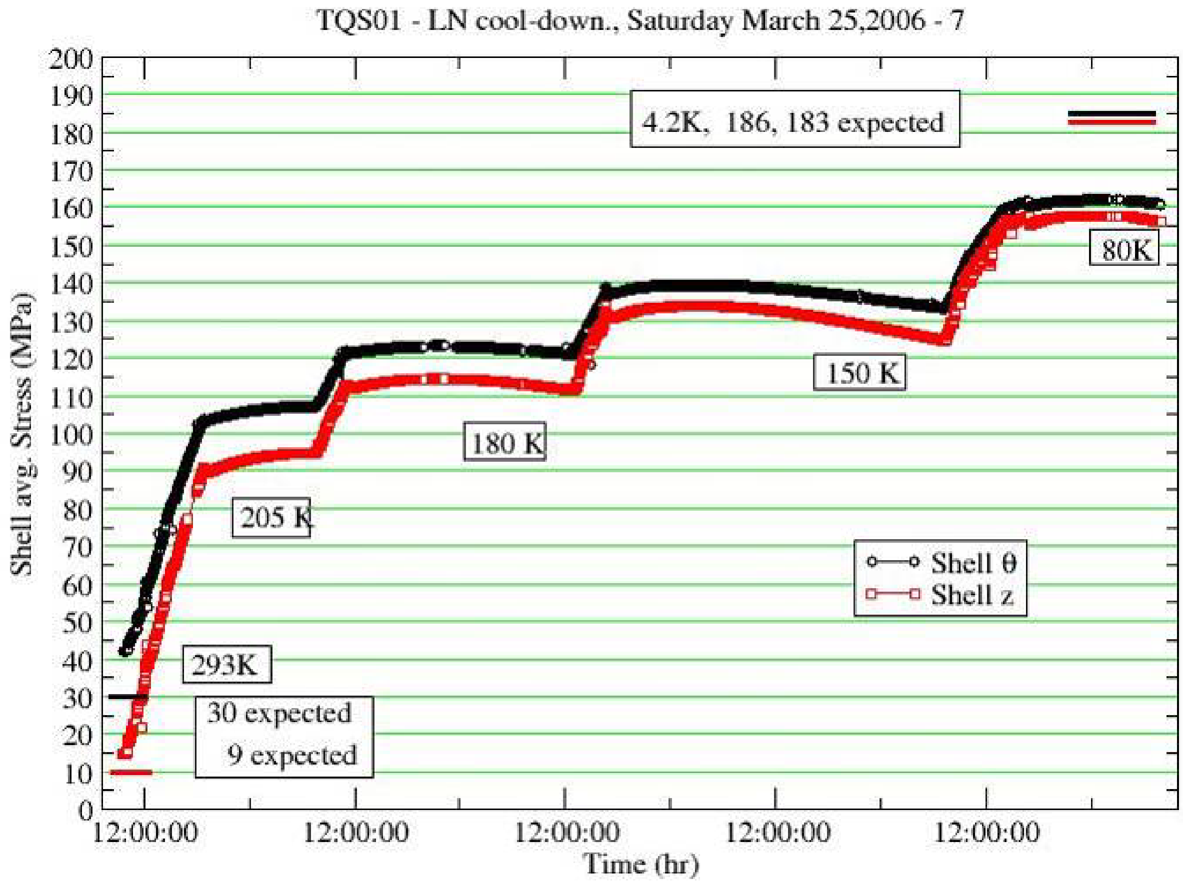
LARP



- Yoke-shell friction coefficient needs to be increased from 0.2 to 0.6
- Calculated coil preload increases when yoke-shell friction coefficient is increased
- Additional studies recommended by TQ mechanical review (February '06)

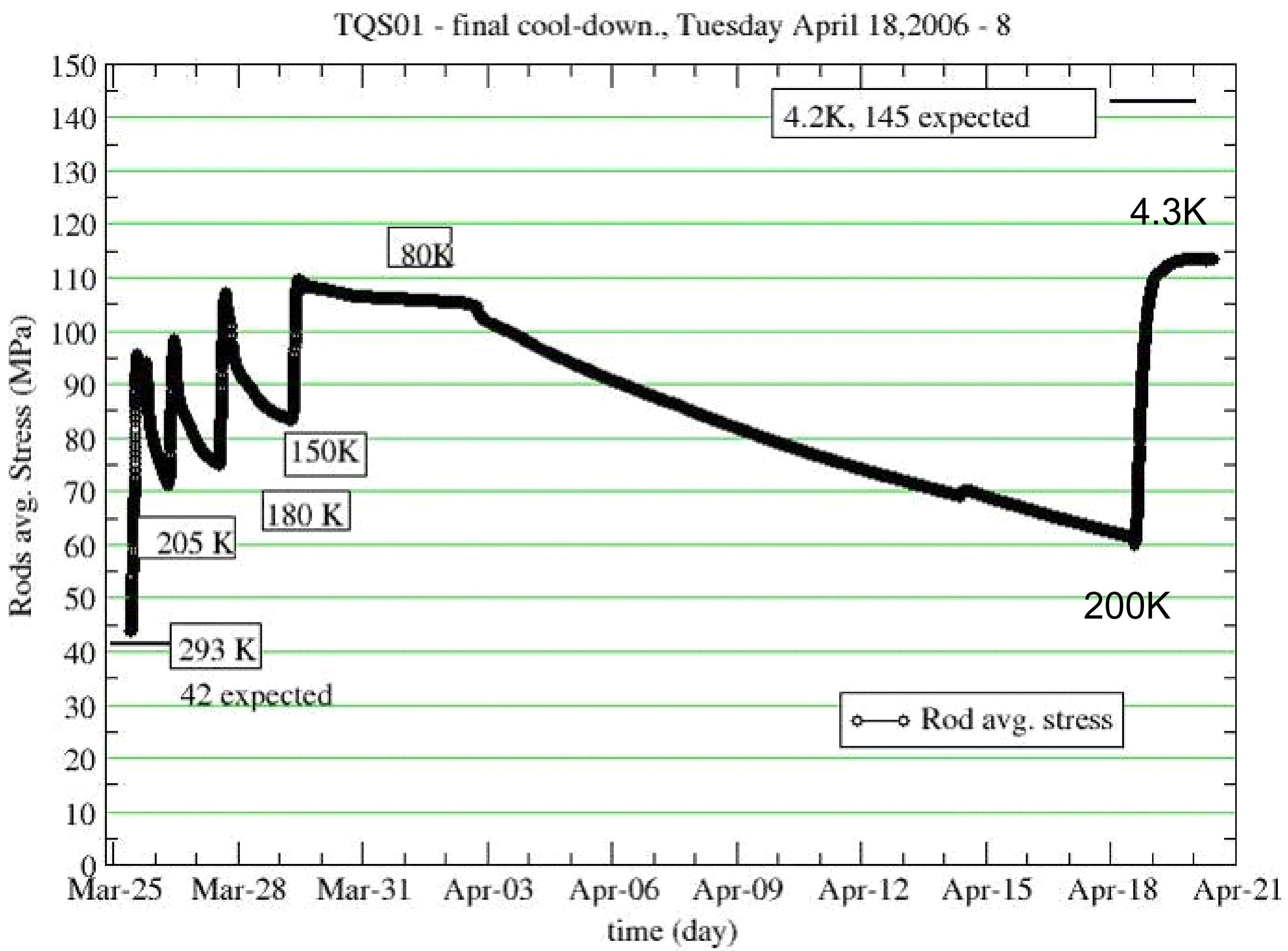
TQS01 Test

TQS01 Mechanical (LN) Cool-Down

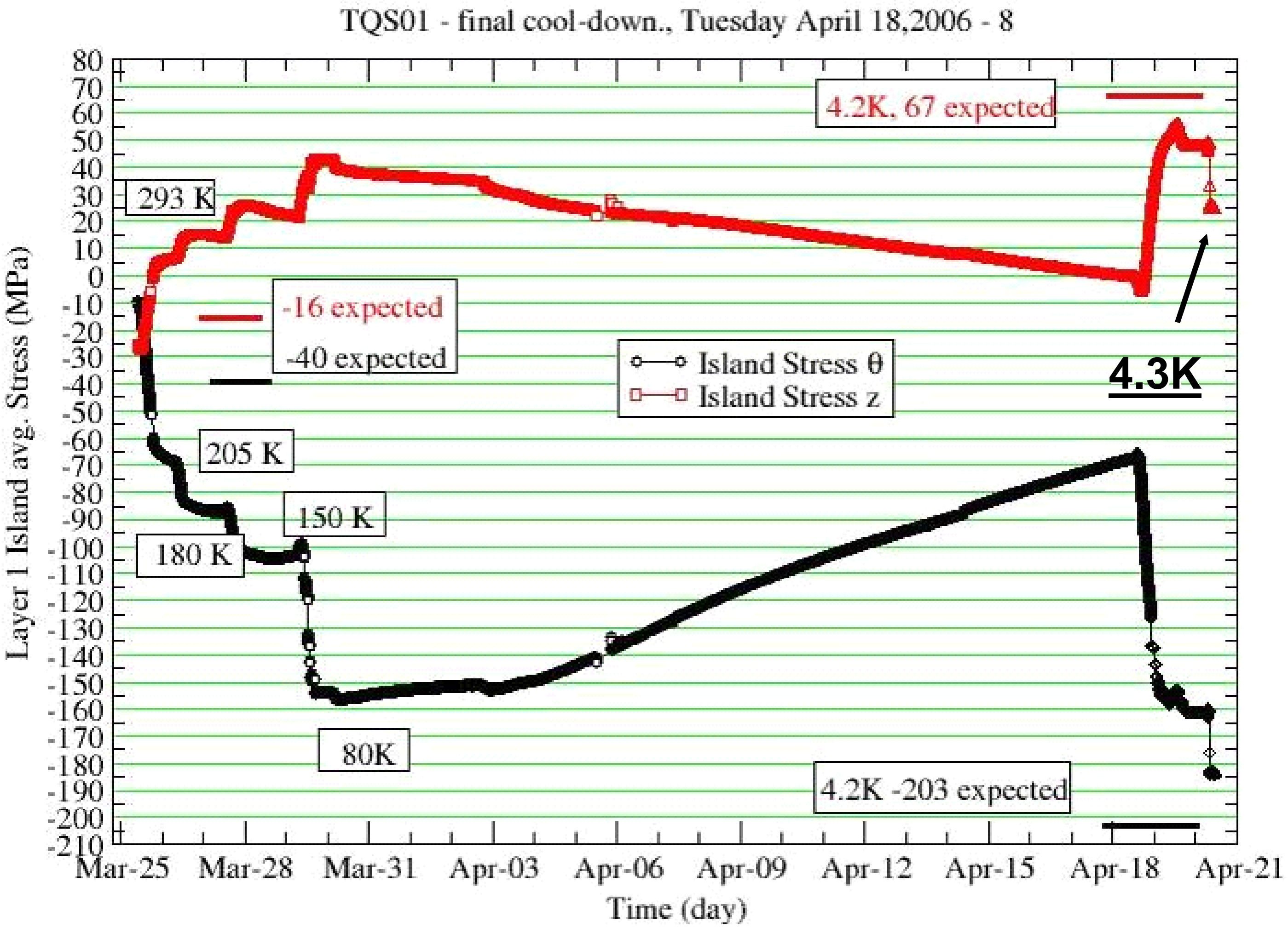


- LN cool-down was performed in steps down to 80 K
- Stress was measured in shell, rods and bronze pole

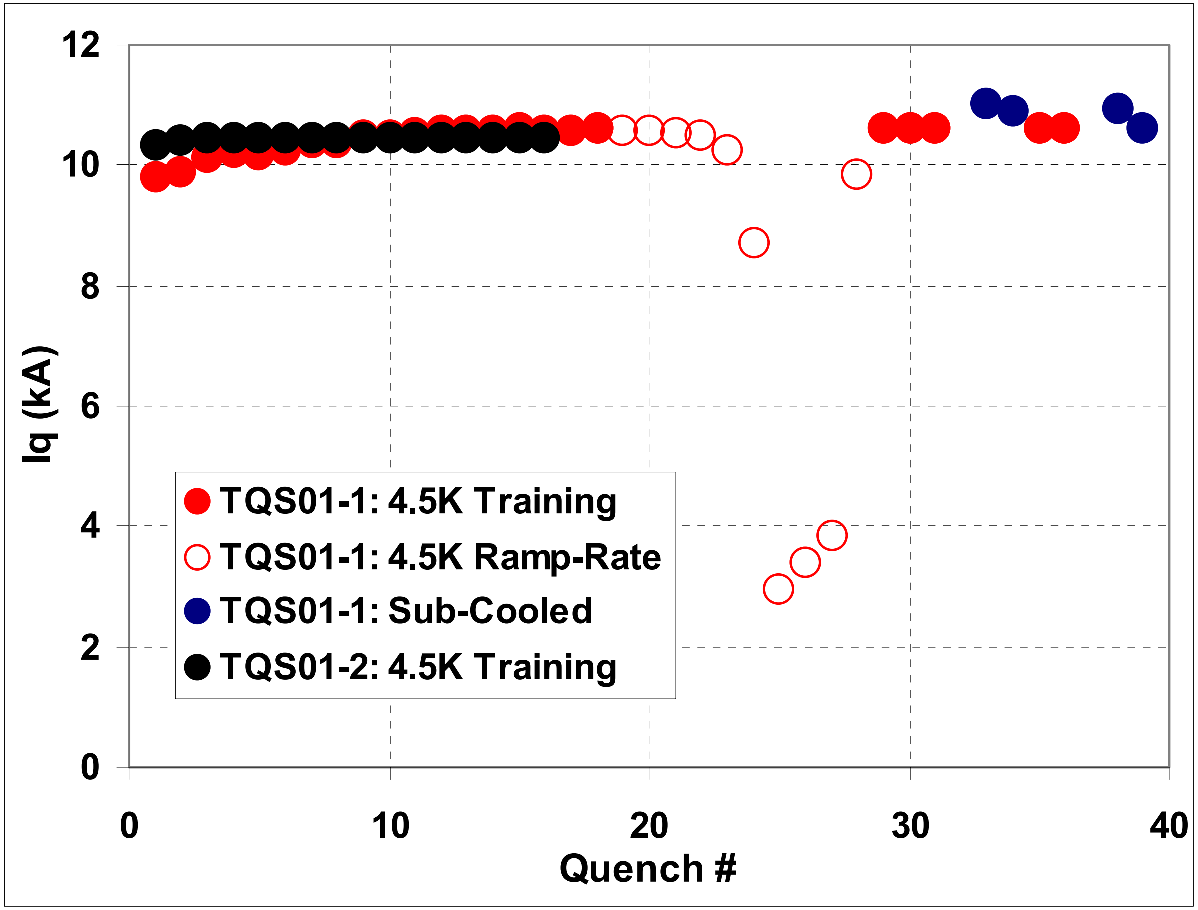
Axial Rod Stress during Cool-down



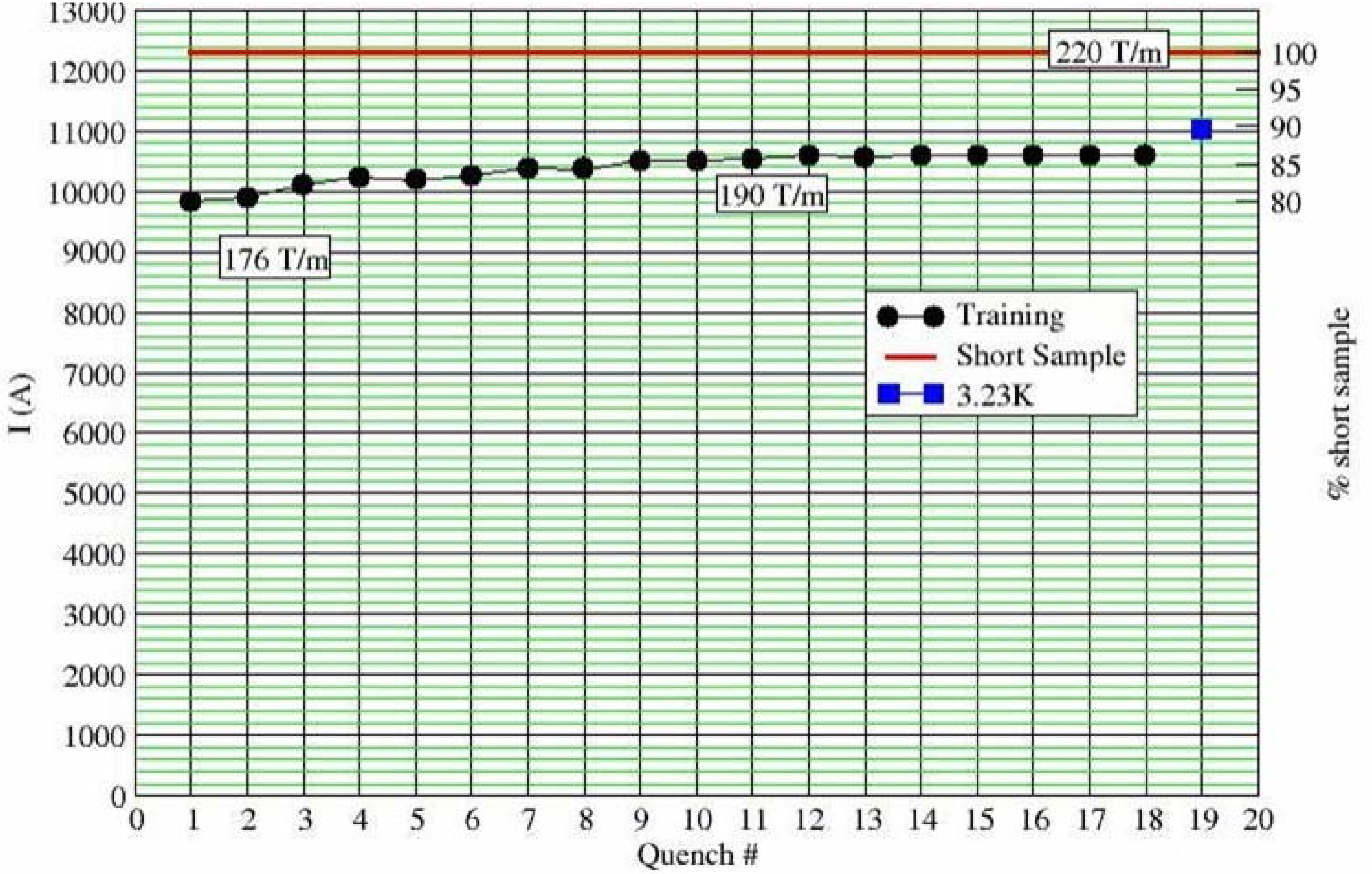
Pole Stress during Cool-down



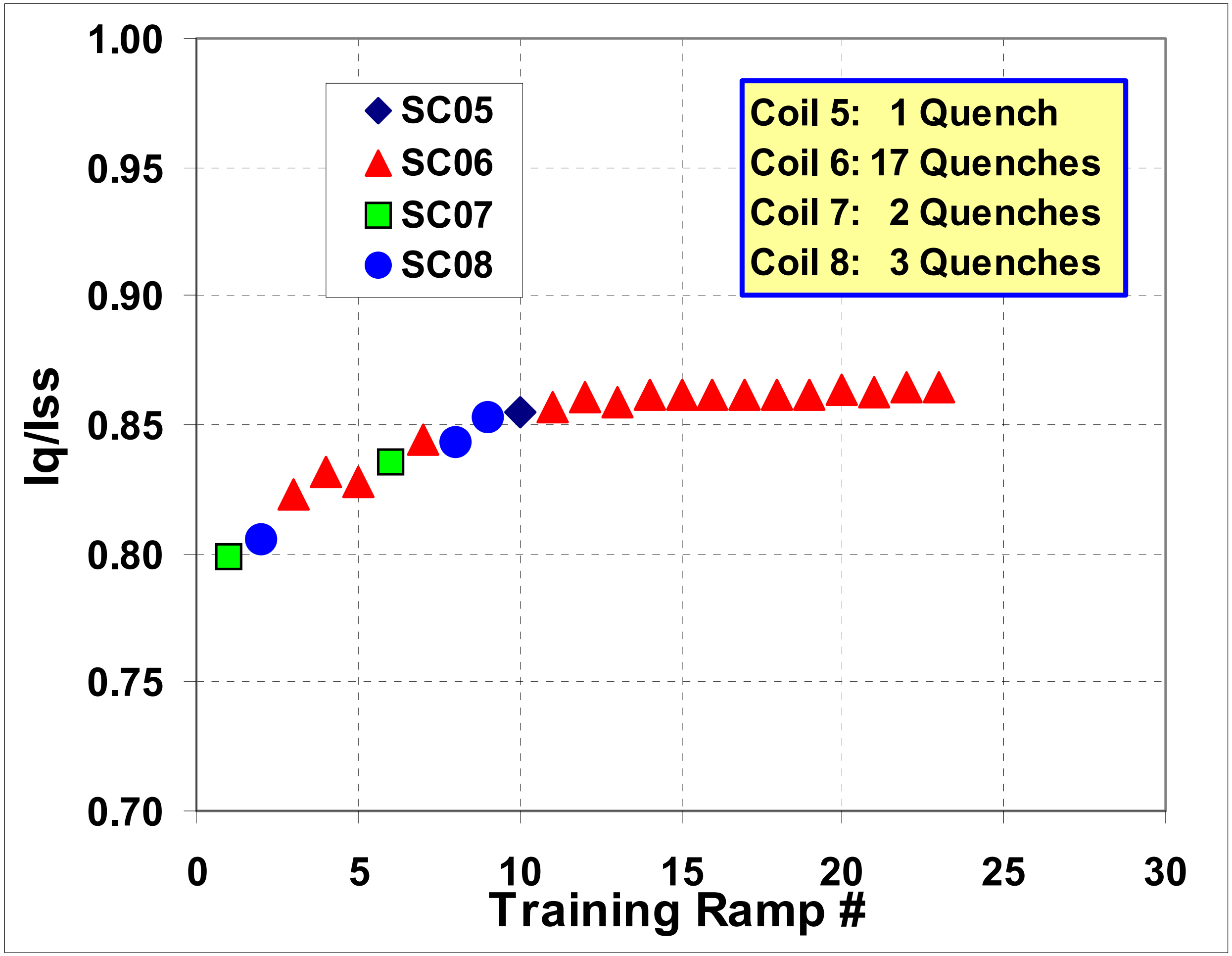
TQS01 Quench History



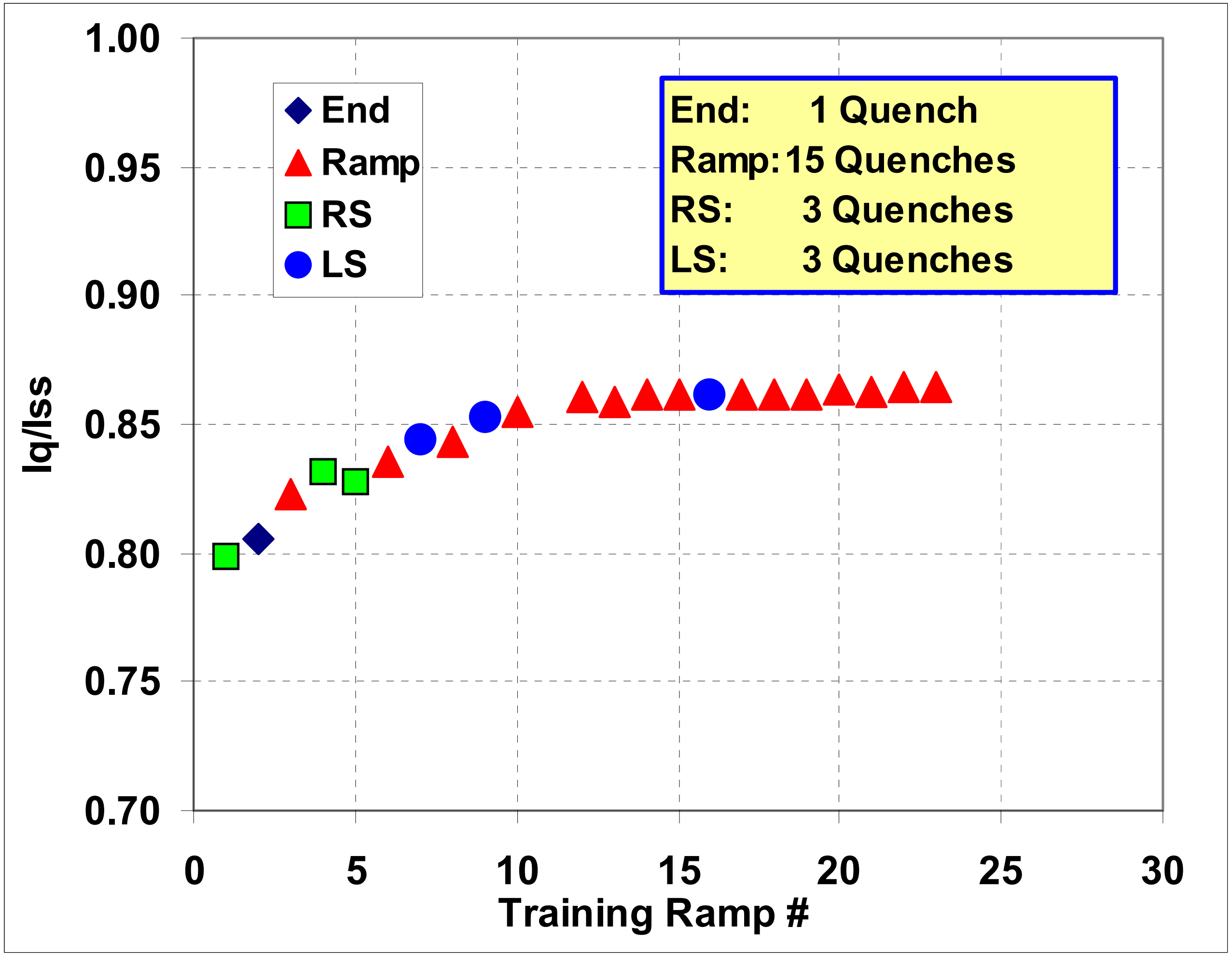
TQS01 Training



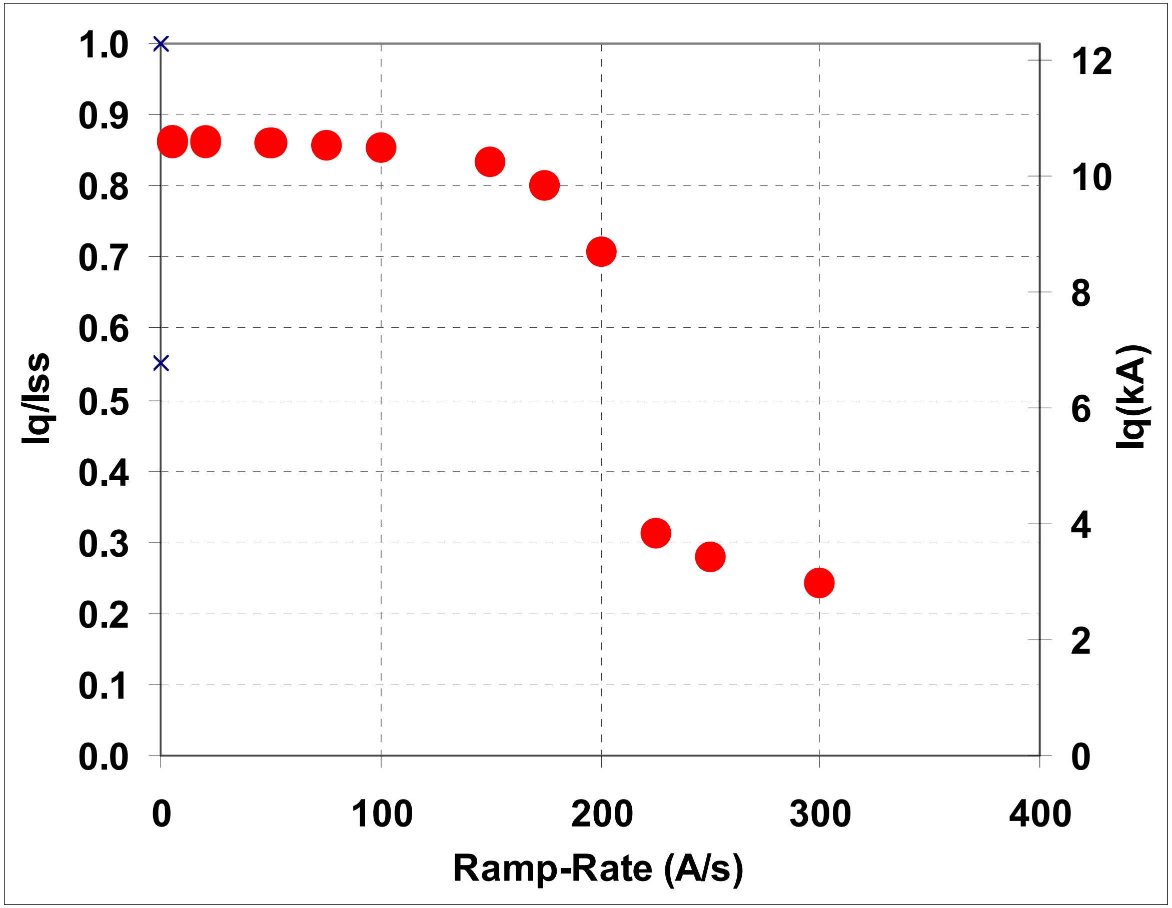
TQS01 Quench Locations (Coil)



TQS01 Quench Locations (Area)



TQS01 Ramp Rate Dependence



TQ-SQ Comparison

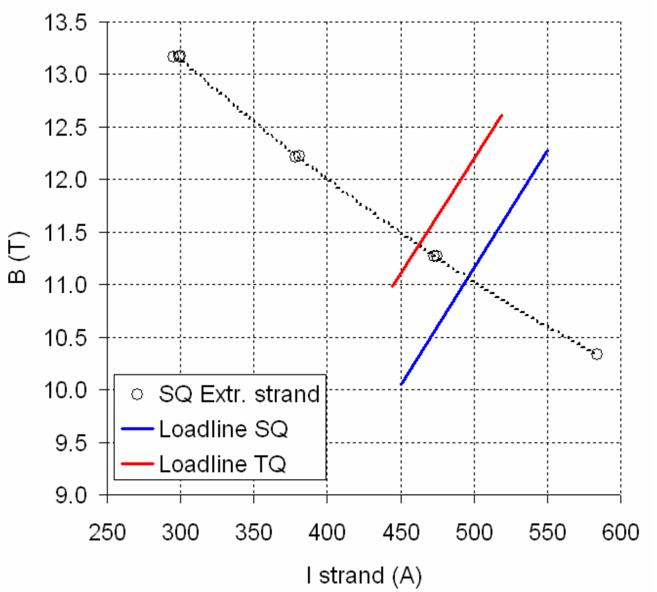
Load Lines, Lorentz Forces and Coil Stress:

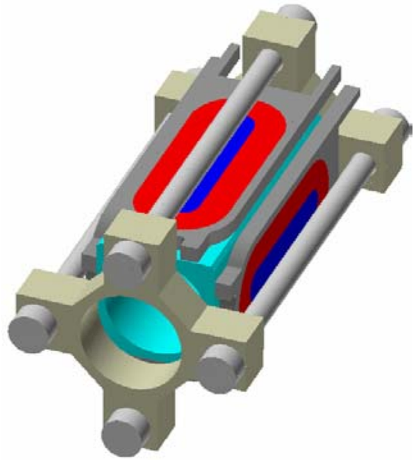
TQ:

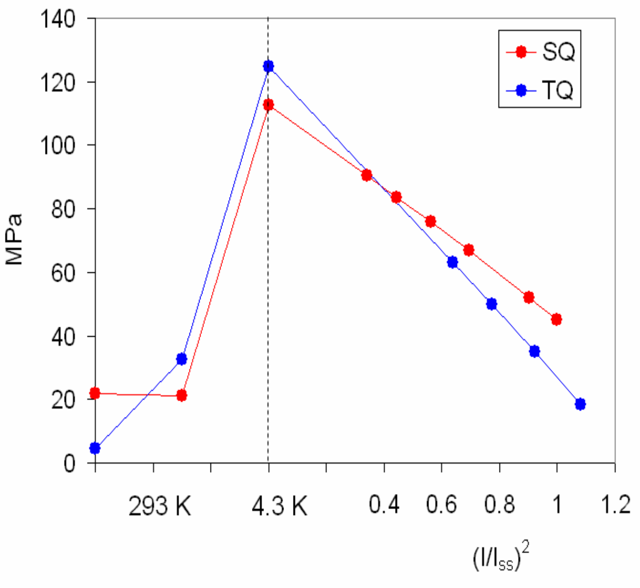
I_{strand} ~ 460 A; B_{peak} ~ 11.4 T; Coil stress: 100-150 MPa; Fz=350 kN; σ_z=81 MPa

SQ:

I_{strand} ~ 490 A; B_{peak} ~ 11.1 T; Coil stress: 100-150 MPa; Fz=340 kN; σ_z=87 MPa







SQ02 Training (4.5K & 1.8K)

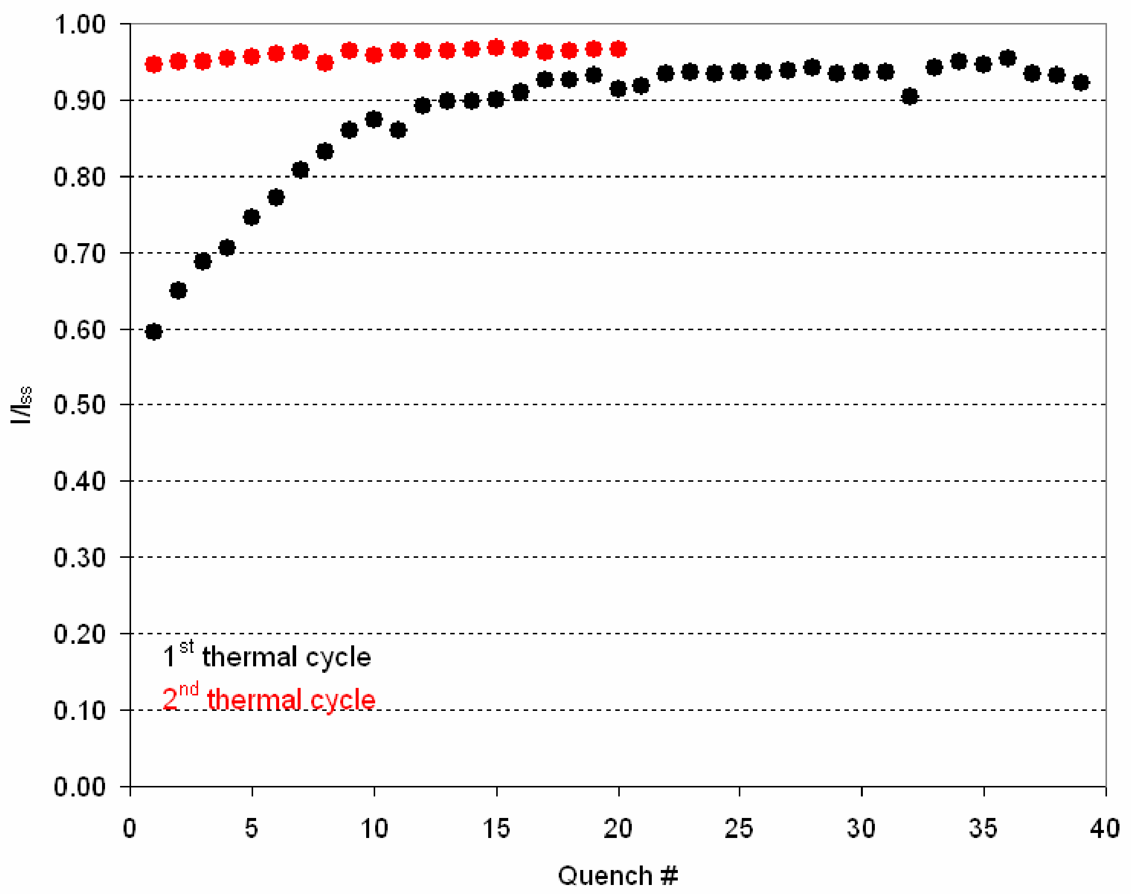
Tested at LBNL (10/05)

First thermal cycle

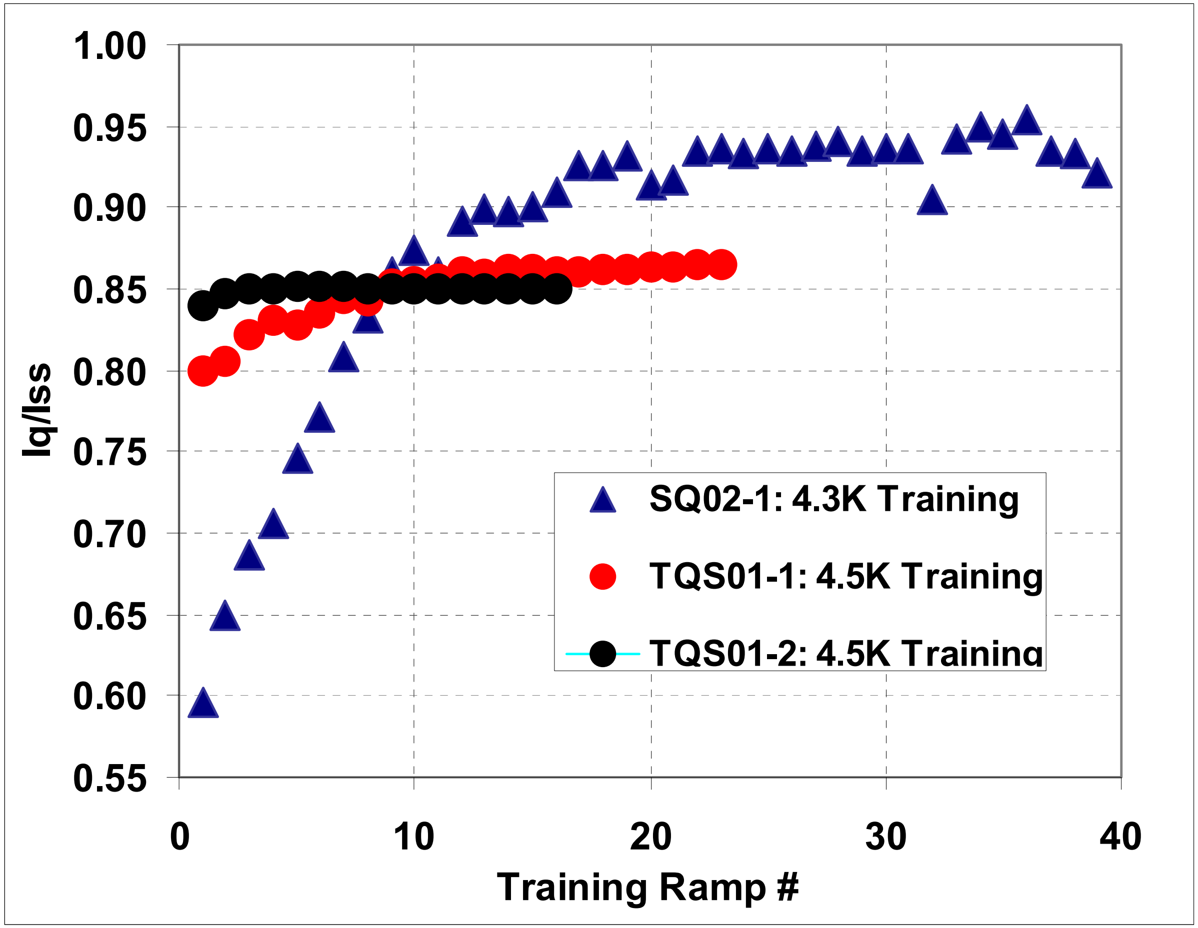
- 1^{st} quench: 60 % I_{ss}
- 90 % in 13 quenches
- I_{max} = 95 % I_{ss}

Second thermal cycle

- 1^{st} quench: 95 % I_{ss}
- I_{max} = 97 % I_{ss}
  - I_{max} = 9.6 kA
  - B_{max} = 10.7 T
  - G_{max} = 81 T/m



TQ-SQ Training Comparison



SQ02b Training (4.5K & 1.8K)

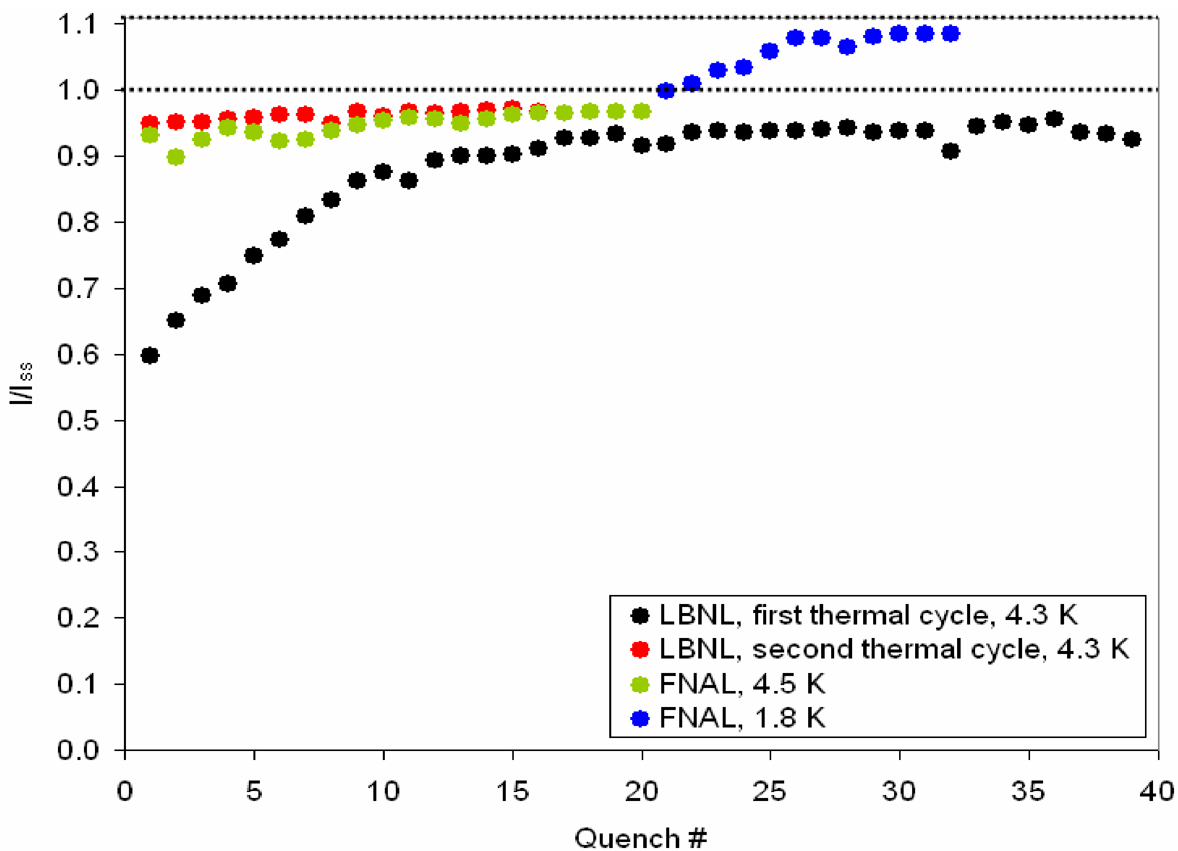
Tested at FNAL (03/06)

4.5 K

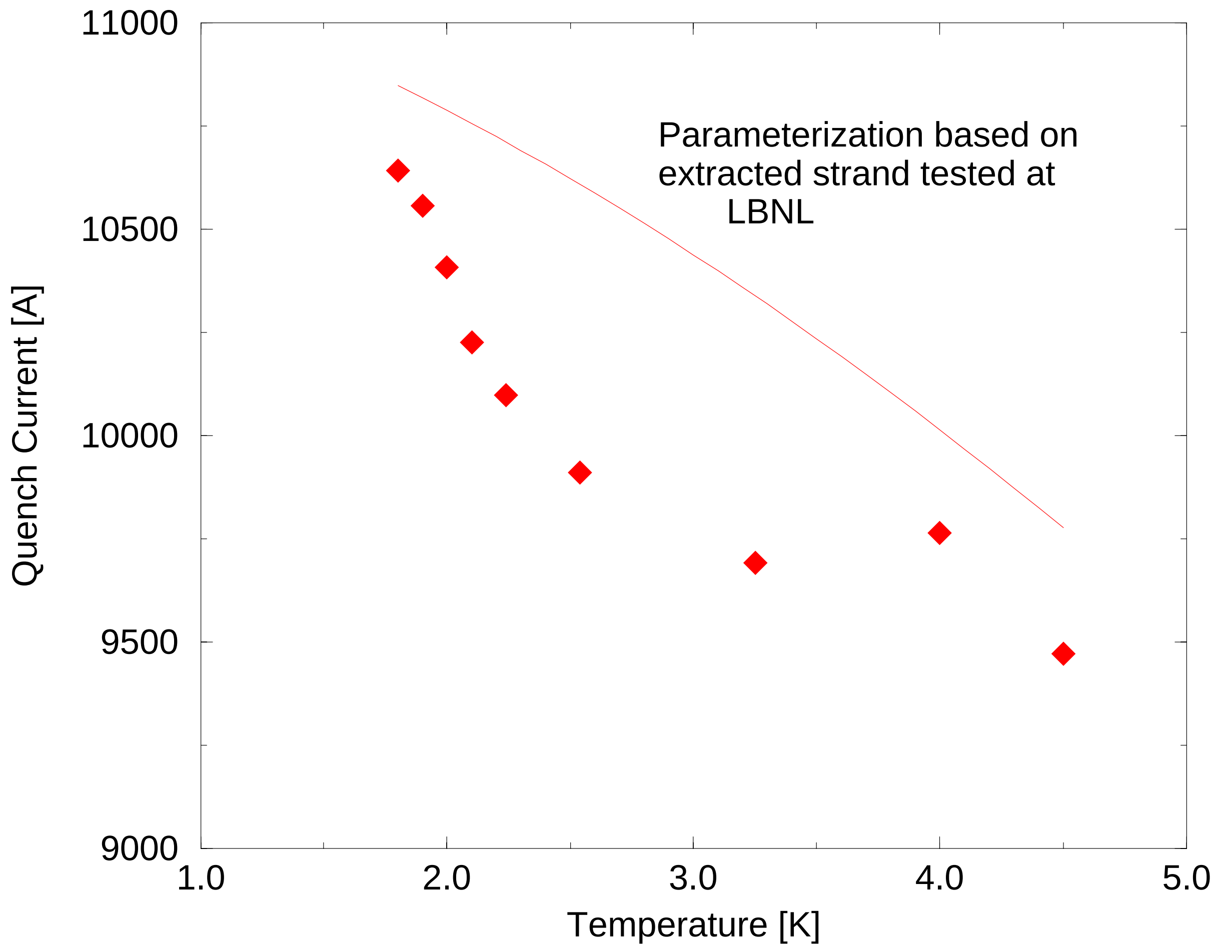
- 1st quench
  - 9.1 kA (93 % I_{ss})
- Highest quench
  - 9.5 kA (97 % I_{ss})
- Similar as 2nd TC at LBNL

1.8 K

- 1st quench
  - 9.8 kA (90 % I_{ss})
- Highest quench
  - 10.6 kA (98 % I_{ss})

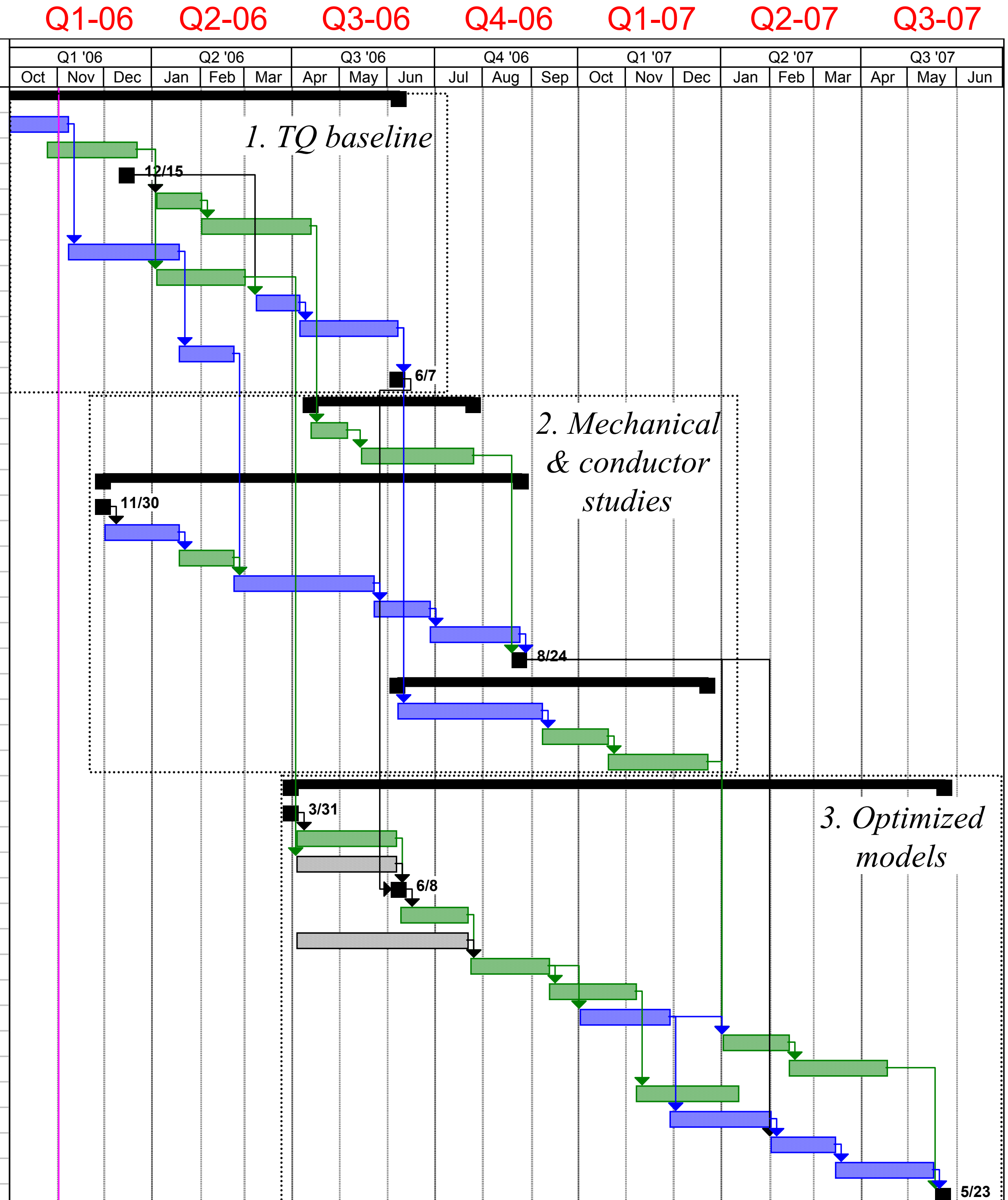


SQ Temperature Dependence



FY06 Plan from Nov. 2005 DOE review

ID	Task Name	Start	Finish
1	**TQS01 & TQC01**	**Tue 9/13/05**	**Wed 6/7/06**
2	TQS01 winding/curing	Tue 9/13/05	Mon 11/7/05
3	TQS01 reaction/potting	Tue 10/25/05	Wed 12/21/05
4	TQ01 mech. design review	Thu 12/15/05	Thu 12/15/05
5	TQS01 assembly	Tue 1/3/06	Tue 1/31/06
6	TQS01 test & analysis	Wed 2/1/06	Tue 4/11/06
7	TQC01 winding/curing	Tue 11/8/05	Tue 1/17/06
8	TQC01 reaction/potting	Tue 1/3/06	Tue 2/28/06
9	TQC01 assembly	Wed 3/8/06	Tue 4/4/06
10	TQC01 test & analysis	Wed 4/5/06	Tue 6/6/06
11	TQ01 spares winding/curing	Wed 1/18/06	Tue 2/21/06
12	TQ01 evaluation review	Wed 6/7/06	Wed 6/7/06
13	**TQS02**	**Wed 4/12/06**	**Tue 7/25/06**
14	Assembly	Wed 4/12/06	Fri 5/5/06
15	Test & analysis	Mon 5/15/06	Tue 7/25/06
16	**TQC02**	**Wed 11/30/05**	**Thu 8/24/06**
17	Conductor available	Wed 11/30/05	Wed 11/30/05
18	Strand/cable testing	Thu 12/1/05	Tue 1/17/06
19	Cable fabrication/insulation	Wed 1/18/06	Tue 2/21/06
20	Coil fabrication	Wed 2/22/06	Mon 5/22/06
21	Assembly	Tue 5/23/06	Tue 6/27/06
22	Test & analysis	Wed 6/28/06	Wed 8/23/06
23	TQ02 evaluation review	Thu 8/24/06	Thu 8/24/06
24	**TQE01**	**Wed 6/7/06**	**Fri 12/22/06**
25	TQC01 Disassembly	Wed 6/7/06	Thu 9/7/06
26	TQE01 Assembly	Fri 9/8/06	Thu 10/19/06
27	Test & analysis	Fri 10/20/06	Fri 12/22/06
28	**TQS03 & TQC03**	**Fri 3/31/06**	**Wed 5/23/07**
29	Conductor available	Fri 3/31/06	Fri 3/31/06
30	Strand/cable testing	Mon 4/3/06	Mon 6/5/06
31	Coil optimization	Mon 4/3/06	Mon 6/5/06
32	TQ03 readiness review	Thu 6/8/06	Thu 6/8/06
33	Cable fabrication/insulation	Fri 6/9/06	Fri 7/21/06
34	Parts procurement	Mon 4/3/06	Fri 7/21/06
35	Practice coils	Mon 7/24/06	Mon 9/11/06
36	TQS03 winding/curing	Tue 9/12/06	Mon 11/6/06
37	TQS03 reaction/potting	Mon 10/2/06	Tue 11/28/06
38	TQS03 Assembly	Tue 1/2/07	Mon 2/12/07
39	TQS03 test & analysis	Tue 2/13/07	Mon 4/16/07
40	TQC03 winding/curing	Tue 11/7/06	Thu 1/11/07
41	TQS03 reaction/potting	Wed 11/29/06	Wed 1/31/07
42	TQC03 Assembly	Thu 2/1/07	Wed 3/14/07
43	TQC03 test & analysis	Thu 3/15/07	Wed 5/16/07
44	TQ03 evaluation review	Wed 5/23/07	Wed 5/23/07



Progress Summary

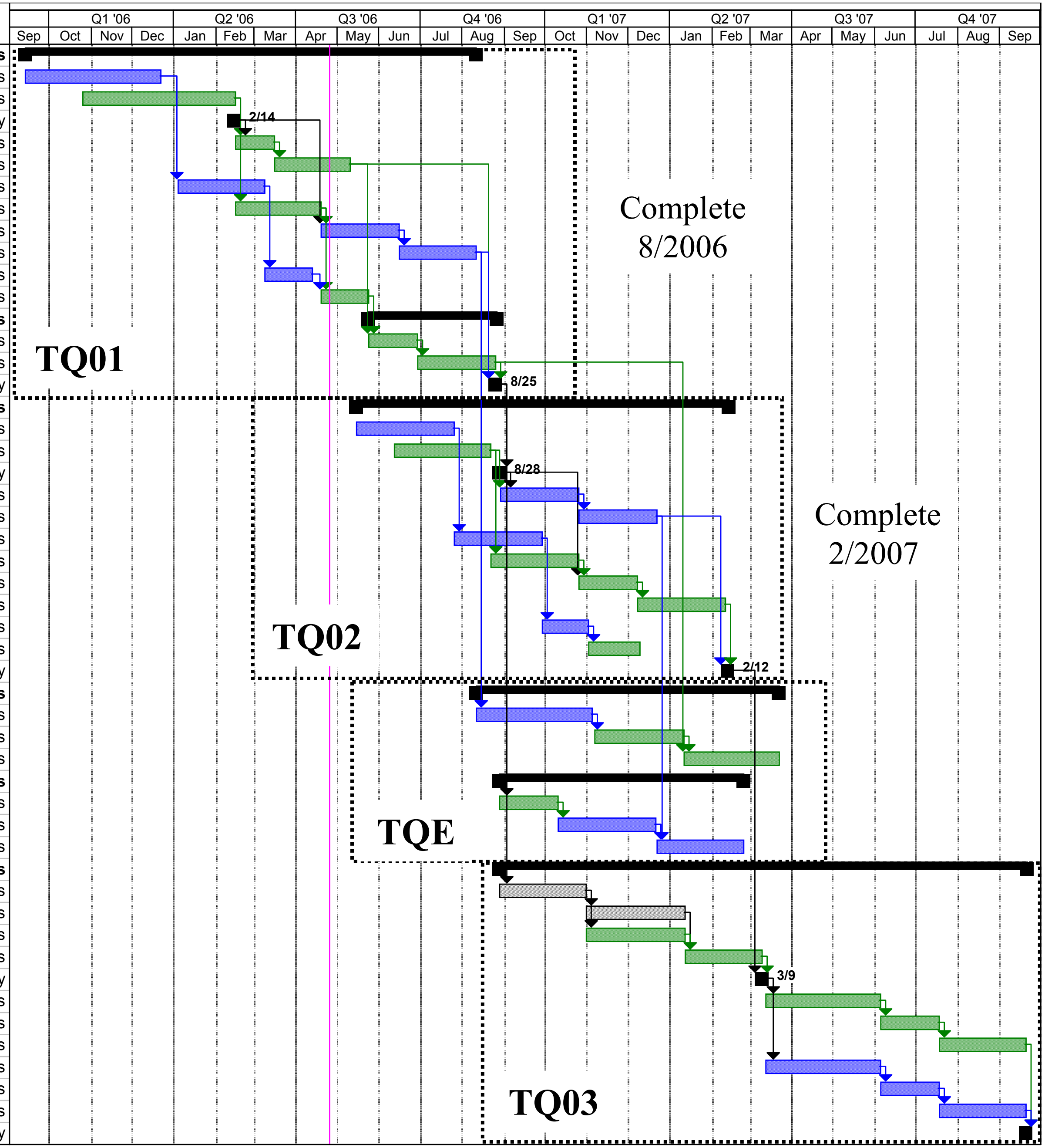
- **Coil fabrication:**
  - 4 practice coils and 8 production coils completed
  - Further optimization is needed, but no major change
- **Mechanical design**
  - Detailed analysis and measurements from models available
  - Program goal: structure optimization and evaluation
- **Feedback from TQS01 test**
  - First quench at 80% of short sample
  - Achieved 87% of short sample
  - We have a good basis to build and improve on
- **Next steps**
  - TQC01, TQS01b tests in June-July
  - TQ02 coil fabrication starts in May-June

Basis for the Updated Plan

- **Schedule information from TQS01 an TQC01**
  - More accurate information on sub-task requirements
  - Need to make up for some delay to support 2009 milestone
- **Feedback from TQS01 test**
  - First quench at 80% of short sample
  - Achieved 87% of short sample
  - We have a good basis to build and improve on
- **TQS01 & TQC01 coil fabrication approach was successful**
  - Quality and consistency of fabricated coils
  - Efficiency of the process: resources and facilities
  - Program and team integration
  - Need optimization (cable, end parts, layer transition), but no major changes
- **TQS01 test information is available before start of TQC02 winding**
- **Recommendations from TQ the mechanical review**
  - Extract maximum information at each step; explore variants

Revised TQ Plan – April 27, 2006 Q1-06 Q2-06 Q3-06 Q4-06 Q1-07 Q2-07 Q3-07 Q4-07

ID	Task Name	Start	Finish	Duration
1	**TQS01 & TQC01**	**Tue 9/13/05**	**Thu 8/10/06**	**225 days**
2	TQS01 winding/curing	Tue 9/13/05	Wed 12/21/05	70 days
3	TQS01 reaction/potting	Tue 10/25/05	Tue 2/14/06	70 days
4	TQ01 mech. design review	Tue 2/14/06	Tue 2/14/06	1 day
5	TQS01 assembly	Wed 2/15/06	Tue 3/14/06	20 days
6	TQS01 test & analysis	Wed 3/15/06	Tue 5/9/06	40 days
7	TQC01 winding/curing	Tue 1/3/06	Tue 3/7/06	45 days
8	TQC01 reaction/potting	Wed 2/15/06	Tue 4/18/06	45 days
9	TQC01 assembly	Wed 4/19/06	Wed 6/14/06	40 days
10	TQC01 test & analysis	Thu 6/15/06	Thu 8/10/06	40 days
11	TQ01 spares winding/curing	Wed 3/8/06	Tue 4/11/06	25 days
12	TQ01 spares reaction/potting	Wed 4/19/06	Tue 5/23/06	25 days
13	**TQS01b**	**Wed 5/24/06**	**Fri 8/25/06**	**66 days**
14	Inspect/Assembly	Wed 5/24/06	Wed 6/28/06	25 days
15	Test & analysis	Thu 6/29/06	Thu 8/24/06	40 days
16	TQ01 evaluation review	Fri 8/25/06	Fri 8/25/06	1 day
17	**TQC02 & TQS02**	**Mon 5/15/06**	**Mon 2/12/07**	**185 days**
18	TQC02 winding/curing	Mon 5/15/06	Tue 7/25/06	50 days
19	TQC02 reaction/potting	Mon 6/12/06	Mon 8/21/06	50 days
20	TQ02 mech. design review	Mon 8/28/06	Mon 8/28/06	1 day
21	TQC02 assembly	Tue 8/29/06	Tue 10/24/06	40 days
22	TQC02 test & analysis	Wed 10/25/06	Thu 12/21/06	40 days
23	TQS02 winding/curing	Wed 7/26/06	Wed 9/27/06	45 days
24	TQS02 reaction/potting	Tue 8/22/06	Tue 10/24/06	45 days
25	TQS02 assembly	Wed 10/25/06	Thu 12/7/06	30 days
26	TQS02 test & analysis	Fri 12/8/06	Fri 2/9/07	40 days
27	TQ02 spares winding/curing	Thu 9/28/06	Wed 11/1/06	25 days
28	TQ02 spares reaction/potting	Thu 11/2/06	Fri 12/8/06	25 days
29	TQ02 evaluation review	Mon 2/12/07	Mon 2/12/07	1 day
30	**TQE01**	**Fri 8/11/06**	**Wed 3/21/07**	**150 days**
31	TQC01 Disassembly	Fri 8/11/06	Fri 11/3/06	60 days
32	TQE01 Assembly	Mon 11/6/06	Wed 1/10/07	40 days
33	Test & analysis	Thu 1/11/07	Wed 3/21/07	50 days
34	**TQE02**	**Mon 8/28/06**	**Fri 2/23/07**	**121 days**
35	TQS01b Disassemble/inspect	Mon 8/28/06	Mon 10/9/06	30 days
36	TQE02 Assembly	Tue 10/10/06	Wed 12/20/06	50 days
37	Test & analysis	Fri 12/22/06	Fri 2/23/07	40 days
38	**TQS03 & TQC03**	**Mon 8/28/06**	**Thu 9/20/07**	**267 days**
39	Coil optimization	Mon 8/28/06	Mon 10/30/06	45 days
40	Tooling, parts	Tue 10/31/06	Thu 1/11/07	45 days
41	Cable fabrication/insulation	Tue 10/31/06	Thu 1/11/07	45 days
42	Practice coils	Fri 1/12/07	Thu 3/8/07	40 days
43	TQ03 readiness review	Fri 3/9/07	Fri 3/9/07	1 day
44	TQS03 coil fabrication	Mon 3/12/07	Mon 6/4/07	60 days
45	TQS03 Assembly	Tue 6/5/07	Tue 7/17/07	30 days
46	TQS03 test & analysis	Wed 7/18/07	Wed 9/19/07	45 days
47	TQC03 coil fabrication	Mon 3/12/07	Mon 6/4/07	60 days
48	TQC03 Assembly	Tue 6/5/07	Tue 7/17/07	30 days
49	TQC03 test & analysis	Wed 7/18/07	Wed 9/19/07	45 days
50	TQ03 evaluation review	Thu 9/20/07	Thu 9/20/07	1 day



TQ Milestones FY06-07

02/2006	Mechanical Design	• Compare FE analysis results, evaluate goals • Evaluate results from mechanical models • Assess readiness to assemble/test magnets
07/2006	TQ01 evaluation	•Compare test results with expectations •Compare performance of mechanical structures •Evaluate the conductor performance
07/2006	TQ02 readiness	• Evaluate TQ01 coil fabrication results • Evaluate TQ02 conductor and cable • Finalize coil optimization choices • Assess readiness for coil fabrication
03/2007	TQ02 & TQE evaluation	• Evaluate mechanical design optimization results • Evaluate the RRP conductor performance • Assess if stated TQ goals have been achieved • Compare mechanical designs performance • Validate analysis programs & methods • Feedback/recommendations for LQ and HQ

March 2007 Milestone

- Technology demonstration and design evaluation:
  - *consistently achieve G>200 T/m after training and thermal cycle*
  - *evaluate the required design margins (fraction of short sample)*
  - *characterize the mechanical performance of the two structures*
- Support the follow-on model magnet R&D:
  - LQ models:
    - *Provide the optimized coil design and tooling for LQ*
    - *Feedback on coil fabrication methods (integrate with LR)*
    - *Input for structure selection (integrate with DS)*
  - HQ models:
    - *Design methods, coil technology, possibly re-use coils*
    - *Input for structure selection (integrate with DS)*

Goal: achieve these objectives with TQ02 and TQE (TQ03 as backup)

Summary

TQ Progress and Goals:

- Some delay, but overall good progress for TQ01
- Established a performance reference for further optimization
- Updated plan takes into account the new information
- TQ goal #1: provide the required basis for a timely start of LQ
- TQ goal #2: provide the required basis for LQ structure selection

Support of LQ and HQ:

- Modularity of TQ tooling should allow smooth transition to LQ
- TQ coils may be used as inner double-layer for a "phase 1" HQ