LARP Collaboration Meeting
LBNL April 26-28, 2006

LQ Conceptual Design and Analysis

Giorgio Ambrosio

OUTLINE:

- *Goals, Input and Output*
- *Sub-tasks*
- *Status and plans*

Goal, inputs and outputs

GOAL: design study of Long Quadrupole

- 4 m long, 90 mm aperture, G > 200 T/m,

➔ *TQs' design is the baseline*

INPUT from other parts of the magnet program:

➔ TQs fabrication and test performance

➔ LRs fabrication and test performance

➔ Conductor R&D

➔ SQ02 test performance

OUTPUT: analysis and recommendations for

➔ Coil design (quench protection included)

➔ Coil fabrication technology and tooling

➔ Magnet supporting structure

Sub tasks

- **Strand and cable**
  - Define strand and cable characteristics
- **Coil fabrication technology**
  - Define all steps of coil fabrication (procedures and materials)
- **Magnetic design**
  - Develop modifications to TQ magnetic design if necessary
- **Mechanical design**
  - Understand mechanical behavior and impact on performance of TQ
  - Develop new features/designs
- **Analysis and integration**
  - Analyze and compare supporting structures for LQ mechanical design
- **Quench protection**
  - Propose quench protection scheme

New task sheet

In the past months the work for the design of the <u>Long Racetrack</u>, originally thought as a small sub-task of the Long Quadrupole Design Study, has significantly increased.

Therefore it was decided to change the LQ task sheet adding the Long Racetrack in the scope and milestones

a copy f the new task sheet can be found on the LARP web site.

New statement of work

Statement of work:

According to the current LARP Magnet R&D plan the demonstration of Nb3Sn technology for the LHC luminosity upgrade will be performed using 4-m long quadrupoles (LQ) based on the TQ model design and technology. The LQ quadrupoles has to provide a field gradient of 230+ T/m at 1.9 K in the aperture of 90 mm and demonstrate reliable quench performance. The work on LQ will start in FY08 after fabrication and testing series of TQ models and long racetrack coils (LR).

The goal of this task is to perform conceptual design studies of LQ quadrupoles in order to determine their optimal design, technology and target parameters. The studies include analysis of data collected during fabrication and test of TQ model magnets (mechanical structure evaluation) and LR racetrack coils; analysis and comparison of Nb3Sn strand and cable parameters; magnetic, mechanical and quench protection analysis and optimization. Based on these studies the proposals for the LQ R&D phase including LQ design and parameter, baseline technology, cost and schedule will be prepared.

This task includes also the completion of the design of the Long Racetracks addressing all issues still open (for instance quench protection, choice of segmented or single shell, and effects of different thermal contractions) and the generation of a design report for each Long Racetrack.

New milestones

FY2006 Milestones:

- Analysis of long coils during heat treatment and cooldown (Q1-Q4)
- Completion of LRS01 design and generation of design report (by end of April 06)
- Quench protection analysis of LQ based on TQ coils (Q2-Q3)
- Specification of strand and cable parameters for the LQ practice coils and first model to procure in FY2007 (Q4)
- LQ coil conceptual design finalization (Q4)

FY2007 Plan:

- Completion of LRS02 design and generation of design report (Q1)
- Development of LQ coil fabrication technology based on TQ and LR01 coil fabrication and performance (Q1-Q2)
- Selection of LQ mechanical structures based on TQ series performance and analysis (Q2-Q3)
- Develop technical proposal for LQ R&D including model design parameters, baseline technology, cost estimates and schedule
  - draft technical proposals for FY2008 at LARP collaboration meeting (Q2)
  - final proposals for FY2008 (Q4)

LRS01 Design Report

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DESIGN OF THE FIRST LARP LONG RACETRACK MAGNET (LRS01)

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Abstract:

The LHC Accelerator Research Program (LARP) is developing, Nb_3Sn quadrupole magnet models for a luminosity upgrade of the Large Hadron Collider (LHC). A major milestone in this development is to assemble and test two 4m-long quadrupole cold masses by the summer of 2009.

These quadrupole magnets will be the first Nb_3Sn accelerator magnet models significantly longer than 1m, approaching the length of real accelerator magnets. The design is based on the LARP Technological Quadrupoles (TQ), with gradient higher than 200 T/m and aperture of 90 mm, made of two layers without interlayer splice. The mechanical design will be chosen between two designs presently explored for the TQs: traditional collars and Al-shell based design (preloaded by bladders and keys).

The fabrication of the first long quadrupole model is expected to start in the last quarter of 2007. Before that 4m-long racetrack coils will be fabricated and tested in an Al-shell based supporting structure. They will allow a quick start in addressing several issues related with the fabrication of long Nb_3Sn coils. The design of the first Long Racetrack magnet (LRS01), including

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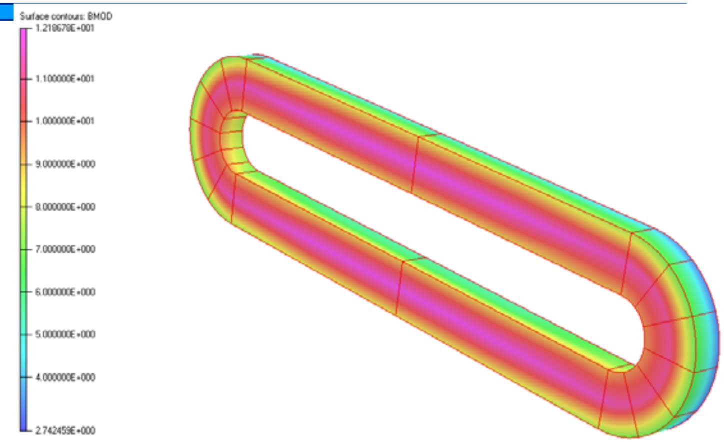
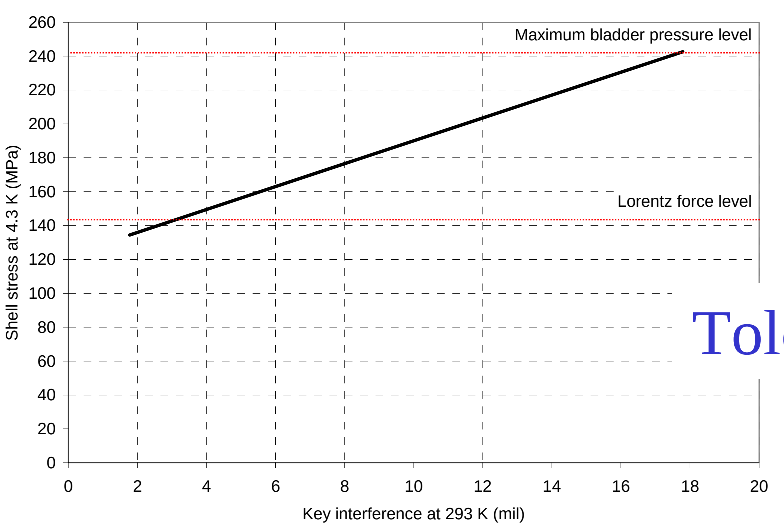
LR – Design Report I

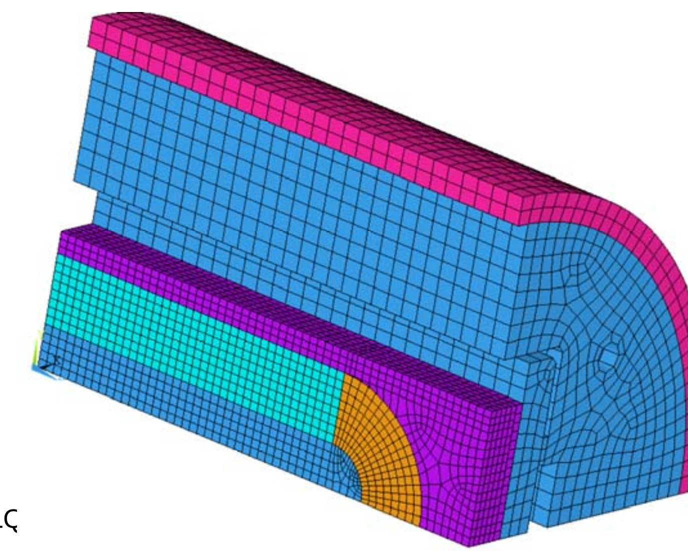
CONTENTS



3D Magnetic and mechanical analysis

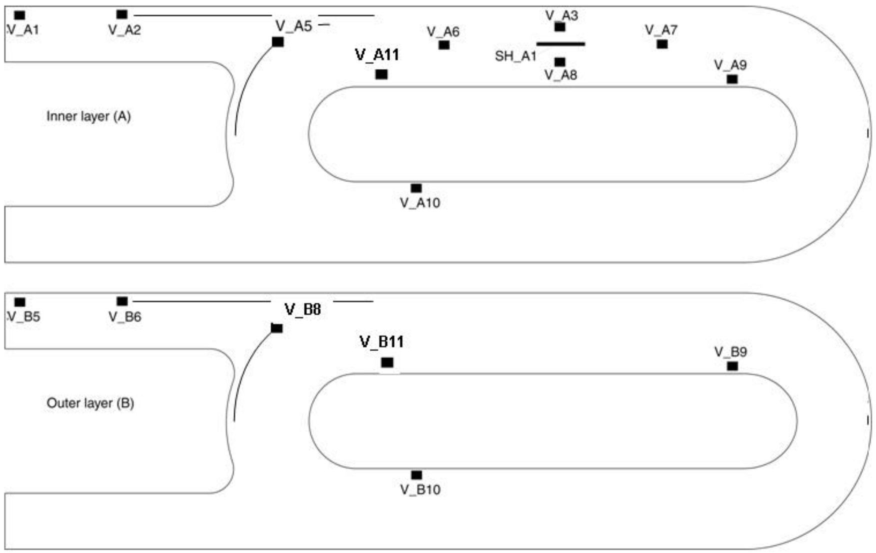


Tolerance analysis

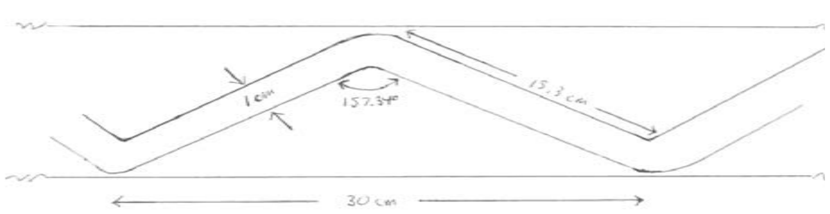


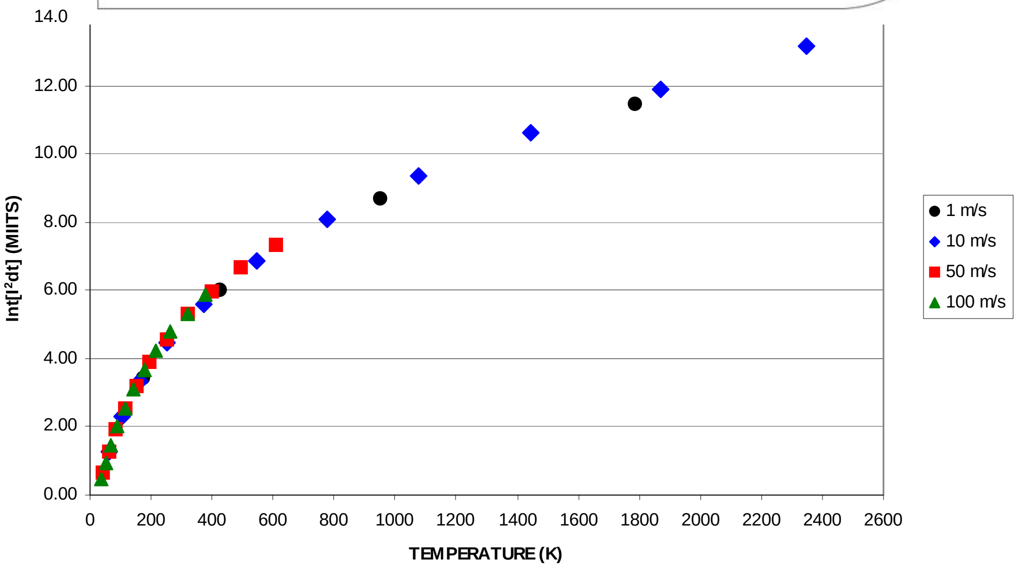
LR – Design Report II

CONTENTS



Quench protection system





Conductor

The Material group is looking at:

- **Possible conductor designs with different <u>copper-to-non-copper ratio</u> in order to know all possible options (and the possible need of development) for the Long Quadrupole**
- **Optimal conductor design (strand & cable) with <u>largest "tolerance" for long unit length</u>**
  - Optimal strand design
  - Optimal cable parameters

Insulation

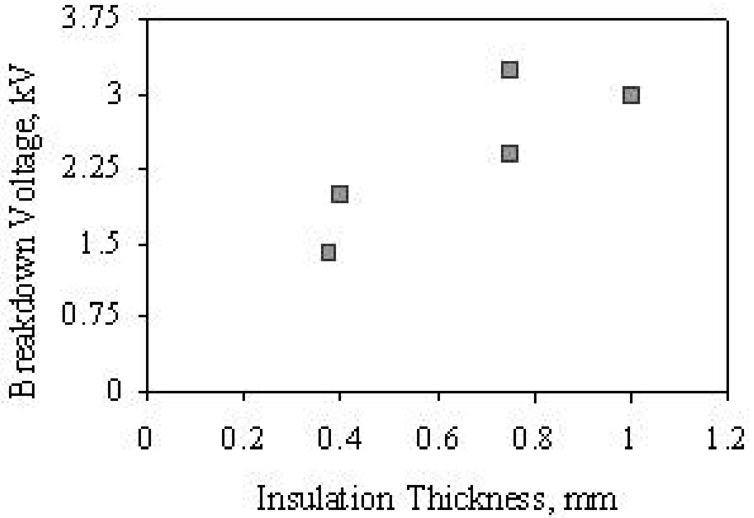
- **We are exploring the option of braiding the insulation on the cable (same small thickness as sleeve, and much easier application to long cable units).**
  - A sample with this kind of insulation (made at NEEW) is being prepared for electrical tests (both before and after transverse pressure application).
- **We are going to test the electrical strength of a TQ practice coil used in mechanical models**
  - Turn-to-ground, layer-to-layer, turn-to-turn

Voltage breakdown vs. thickness

VB vs. thickness

This plot summaries the data presented in the previous slide. The dielectric breakdown strength of the epoxy impregnated ceramic insulation can be estimated from the plot to be 3.5 kV/mm. Note that for a solid ceramic insulation material impregnated with epoxy, the dielectric breakdown strength is 80 kV/mm [2].

This huge difference could be attributed to the fact that the tests described in this paper were **performed on an actual magnet**, which could contain some defects such as voids. Furthermore, the magnet was **tested in superfluid helium bath** and the helium gas could still be trapped inside the coil.



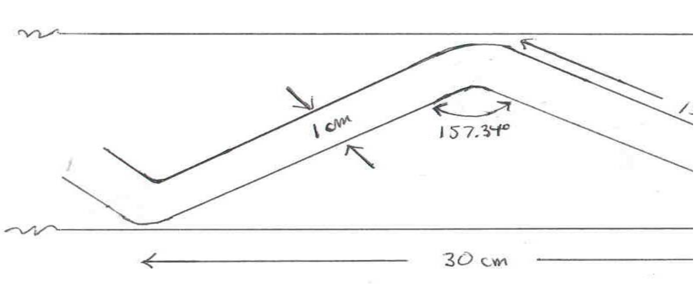
[2] J. Rice, et al., "Mechanical and electrical properties of wrappable ceramic insulation", *IEEE Trans. on Applied Superconductivity*, Vol.9, No.2, pp. 220-223, June 1999

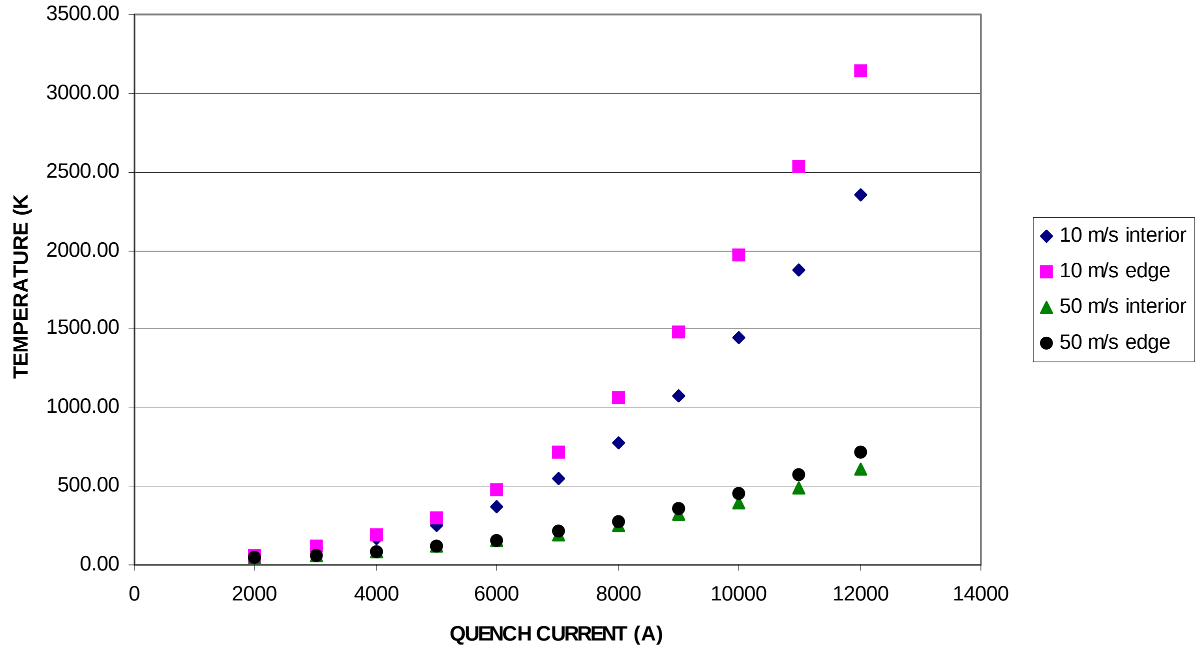
Insulation

- **CTD has developed a new ceramic binder that should replace the present ceramic binder (1008) at significantly lower cost and also shorter procurement time.**
  - Qualification tests (compatibility with coil fabrication process, electrical strength, coil sample mechanical properties, thermal conductivity) of cable stacks fabricated with this new binder are underway.

Quench Protection

- **Presently we are working on the quench protection of the Long Racetrack. This is useful to fine-tune the simulation codes, collect material properties, and design protection heaters that will be used for the Long Quadrupole.**

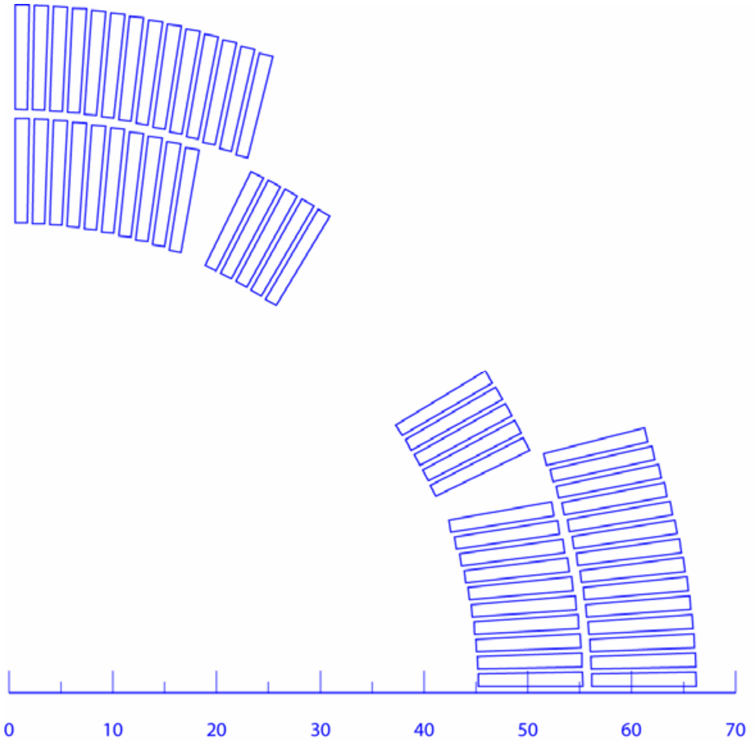




Magnetic design

- **A <u>2D magnetic design</u> was developed with a <u>thick cable insulation</u> (250 um) as close as possible to the present TQ design.**
  - It will be used together with insulation strength measurement and quench protection analysis in order to evaluate pros and cons of different cable insulation thickness.

Magnetic design w thick ins.



Parameter	Unit	Value
N of strands	-	**27**
Strand diameter	mm	**0.700**
Bare width	mm	**10.050**
Bare inner edge thickness	mm	**1.172**
Bare outer edge thickness	mm	**1.348**
Cabling angle	deg.	**15.5**
Keystoning angle	deg.	**1.000**
Radial insulation thickness	mm	**0.250**
Azimuthal insulation thickness	mm	**0.250**
Copper to non-copper ratio	-	**1.000**

Magnetic design comparison

Parameter	Unit	~TQC	Thick Ins
N of layers	-	**2**	**2**
N of turns	-	**136**	**116**
Coil area (Cu + nonCu)	cm^2	**29.33**	**25.01**
Assumed non-Cu J_c at 12 T, 4.2 K	A/mm^2	**2400**	**2400**
4.2 K temperature			
Quench gradient	T/m	**223.5**	**209.3**
Quench current	kA	**13.47**	**14.94**
Peak field in the coil at quench	T	**11.6**	**11**
1.9 K temperature			
Quench gradient	T/m	**240.6**	**226.1**
Quench current	kA	**14.57**	**16.23**
Peak field in the coil at quench	T	**12.5**	**11.9**

- 5 turns/coil

- 6%

+ 11%

Copper/non_copper ratio = 1 in both designs

Status and plans

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Conductor, insulation, quench protection, magnetic design

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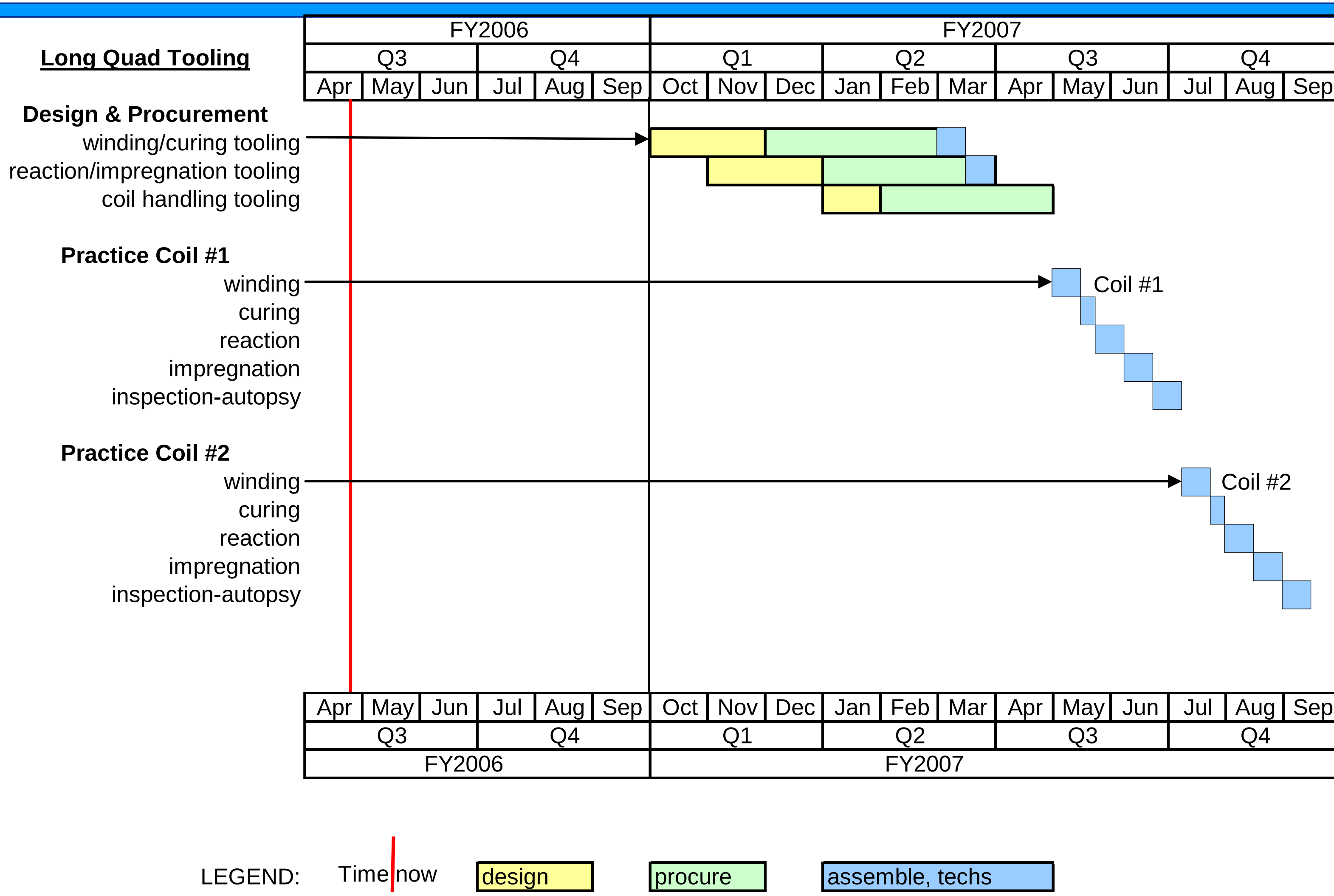
Infrastruct. & Tooling for Long Coils

- **Purpose**
  - Infrastructure & tooling shakedown & commissioning prior to LQ coil fabrication
    - Based on TQ cross section until LQ design is complete
    - Assumes parting plane to pole angle geometry and inner radius of LQ remains the same as TQ design
- **Advantages**
  - Infrastructure is debugged, most of tooling is designed and procured for LQ
    - Winding, reaction & impregnation tooling used for 1 copper coil & one Nb_3Sn coil.

Schedule


FY2006
FY2007
Q3 Q4 Q1 Q2 Q3 Q4
Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
Long Quad Tooling
Design & Procurement
winding/curing tooling
reaction/impregnation tooling
coil handling tooling
Practice Coil #1
winding
curing
reaction
impregnation
inspection-autopsy
Coil #1
Practice Coil #2
winding
curing
reaction
impregnation
inspection-autopsy
Coil #2
LEGEND:
Time now
design
procure
assemble, techs