Design Study of 15T Superconducting Magnet with Nb3Al cable in KEK

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KEK

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Contents

- Introduction
- Nb3Al Strand/Cable Development
- Magnet Design Study
  - 2D model
    - Magnetic Design
    - Mechanical Design
- Bladder test
- Future plan

Introduction

- LHC luminosity upgrade
  - Plan to exchange the magnets
    - Radiation damage
    - $L=10^{34}$ ⇨ 10^{35} /cm²/s
- Development of High field magnet
  - Nb_3Sn
    - US LARP (LHC Accelerator Research Program)
    - Europe (CERN, CEA/Saclay)
  - *Nb_3Al*
    - *Japan (KEK and NIMS)*

Advantage of Nb_3Al

- Better strain tolerance

Transverse Pressure vs Normarized Ic

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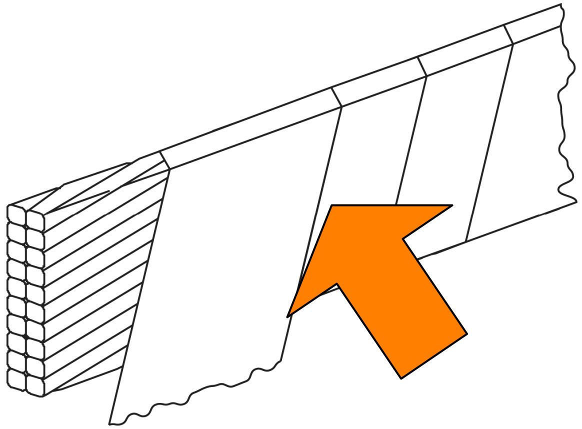


- Interesting candidate for use in high field accelerator magnets

Presented at MT-20
By A. Kikuchi et al.

Development items

- Strand development (KEK and NIMS)
  - higher non-Cu Jc
  - Cu stabilization technique
  - reduce low-field-magnetization

- Cable development (NIMS and Fermilab)
  - trial fabrication
    - packing factor
  - low field instability study
    - magnetization, twist pitch

Rapid Heating Quench Method

Mono-filament

↓

Multi-filament

↓

Precursor (Nb/Al)

↓ ← Rapid Heating Quenching (RHQ)

(Nb/Al)ss — Strand w/o Cu

↓

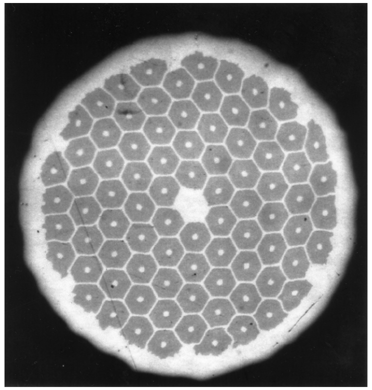
Cu stabilization

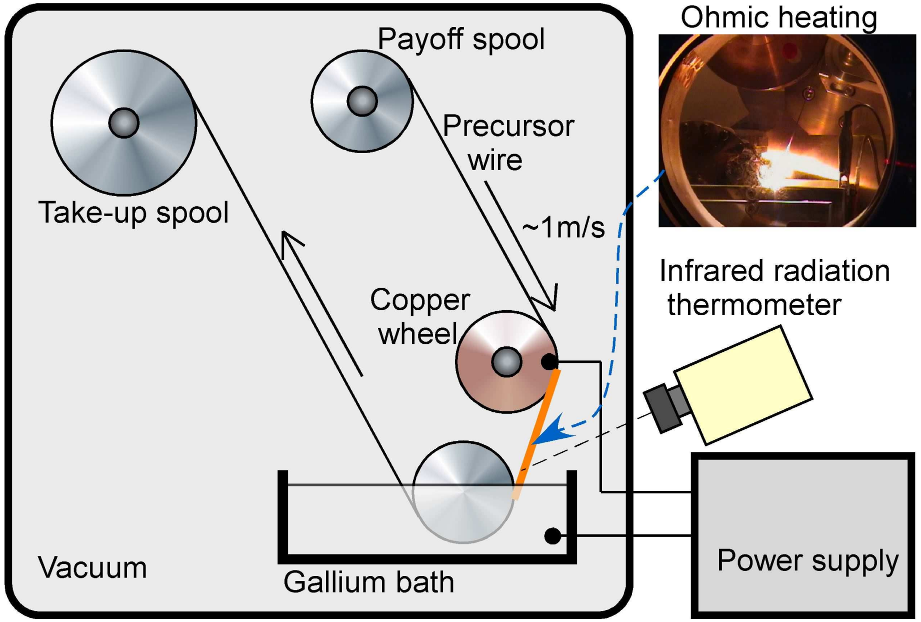
↓

Area reduction

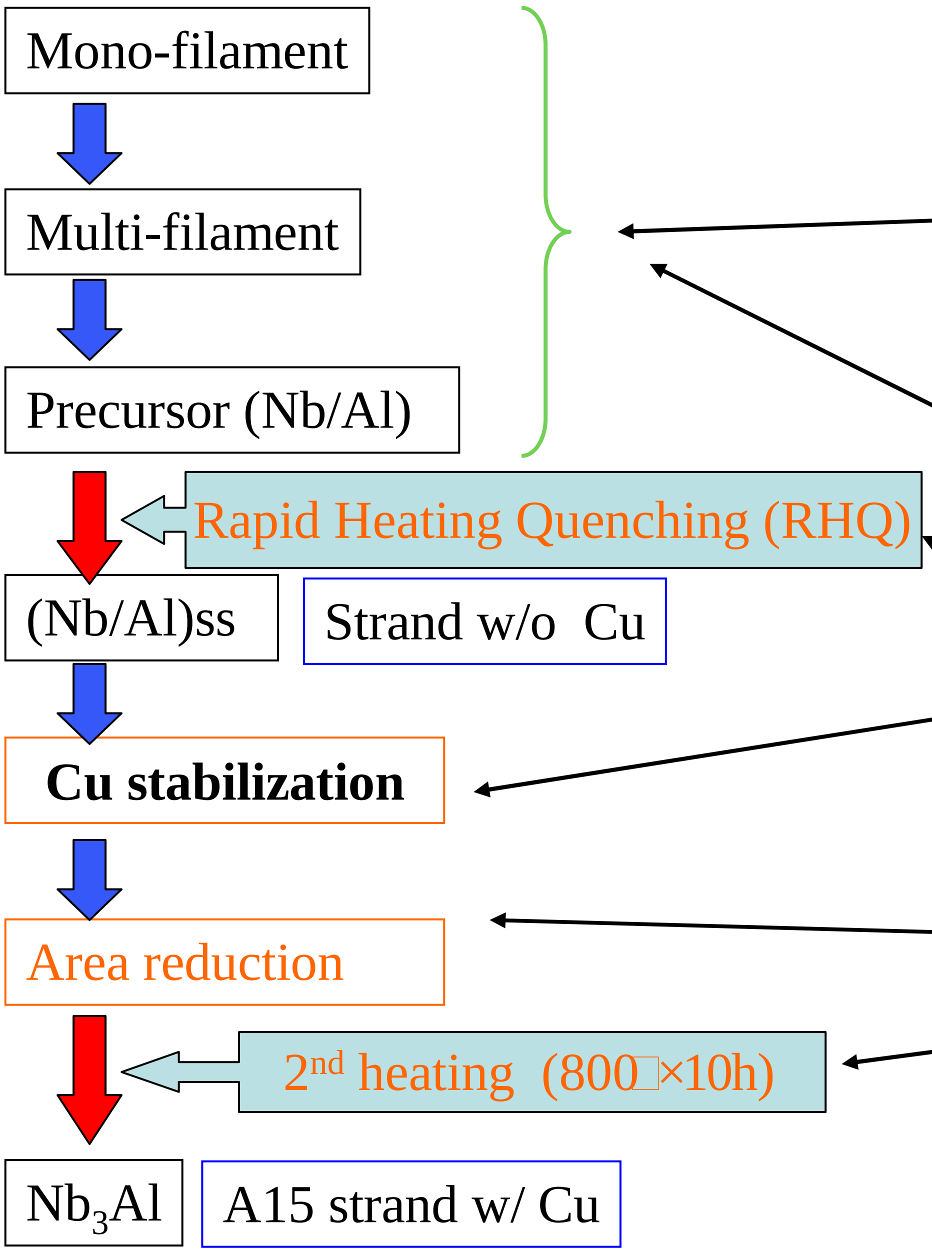
↓ ← 2^{nd} heating (800□×10h)

Nb_3Al — A15 strand w/ Cu





Parameters



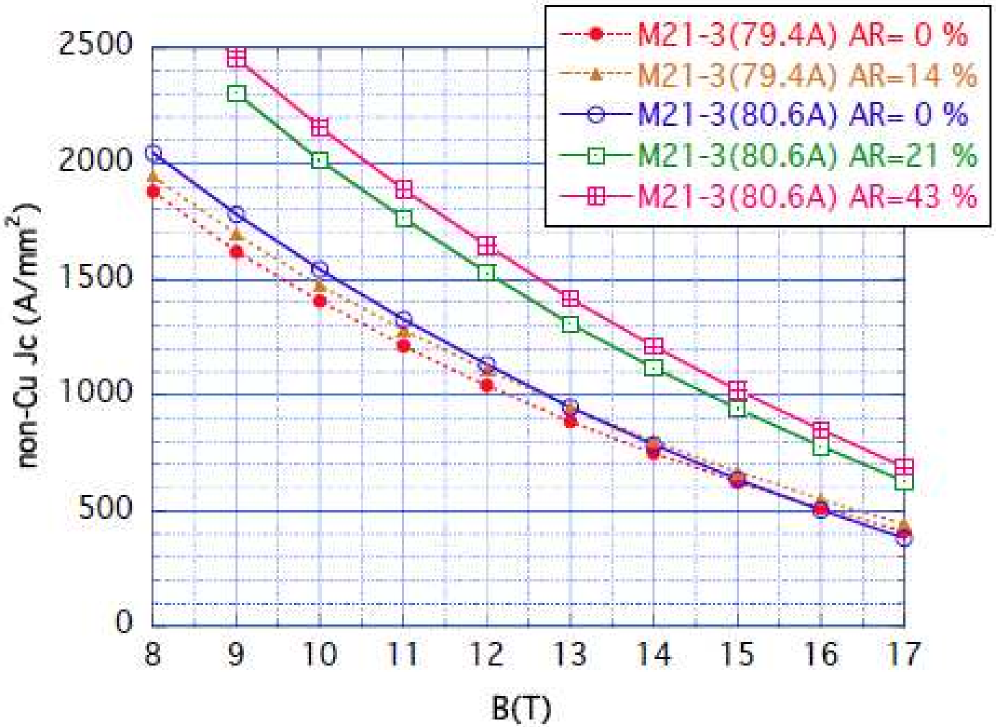
- Parameters
  - Filaments
    - Diameter
    - Distance btw fila.s
  - Material of matrix
    - Nb or Ta
  - RHQ current
  - Cu plating
    - Bonding strength
    - Plating speed
  - Ratio of area reduction
  - 2nd heating
    - Temperature
    - Time

Many parameters !

Parameter survey ~ Improvement of Jc

	M21-3	ME396	ME451	ME458	ME476
Matrix	Nb	Nb	Nb	Nb	Ta
Matrix ratio	0.8	0.6	0.69	0.79	0.8
No. of fila.	144	294	294	546	222
Wire dia. (mm)	0.8	0.8	1.37	1.35	1.35
Fila. dia. (mm)	51	38	62.7	44.2	69
Twist Pit.(mm)	32	32	55	non	54

- *Highest Jc*
  - *1021 A/mm² @ 15 T*



<u>Further study is ongoing</u>

Continuous Cu electro-plating apparatus

In order to obtain good mechanical, electrical and thermal bonding → Ni strike plating process

Nomura plating corp.

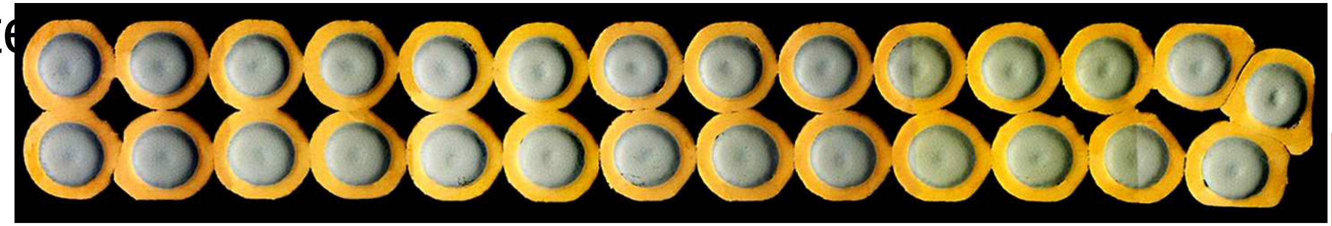
~1.5 m/h

~170 μm Cu

Further improvement is in progress

Development of Rutherford cable

- Dr. Kikuchi (NIMS)
- 1 km-class strand was developed.
- In 2007, Rutherford cable with 27 strand was successfully fabricated in collaboration with Fermi lab. (presente

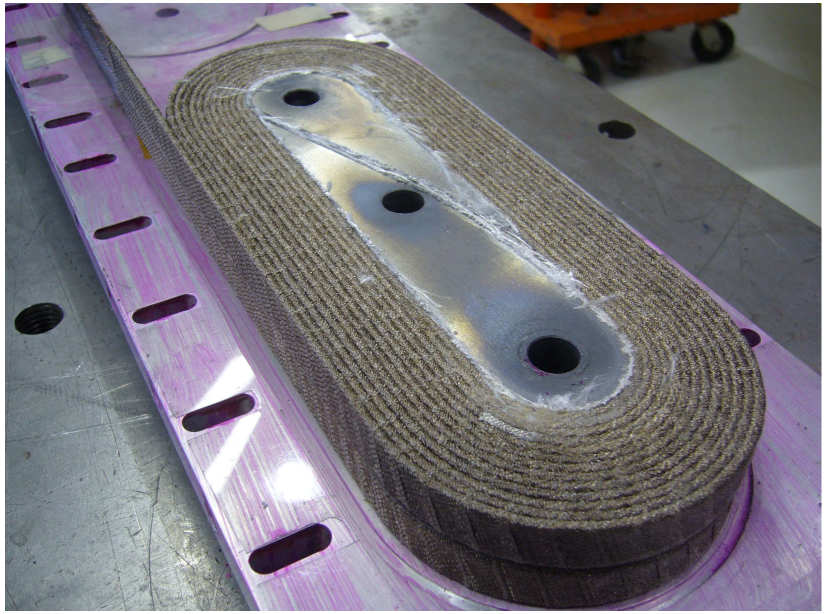


F3

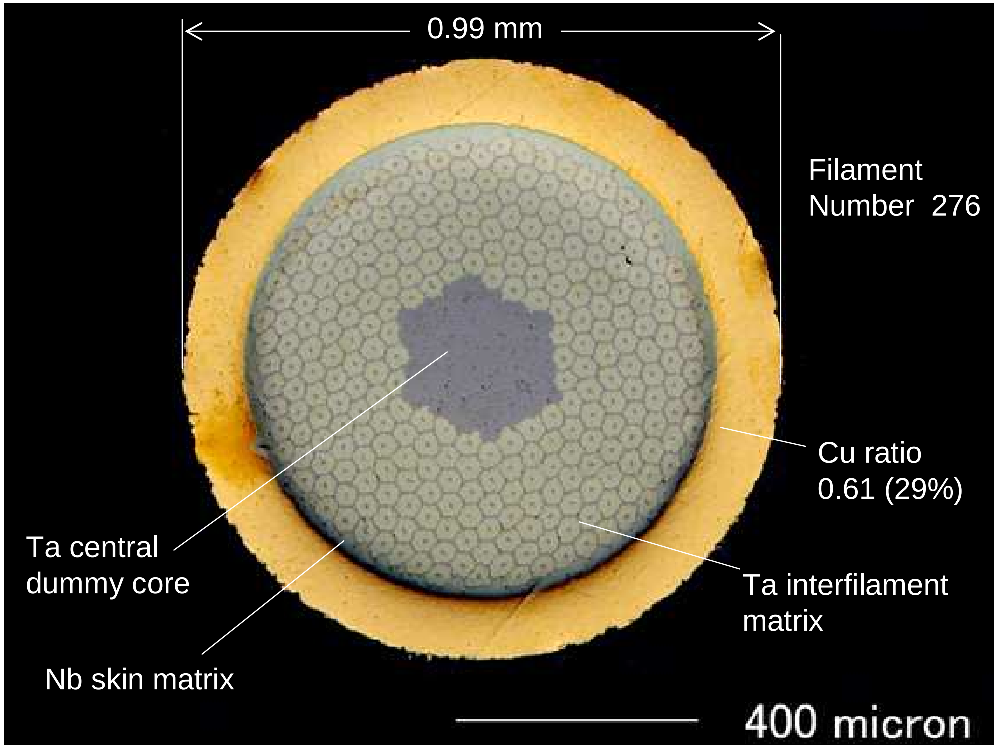
- Small racetrack magnet was fabricated and tested in Fermi lab. (presented at MT20)

8.7 T

***@ 21.8 kA,* 3.95 K**



Latest results



- New strand
  - Reduced Cu ratio
    1 -> 0.61
    (to increase *Ic*)
- Preliminary Results
  - Short sample meas.
    - Ic: ~10 % increase
    - No flux jump @ 4.2K

Fabricated 28 strands rectangular cable (F4)

Test results will be presented at ASC'08

Next Strands

- KEK
  - Inter filament : *Ta*
  - Barrier btw fila.: *Ta*
  - Central dummy: *Ta*
  - Skin: *Ta*
  - ~ 1 km
- NIMS
  - Inter filament : Nb
  - Barrier btw fila.: *Ta*
  - Central dummy: Nb
  - Skin: Nb
  - ~ 1 km

Cu ratio:
0.6 ~ 0.75

Central dummy

Inter fila.

Barrier

Skin

Rutherford cable will be fabricated, this summer.

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Magnet Development

- Small race track coil with Nb_3Al was fabricated and tested successfully in Fermi Lab.

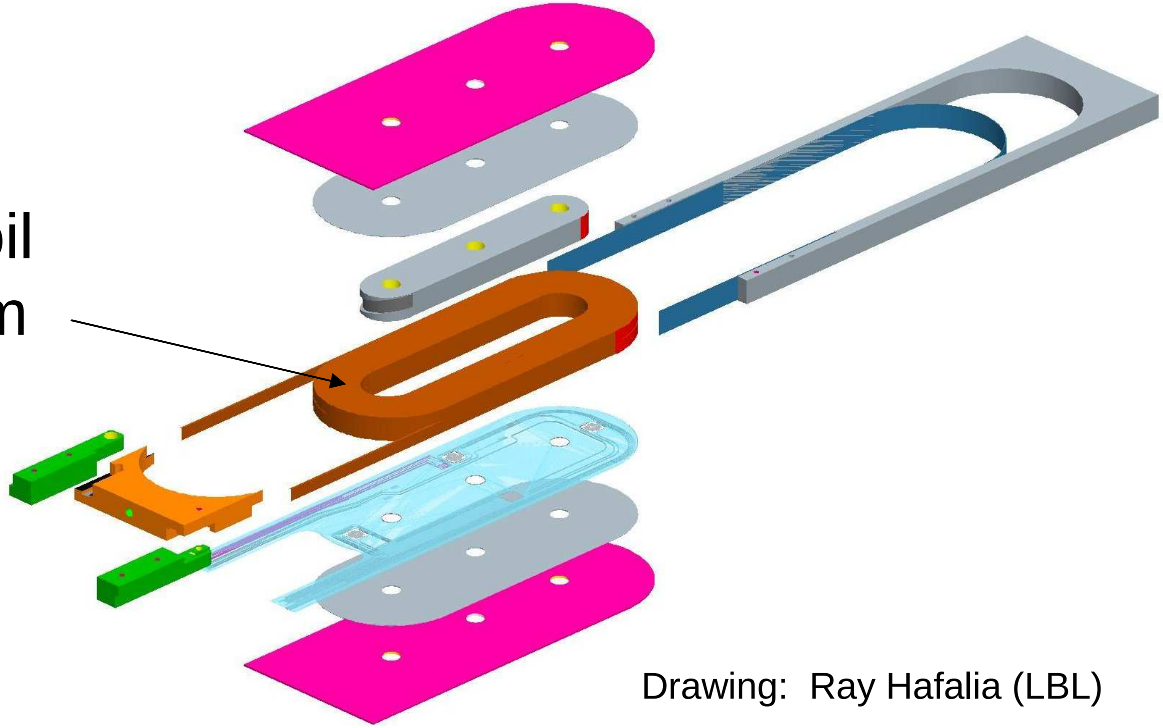
↓

- High field magnet development program has been started since last year, in parallel with the strand/cable R&D.
  - Visit LBL (July '07 - June '08)
    - Learn fabrication technology of Nb3Sn coil for near future development of Nb3Al coil
    - Design Nb3Al subscale magnet

Design study

- First goal of this program
  - 15 T subscale magnet for demonstrating the feasibility of high field magnet with Nb3Al.

•Subscale coil
2 layer race track coil
~200 x 100 x 17 mm



Drawing: Ray Hafalia (LBL)

Basic design concept

- Shell structure
    - Easy assembly and disassembly
- Common coil
    - Simple structure compared with Block dipole
- Use Nb_3Sn subscale coils as backup coils
    - Save the Nb3Al cables
        - Already borrowed 2 subscale coils from LBL

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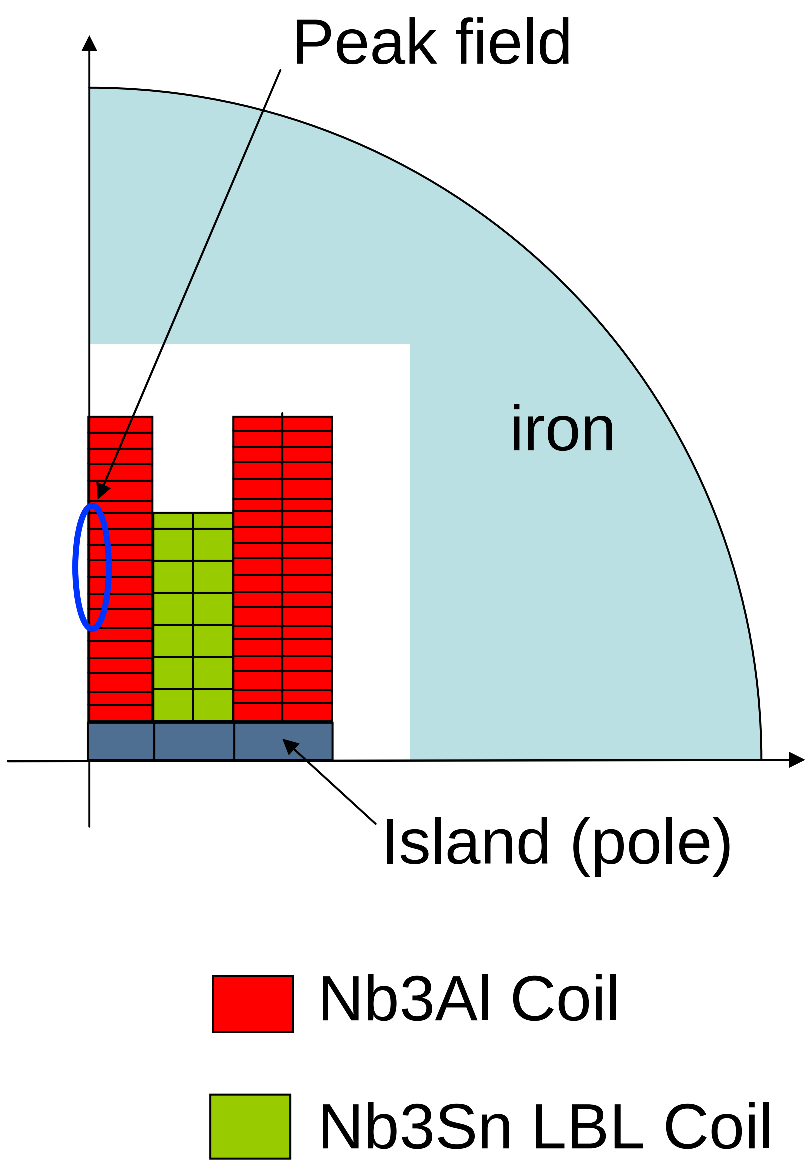
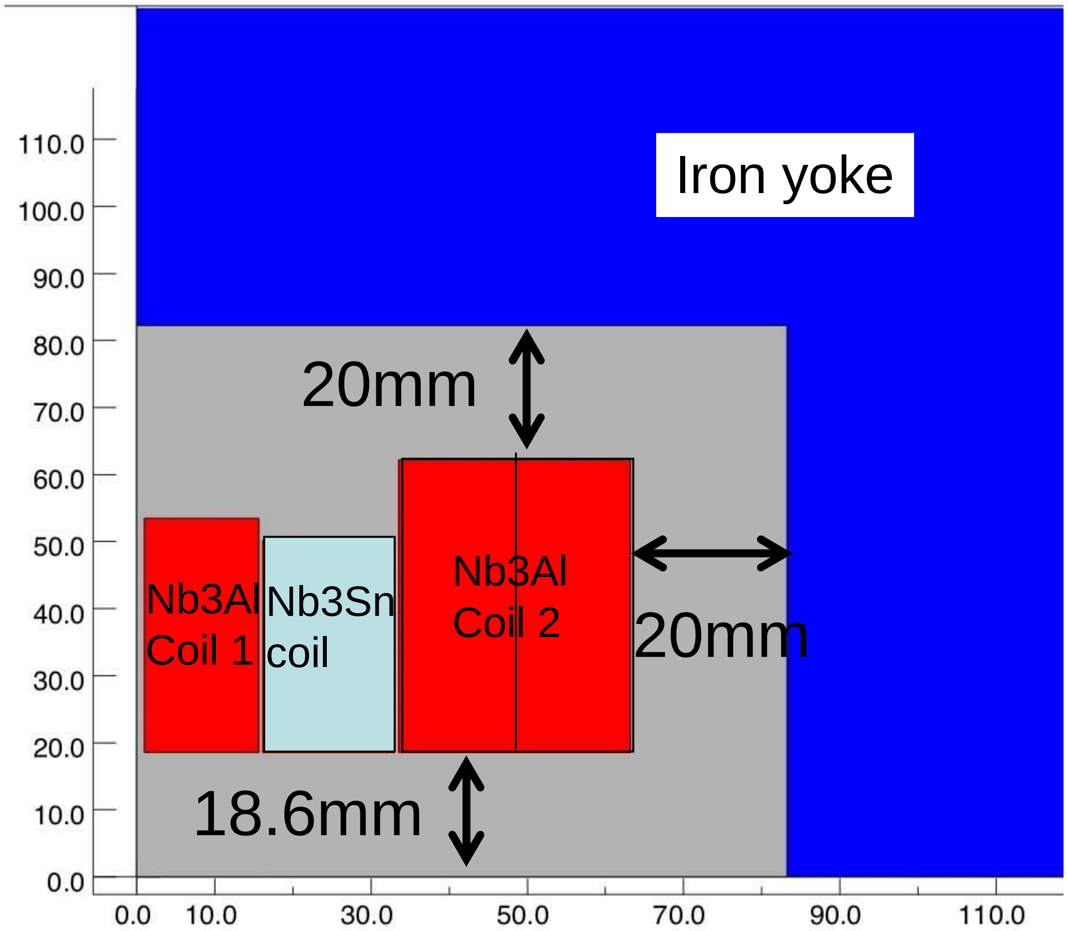
2D Magnetic Design



- Place Nb_3Sn coils between Nb3Al coils
  - Jc
    - Nb3Sn >> Nb3Al

Take advantage of higher Jc to push up peak field

2D Magnetic Design



- Strand parameter
  - Strand Dia. : 1mm
  - Cu ratio : 0.75
  - non-Cu Jc = 873.8 A/mm2 @ 15 T
  - Cable insulation□ 0.25mm

<u>Parameter survey</u>

- No. of strands
- Yoke diameter
- No. of
  - Turns
  - layers

- Conditions
  - Gap btw Coil - yoke : 20mm constant
  - Island width 18.6 mm constant

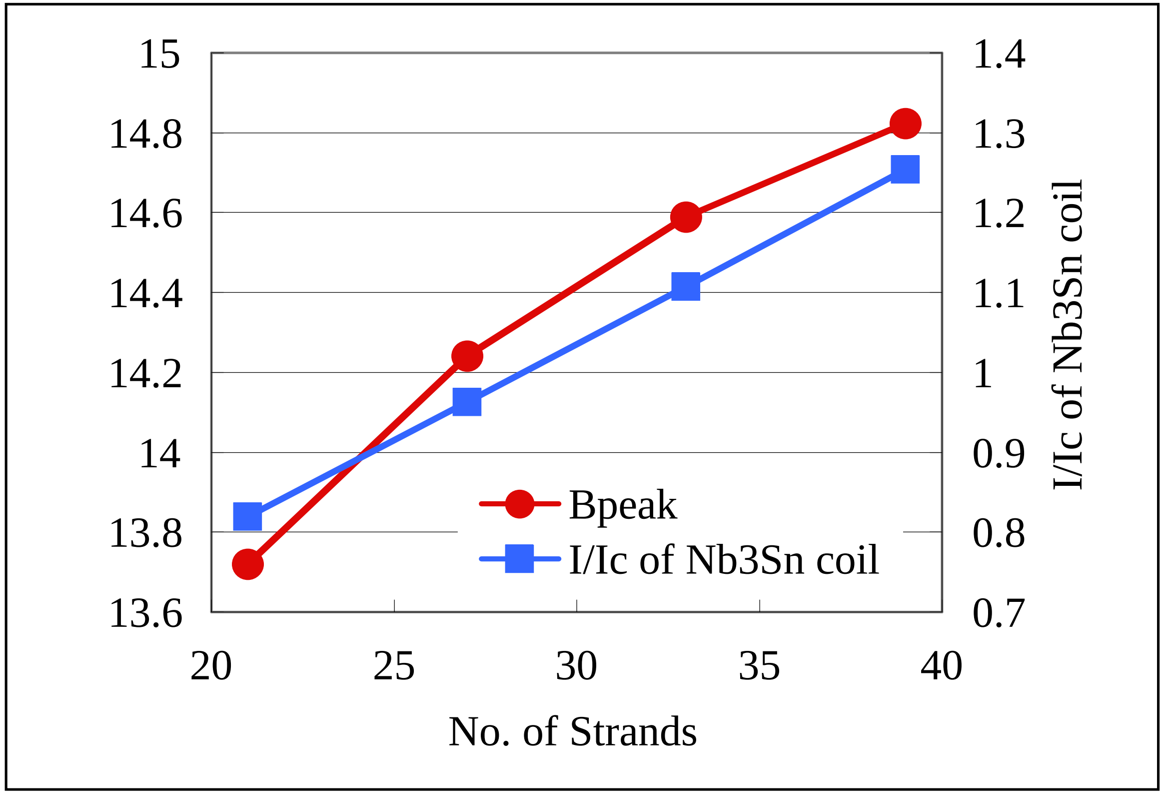
No. of strand Optimization

○Increase -> transfer current↑

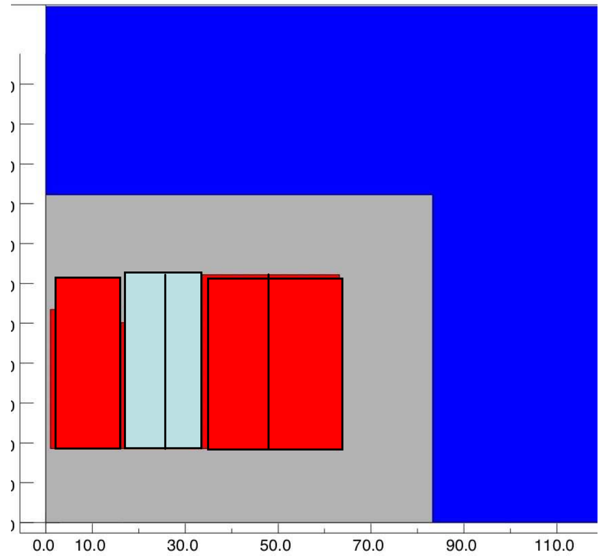
-> J (A/mm^2) in Nb3Sn Coil↑ -> Field↑

× Increase -> cable width↑

-> Nb3Sn Coil moves outward -> Field↓



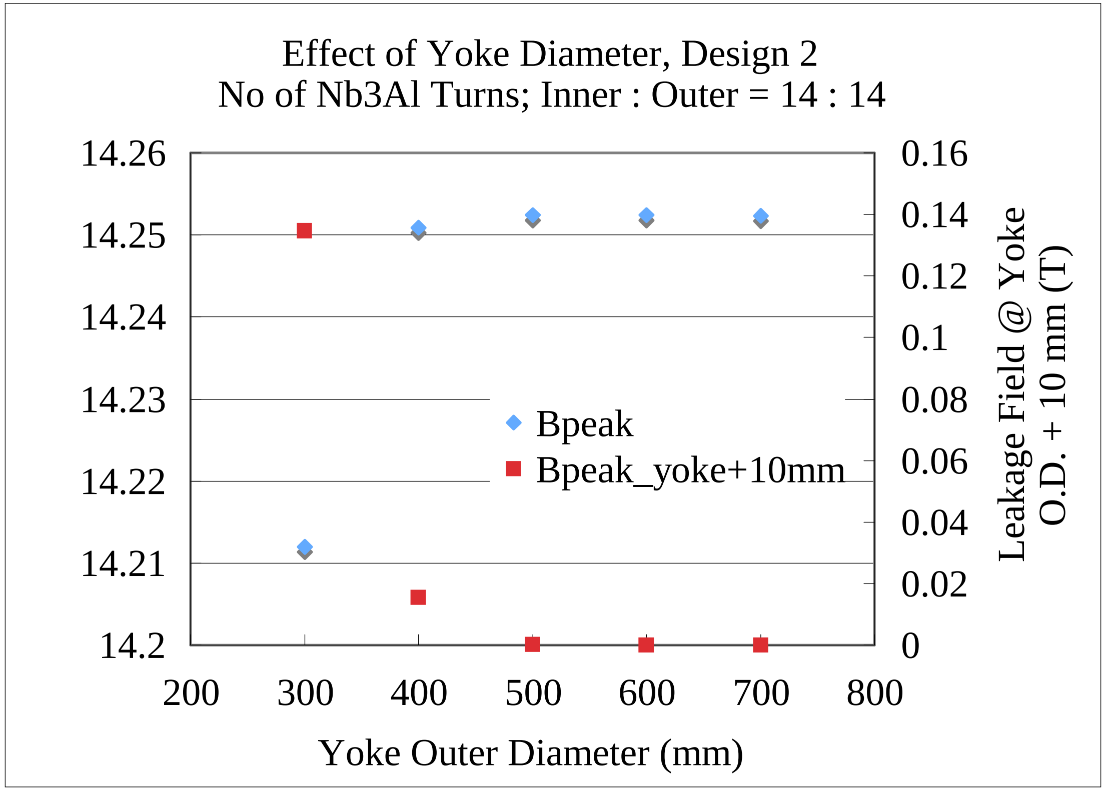
Inner: 1 layer, 14 turns
Outer: 2 layer, 14 turns

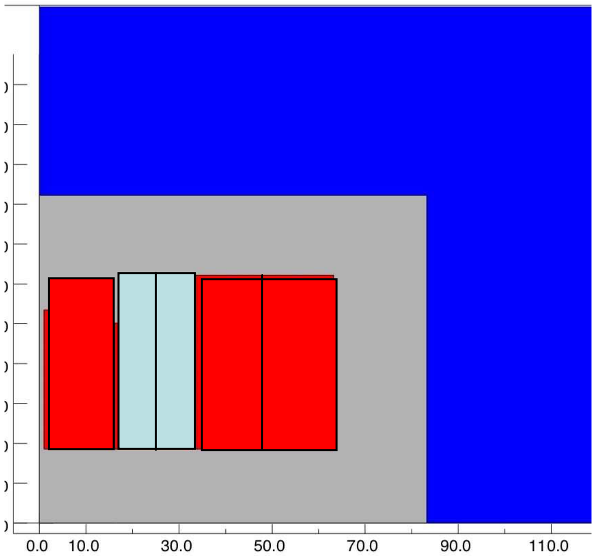


No. of Strand = 27

Yoke diameter Optimization

Inner: 1 layer, 14 turns
Outer: 2 layer, 14 turns

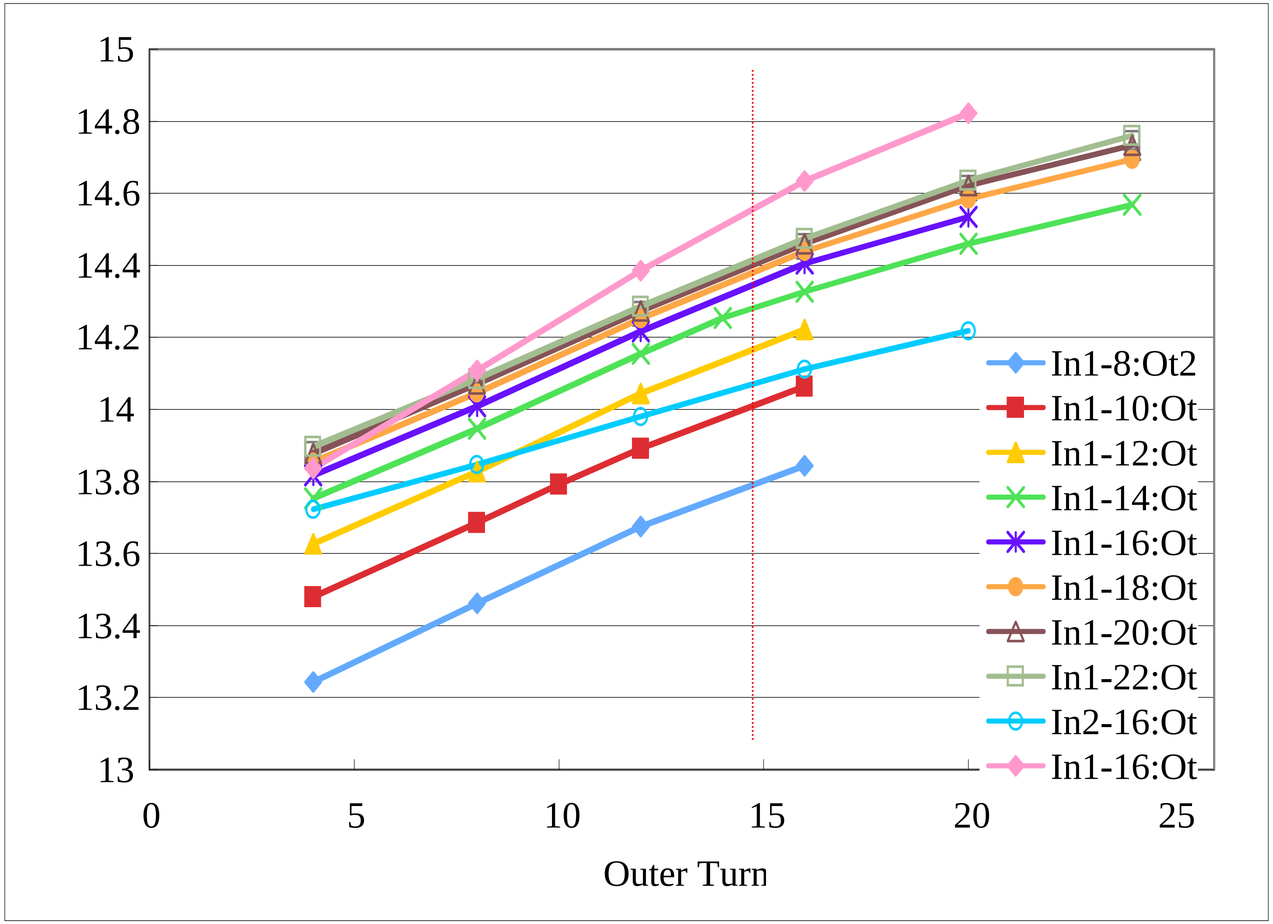


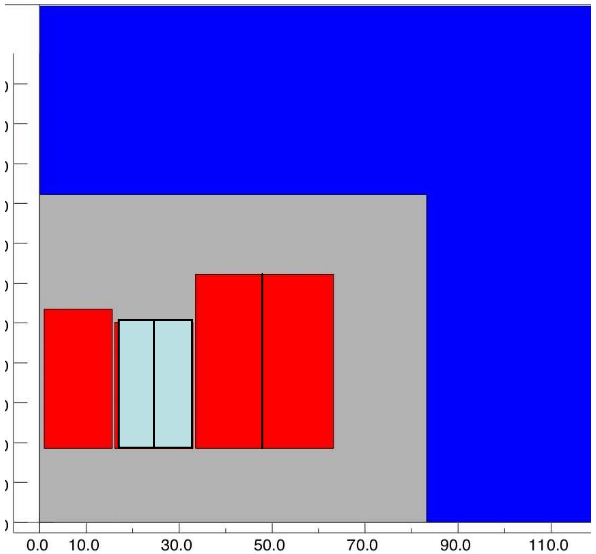


Diameter > 400mm : OK

No. of Turns & layers□Optimization (1)

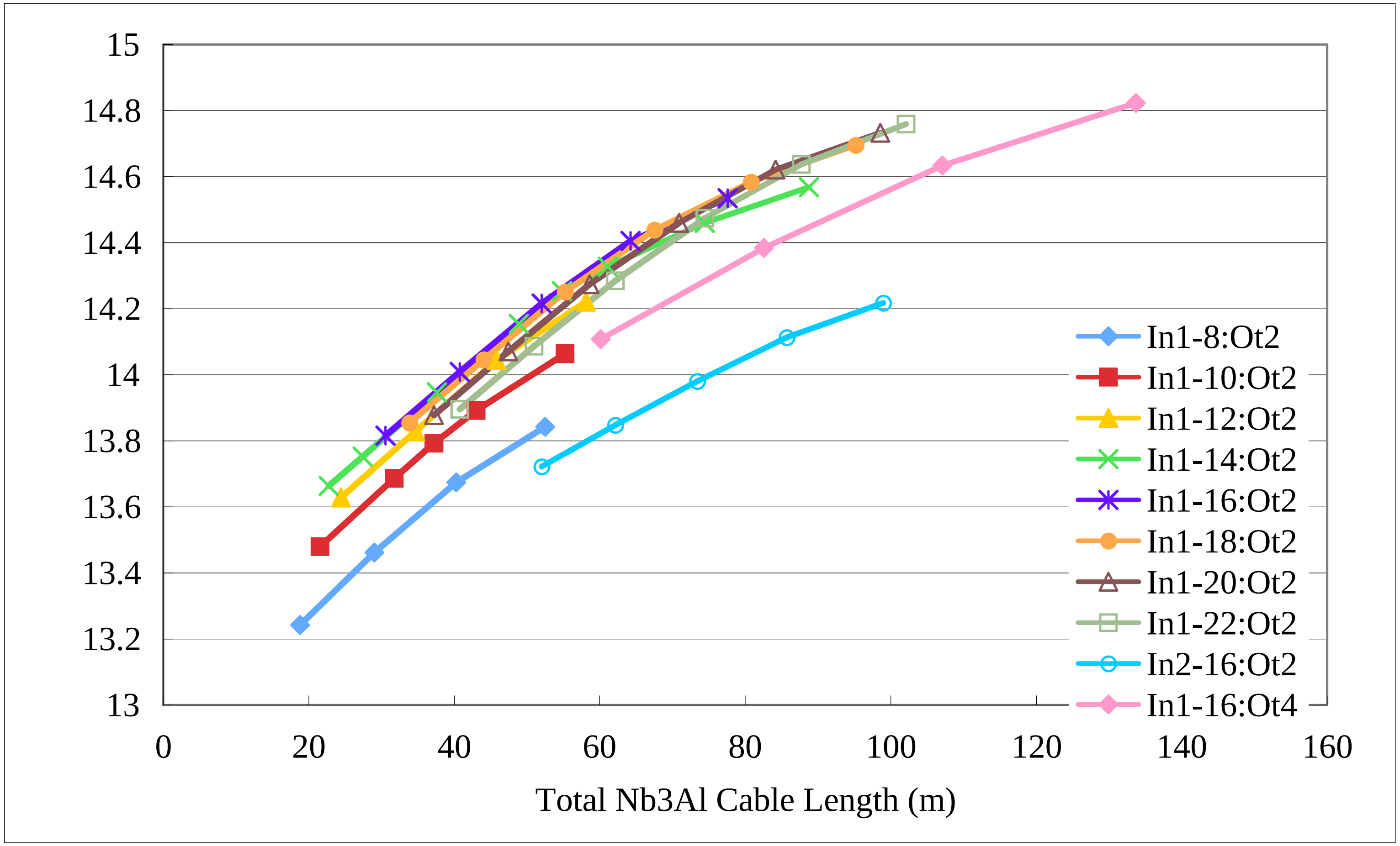
- Yoke Dia.□600 mm





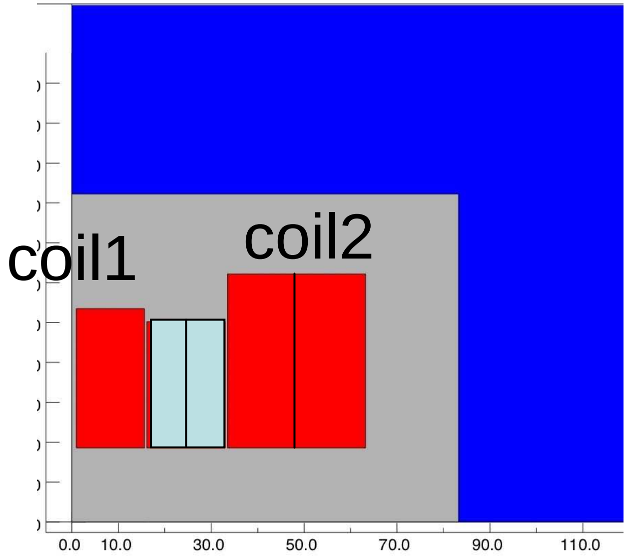
No. of Turns & layers□Optimization (2)

- Yoke Dia.□600 mm



Inner: 1 layer 14 turn, Outer: 2 layer 14 turn

Magnetic design ~ summary



- No. of strands□ 27
- Yoke Dia.□ >400 mm
- Coils
  – Coil 1 (Inner) :
    - 1 layer, 14 turns in quadrant

      -> *Common coil type, 2 layers, 14 turns*

  – Coil 2 (Outer) :
    - *Double Pancake type, 2 layers, 14 turns*

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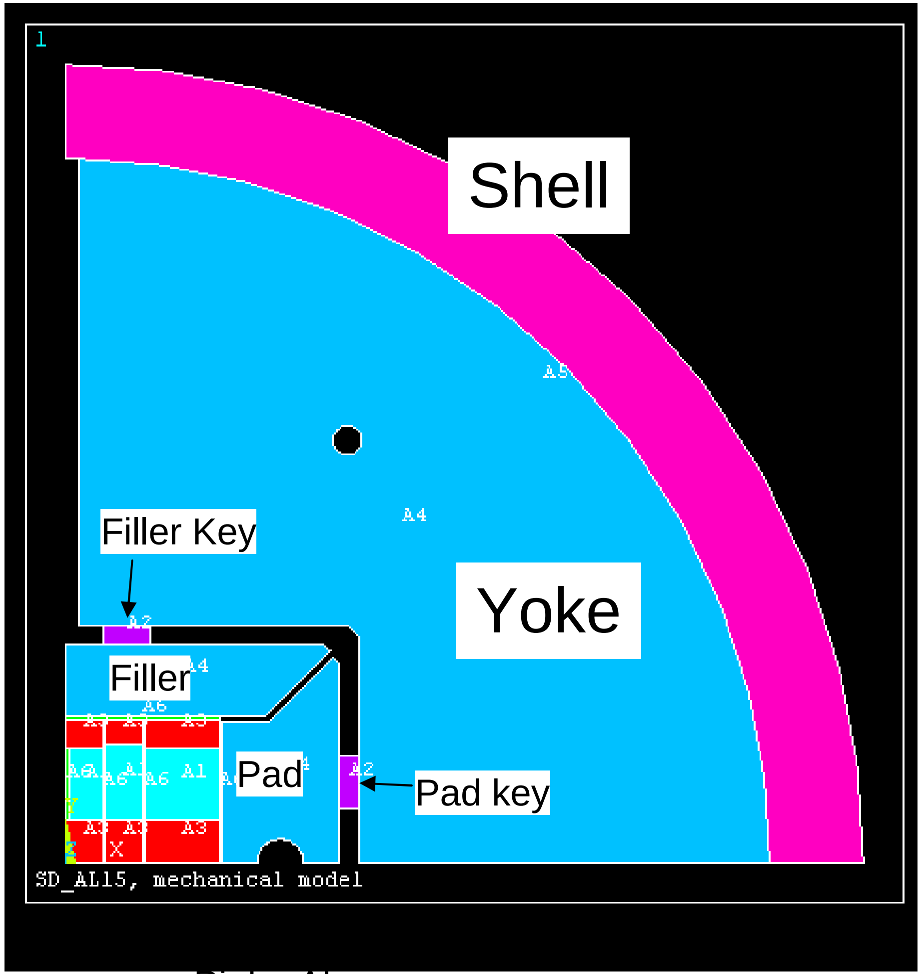
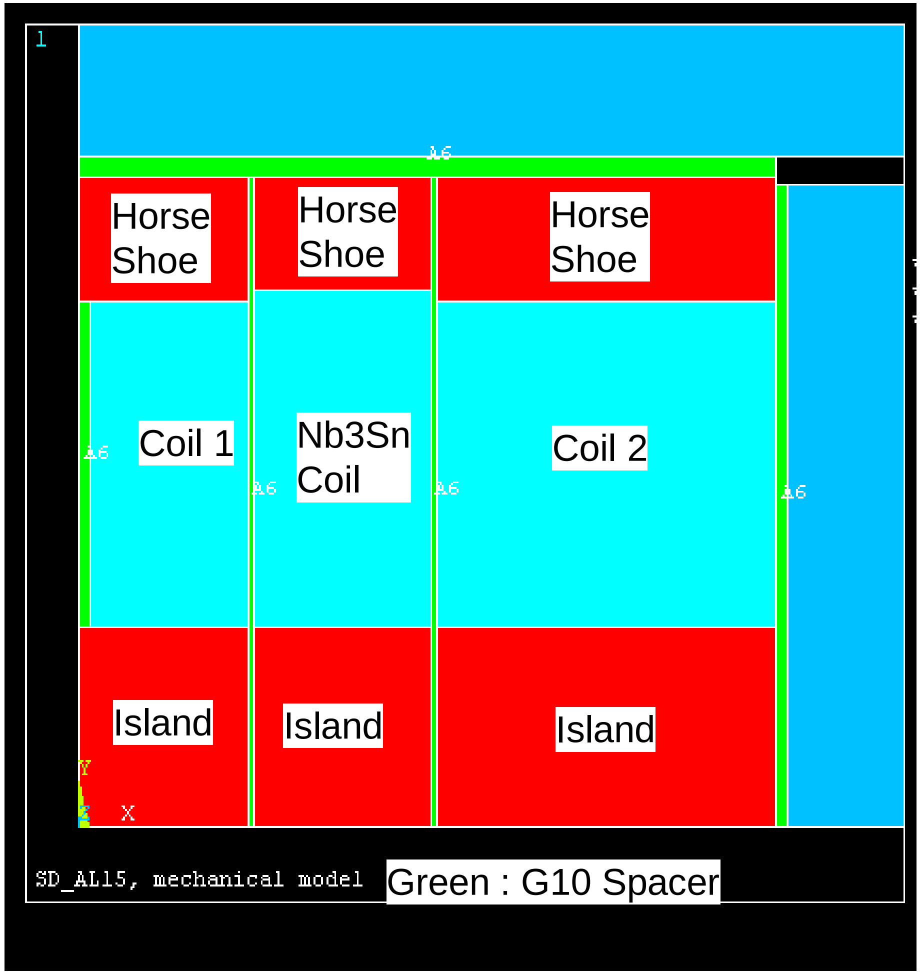
Mechanical Design Optimization

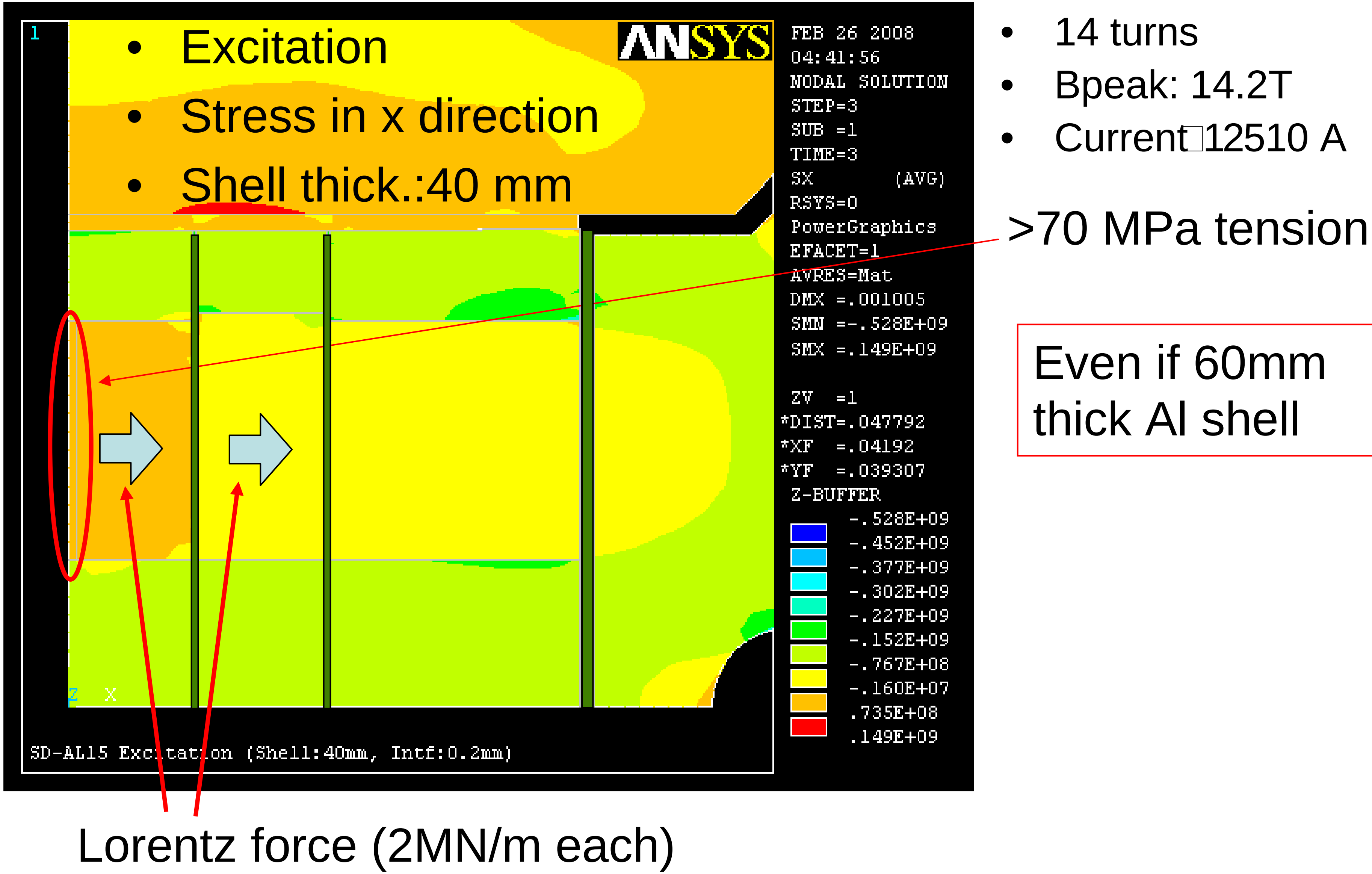




- Pink : Al
- Blue : Iron
- Light blue : Coil
- Red : Aluminum Bronze
- Green : G10
- Purple : SUS

1. Bladder operation
2. Cooling down (4.2K)
3. Excitation (short sample limit)

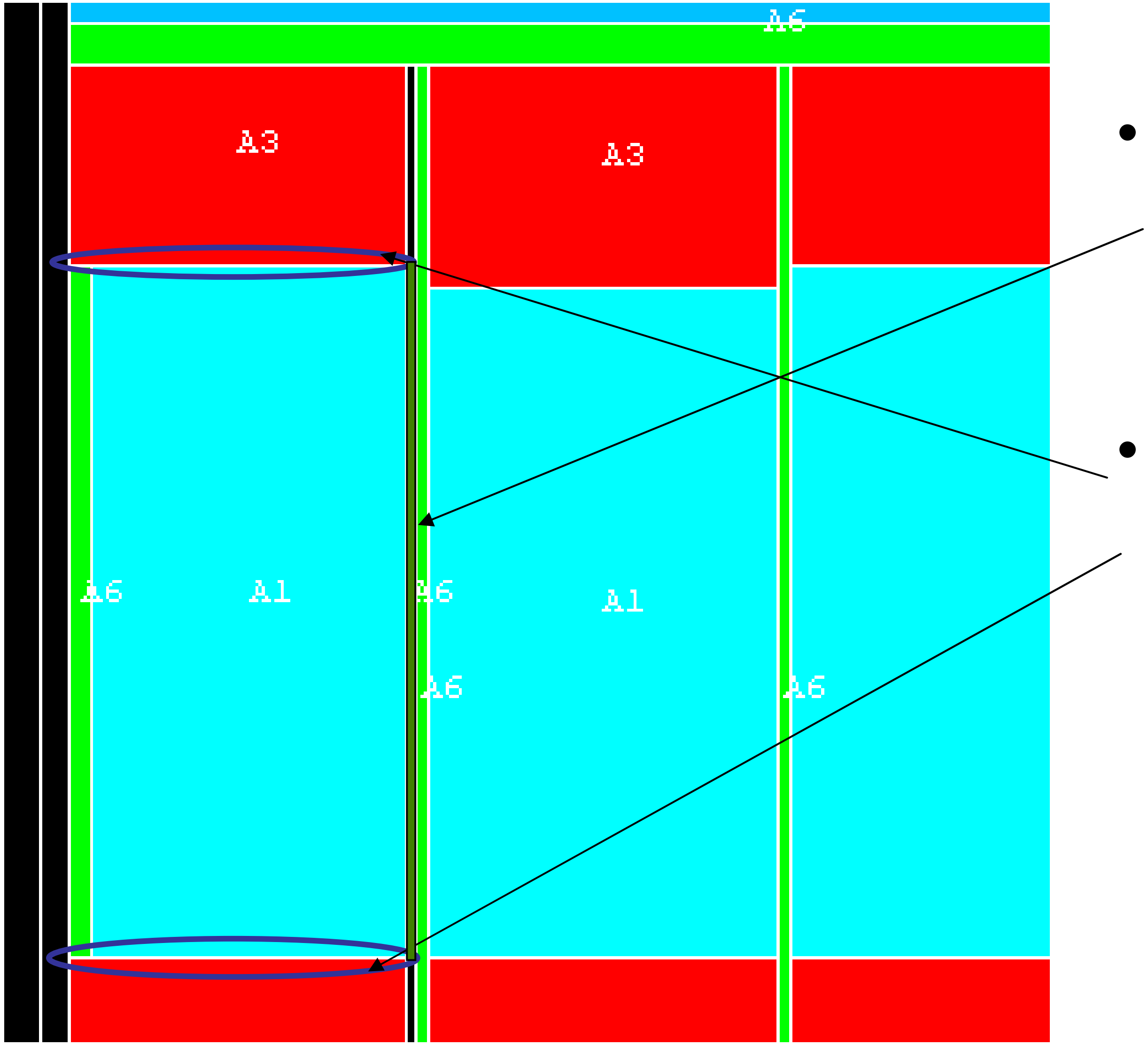
Spacer: type 1



- 14 turns
- Bpeak: 14.2T
- Current12510 A

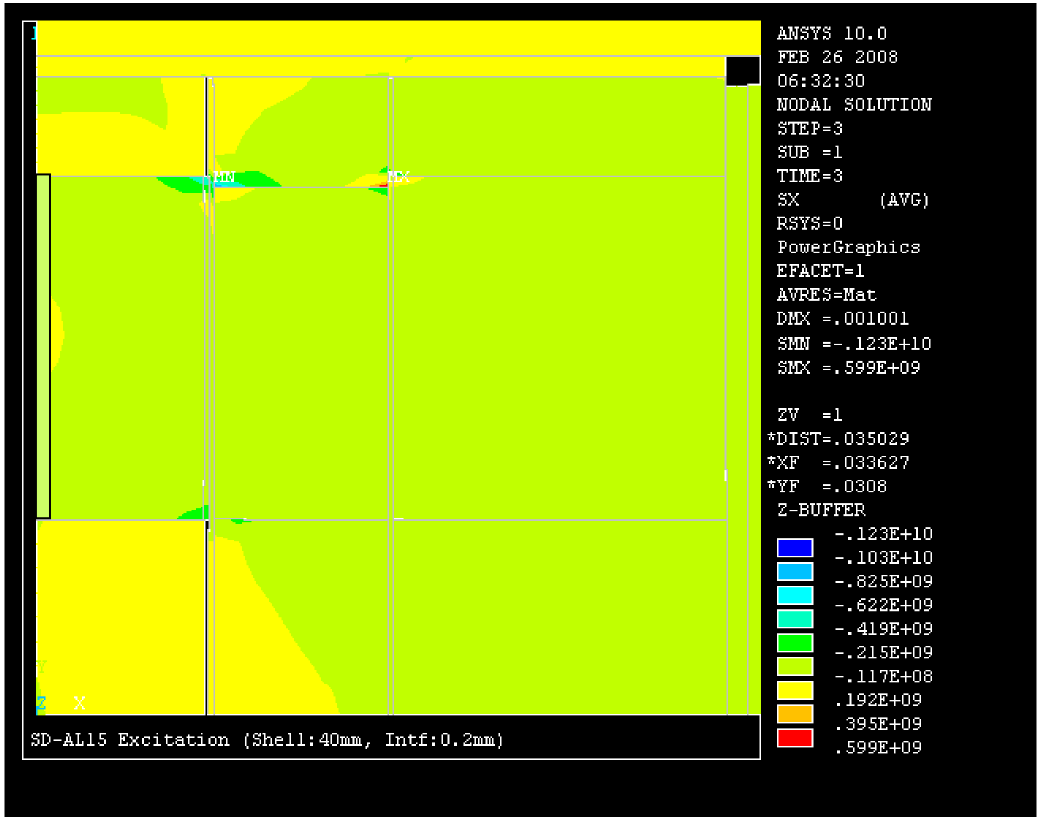
Even if 60mm thick Al shell

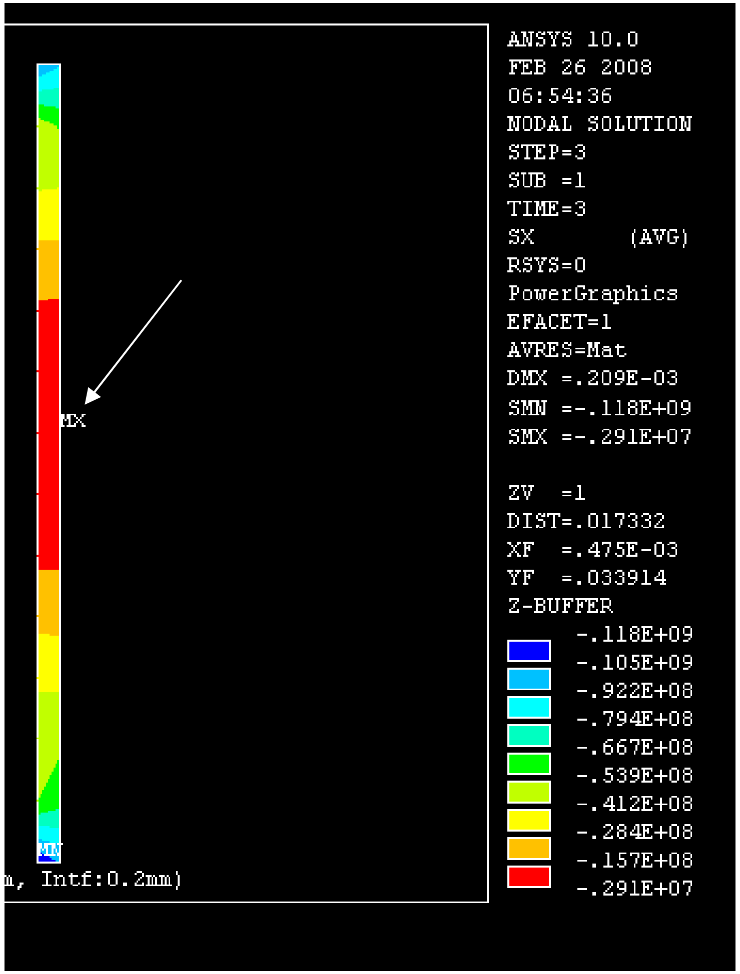
Spacer: type 2



- For Coil 1, spacer covers only coil part
- To decrease shear stress, these are the sliding contact

Stress in x direction





- No. of turns:14
- Al shell□40 mm
- Bpeak: 14.3T
- Current□12336 A

Sigma x in midplane spacer
Min compressive stress □3MPa

Mechanical design ~summary

- Spacer : push only coil part (coil1)
  - Have to test the sliding contact.
- Optimization of Al shell thick. : in progress
  - 40 ~ 45 mm
- Bpeak: 14.3T @ 12336 A

Next: ANSYS 3D analysis

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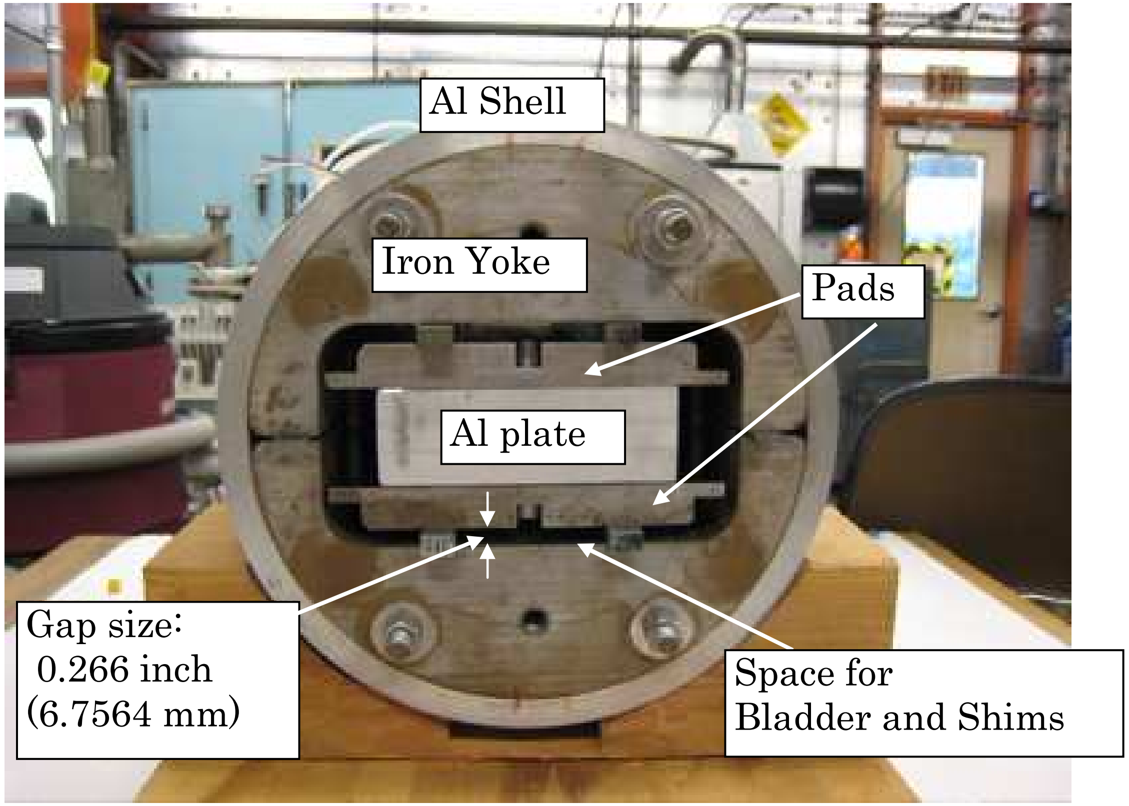
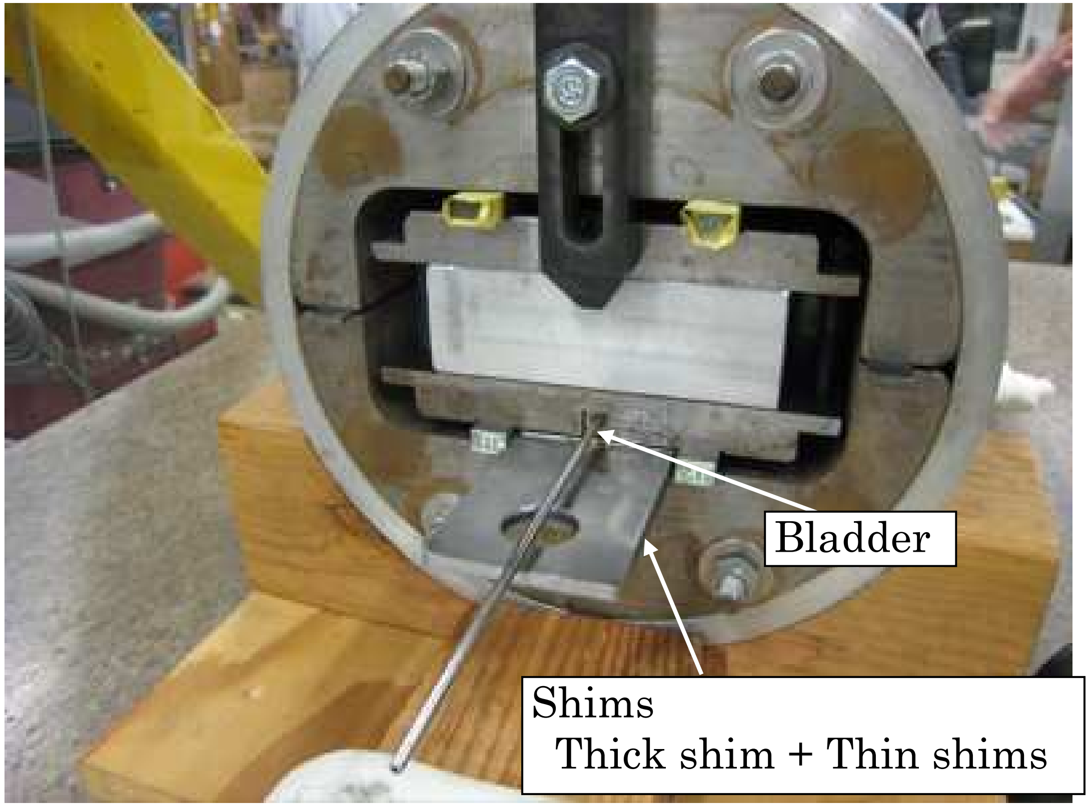
Bladder test

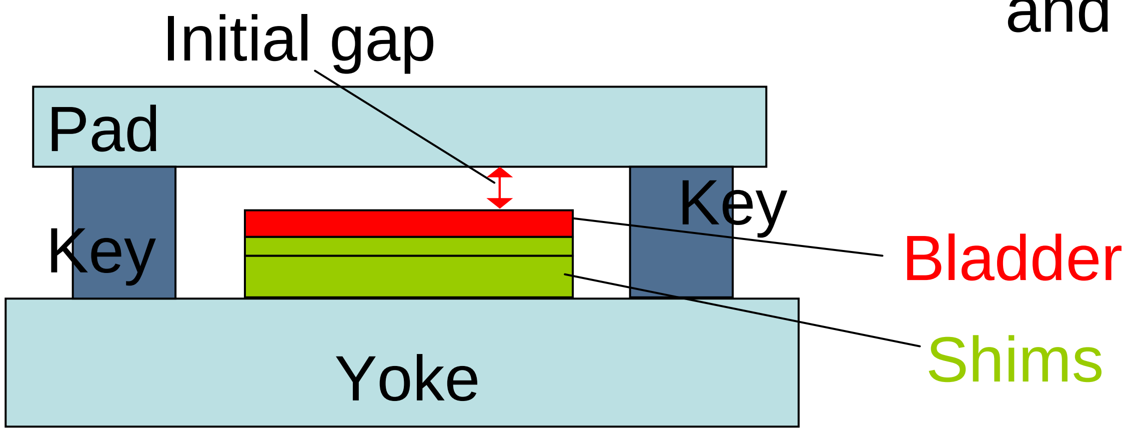
- Bladder : tool to apply pre-stress
  - – Key technology of Shell structure
- We made 4 prototype bladders in Japan and tested using test tools of LBL



Test Procedure



- Set shims and bladder.
- Pumping up to 500 psi and purging several times in order to remove air in the bladder,
- 0 -> 10000psi slowly
- If no problems, purge the pressure.
- Increase the initial gap and repeat above.

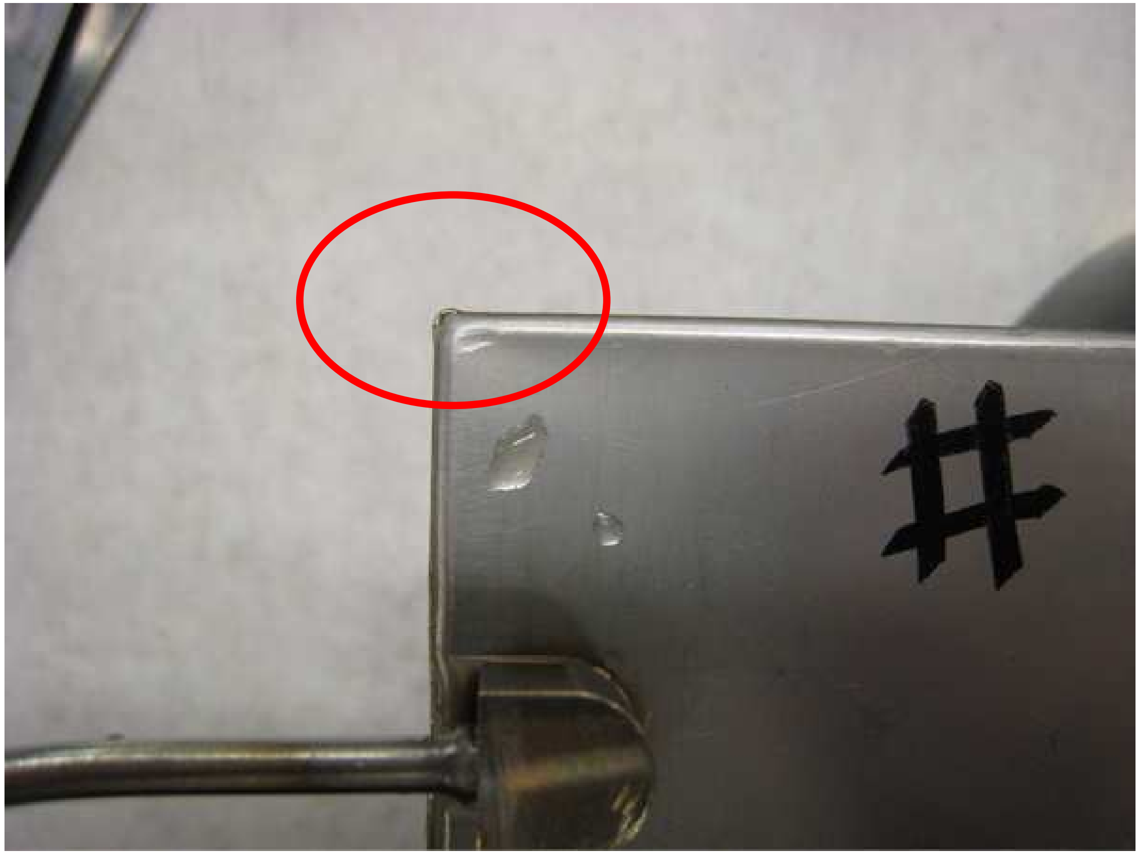


Test results

- Only 2 bladders could be tested.
  - Could not be set in the test tools because the block didn't welded in exact direction←need to modify

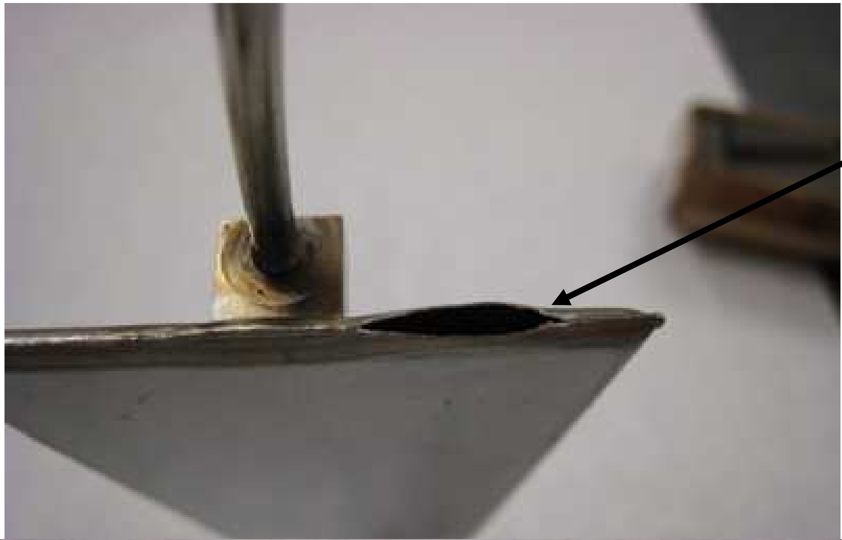
- Bladder 1:
  - Initial gap: 1.13mm
  - After reaching 10000psi, spot leak at the corner
- Bladder 2:
  1. Initial gap: 1.13 mm <- no problem up to 10kpsi
  2. Initial gap: 1.97 mm
     - Burst at 7200 psi

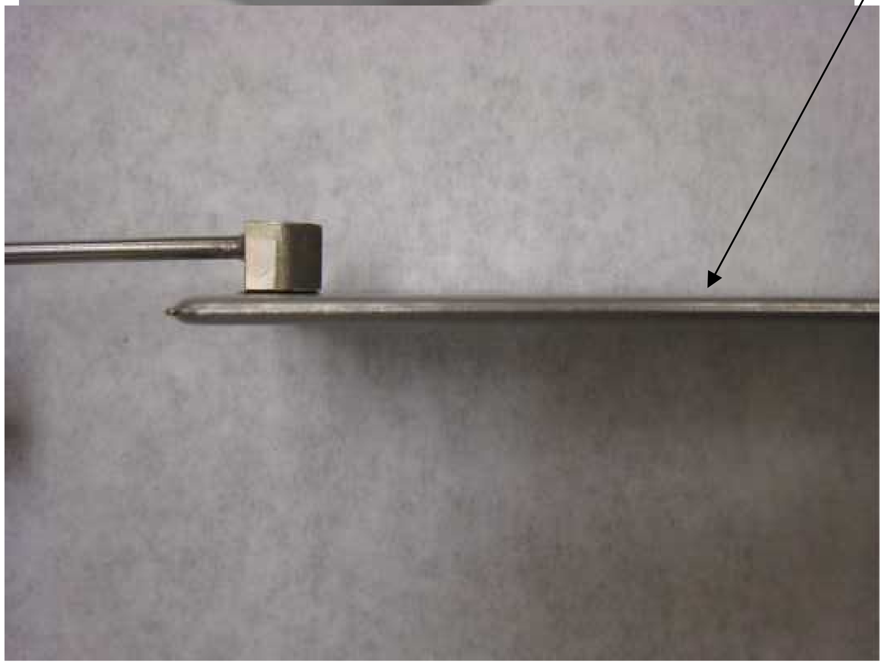
Bladder 1: Spot leak



- Bladder thickness increase by 2.13 mm because of pumping up

Bladder 2: burst





- Typical burst
- Thickness
  - 3.13 mm

In LBL, Usually, the bladder is used with the thickness below ~2mm even after pumping.

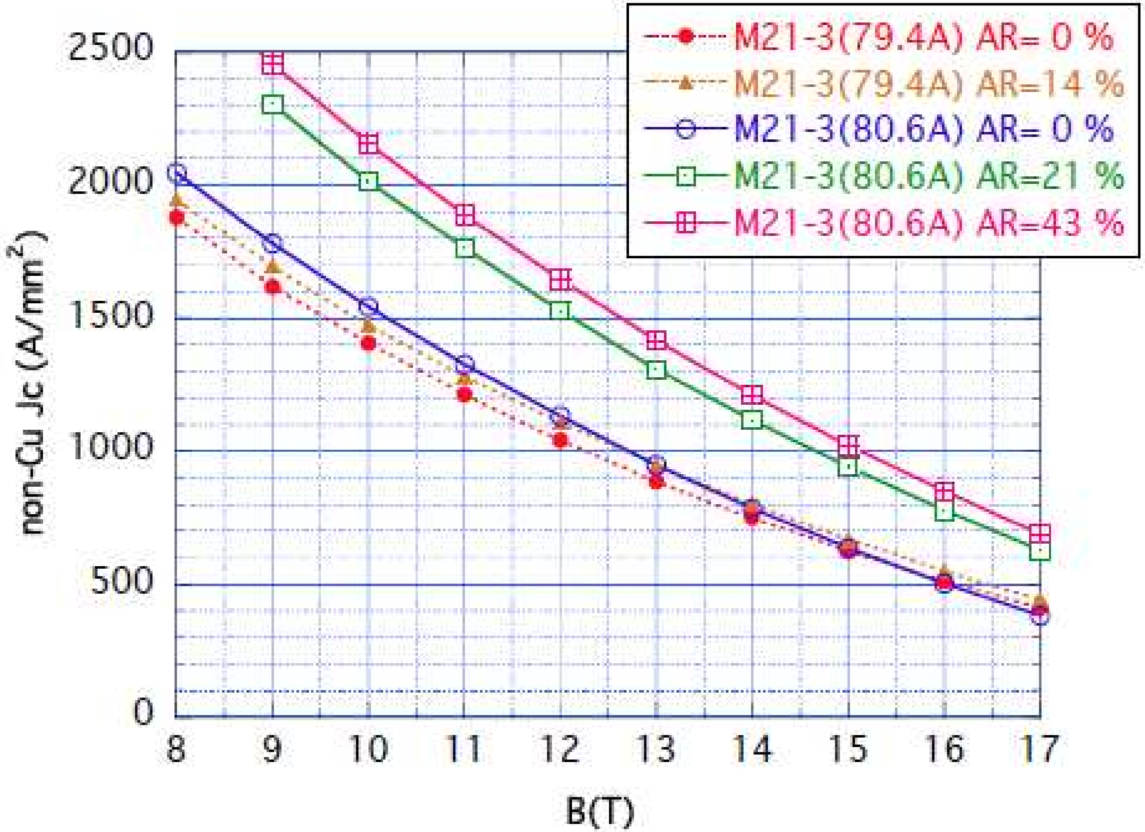
- *Japanese Bladder can be used for the magnet fabrication.*

(Although we have to control the initial gap correctly)

Future plan

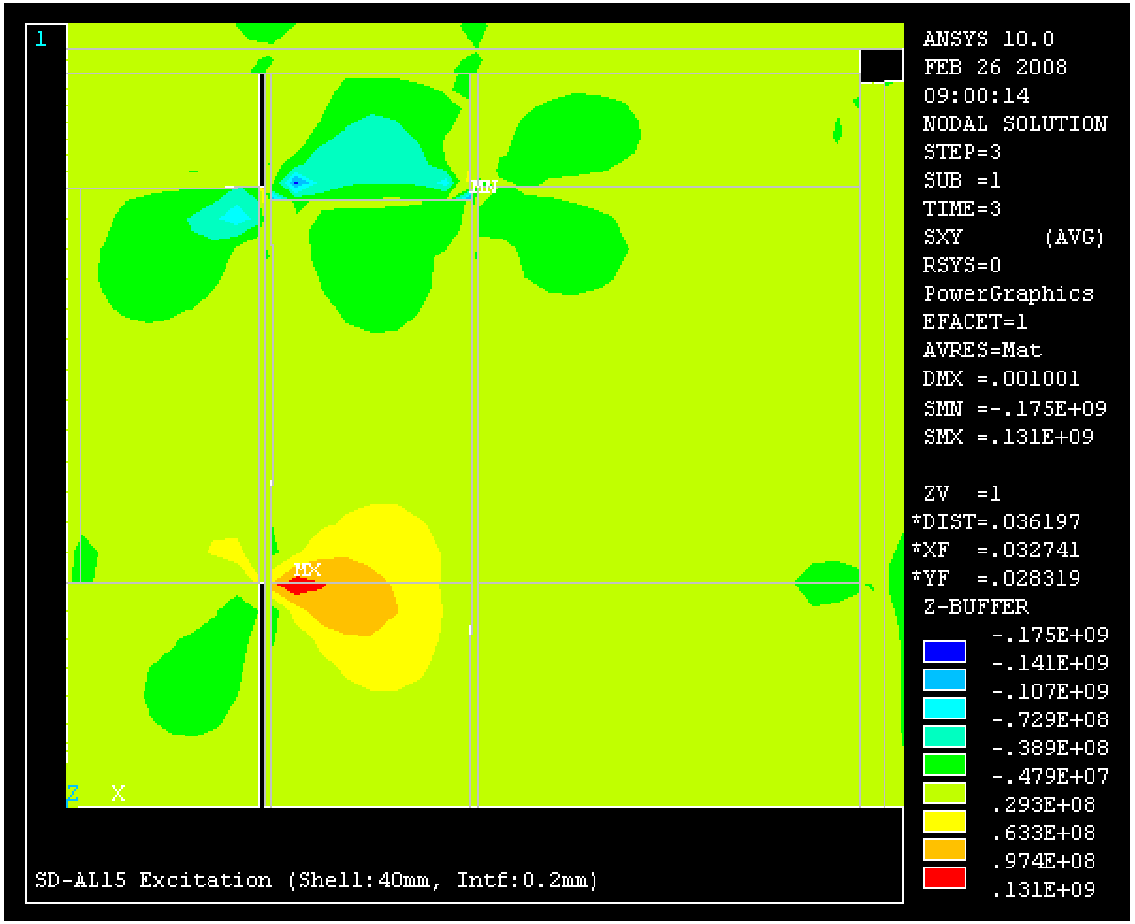
- Analysis using ANSYS 3D
- Detail design of magnet parts
- Nb3Al cabling（summer, 2008）
  - Strand: 1mm dia.
  - 27-28 strands
  - Same parameters as the previous cable.
- First coil at KEK (2008 - 2009)
  - winding
  - Reaction
  - Potting
- …….
- Magnet (2009-2010?)

Highest Non-Cu Jc



2156 A/mm^2 @ 10T
1021 A/mm^2 @ 15T

Shear stress



- Coil1 : ok
- Large shear stress in Nb3Sn coil
  - Need to modify