Development of SECRAL II superconducting magnet

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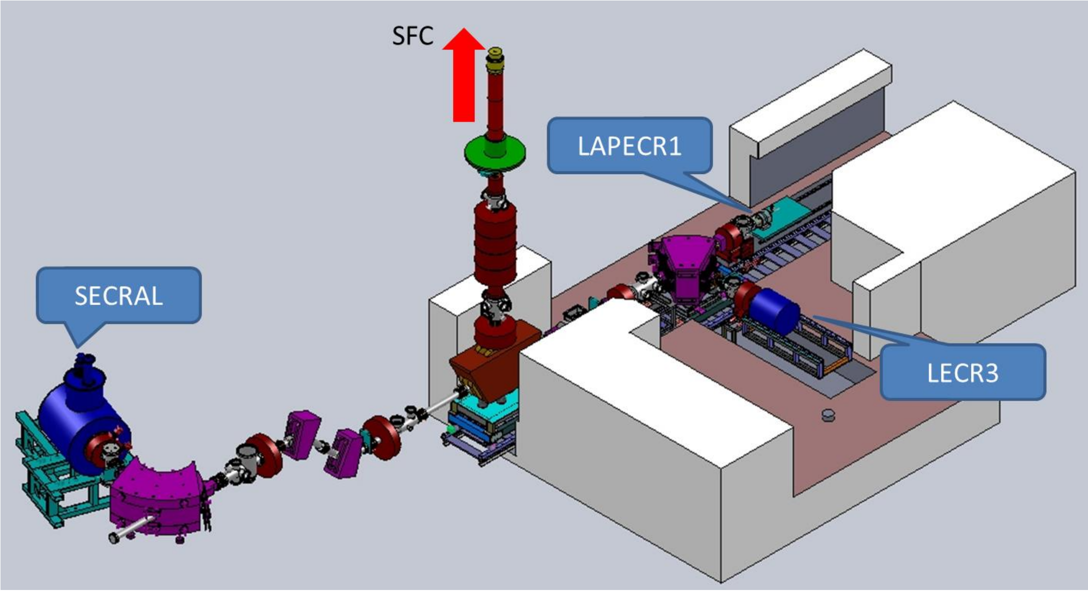
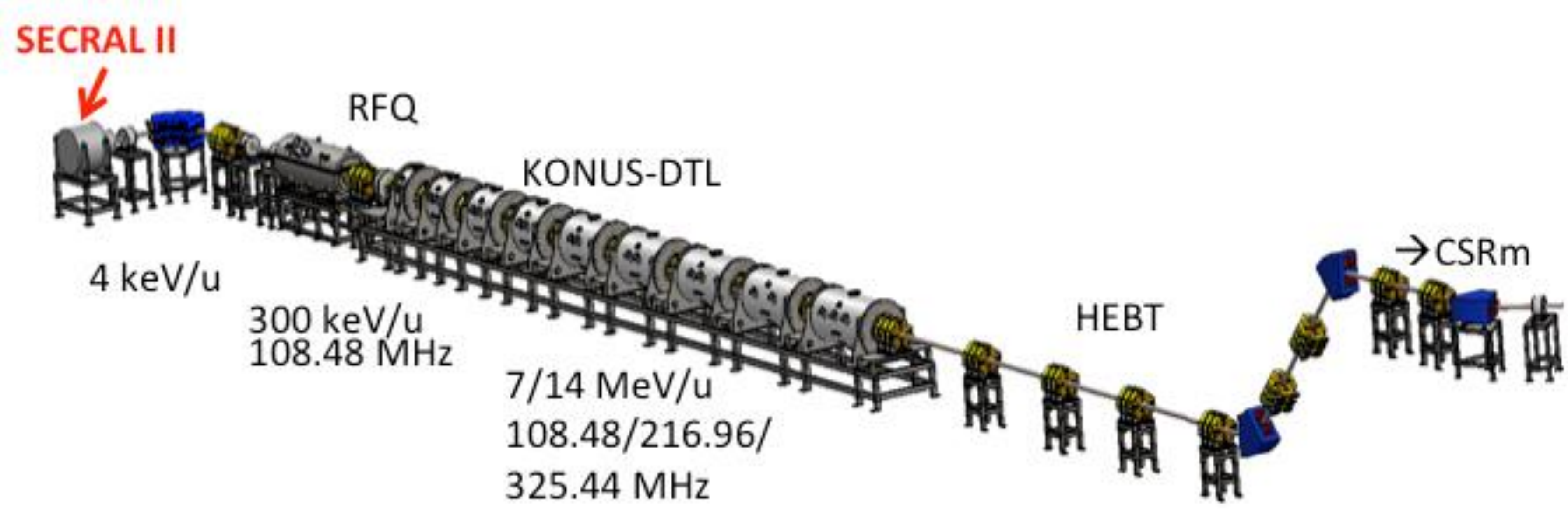
- Magnet design
- Magnet construction
- Magnet test
- Conclusion

Introduction

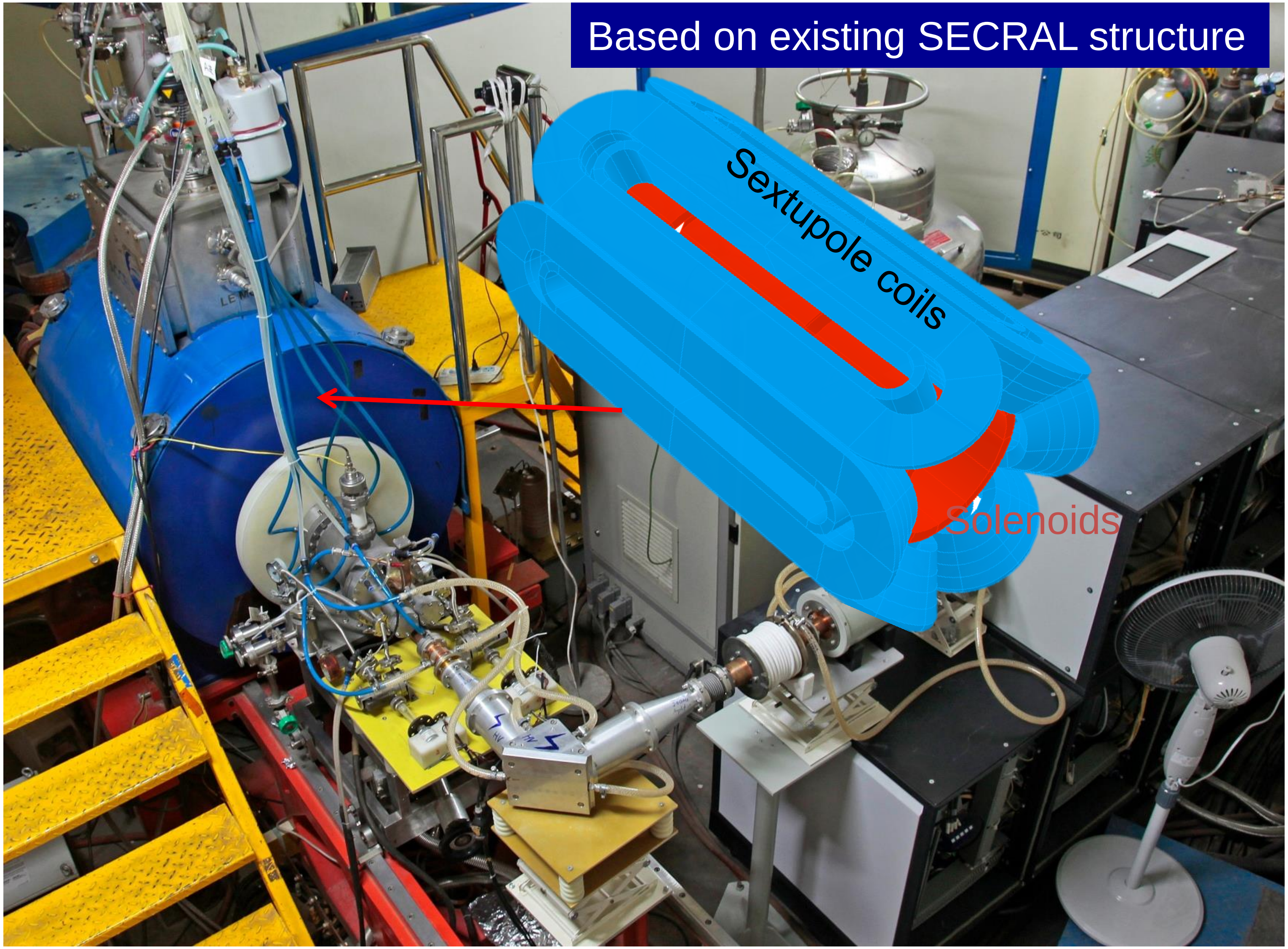


Motivations:

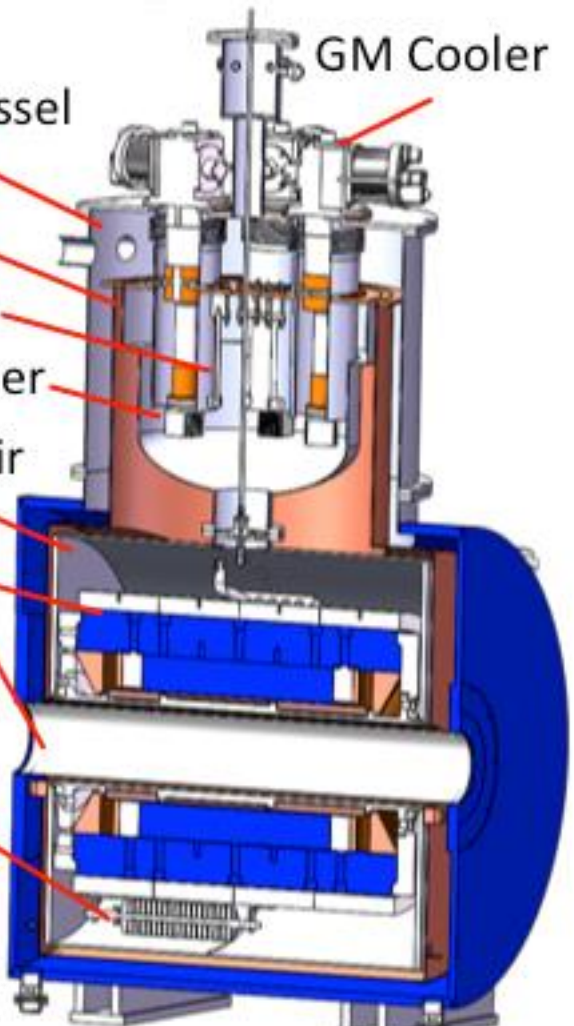
- Spare ECR magnet for the on-line source SECRAL
- Injector ion source for a new injector linac



Magnet design

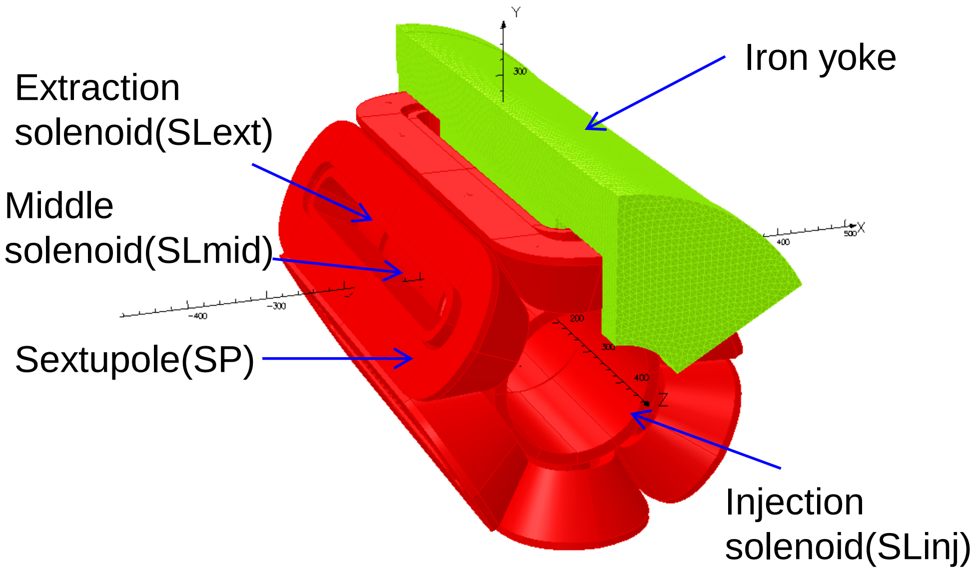


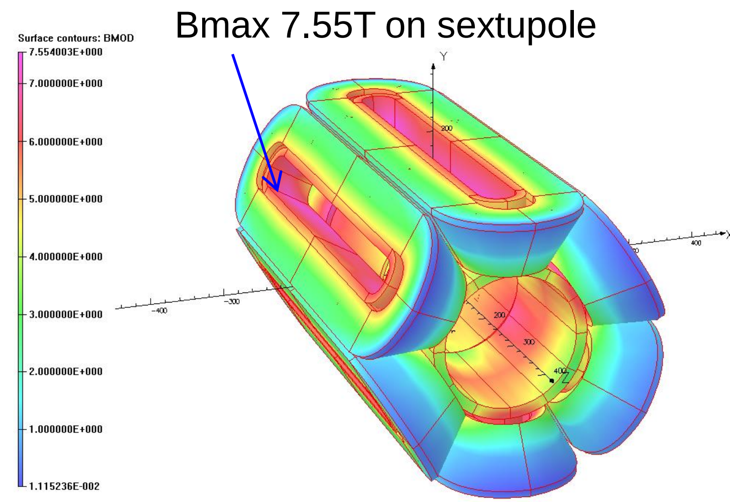
Magnet design

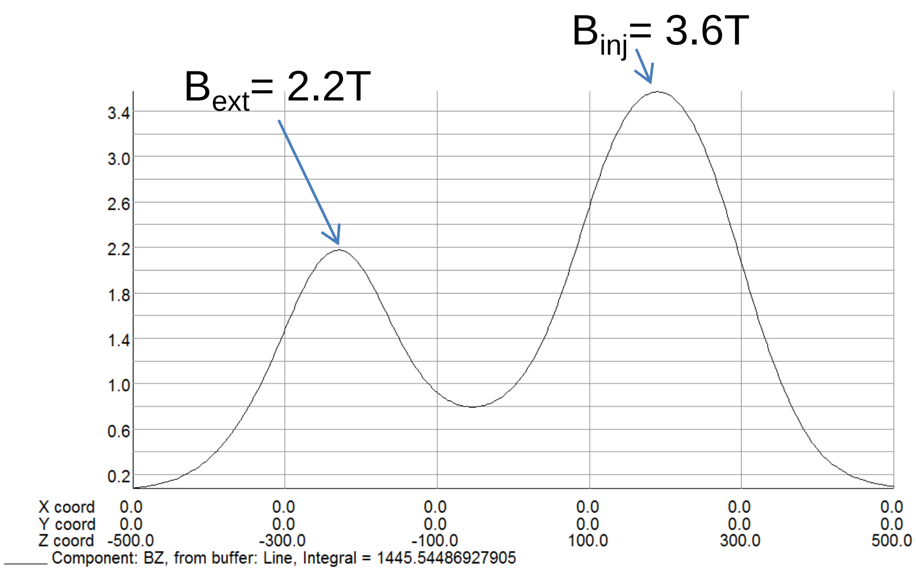


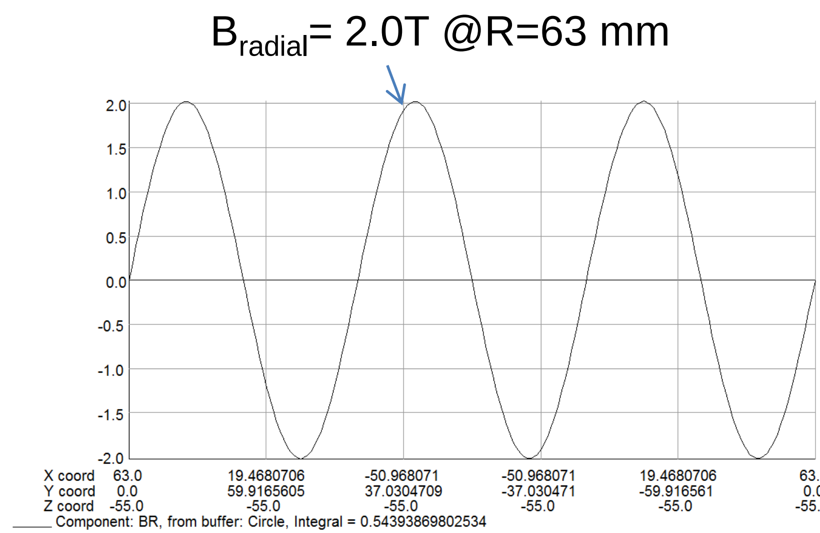
Parameters	Value
ω_{rf} (GHz)	18-28
Axial Field Peaks (T)	3.6 (Inj.), 2.2 (Ext.)
Mirror Length (mm)	420 mm
No. of Axial SNs	3
B_r at Chamber Inner Wall (T)	2.0
Cold mass Length (mm)	~810
SC-material	NbTi
Magnet Cooling	LHe zero boiling-off
Warm bore ID (mm)	~142
Chamber ID (mm)	~126
Dynamic cooling power (W)	~5

Magnet design – magnetic field

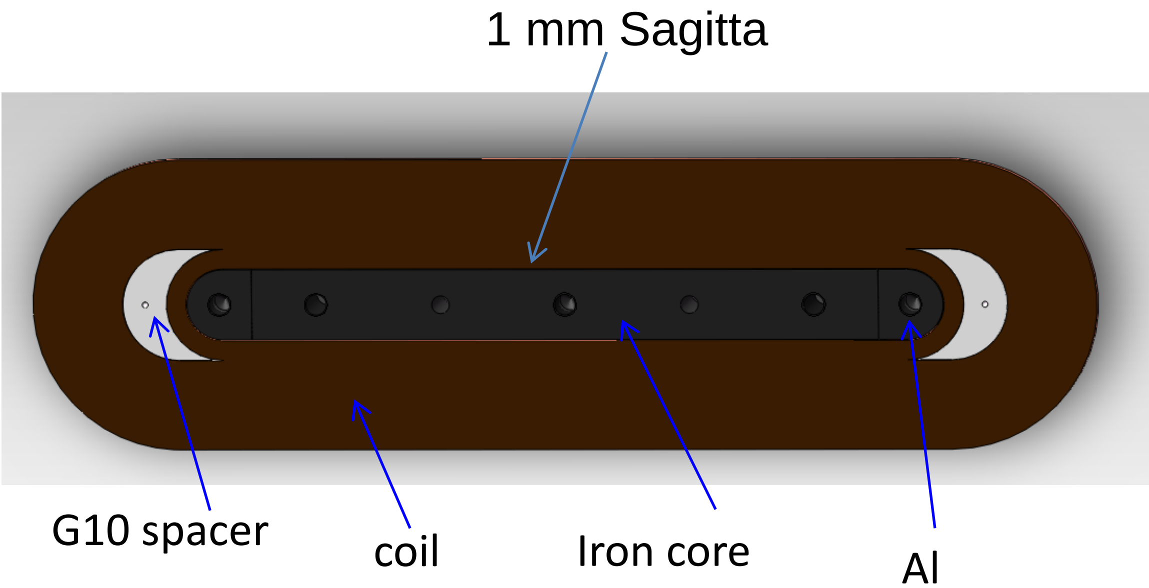


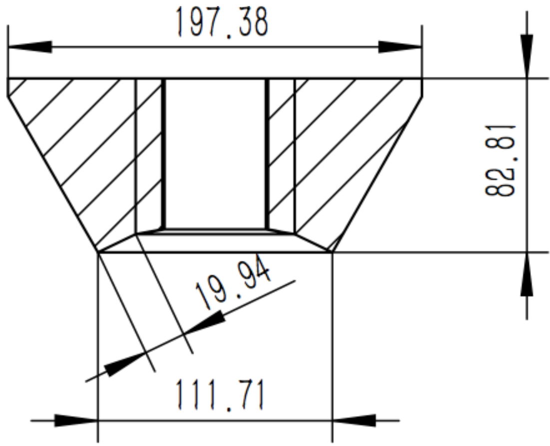






Magnet design - sextupole coil





- Each coil occupying 60 degree in azimuth
- Al pole ends used to match the contraction of iron and coil at 4K
- Straight section of pole has 1 mm sagitta in order to apply winding tension
- Using 2 layers coil at the ends to reduce the maximum field on coil

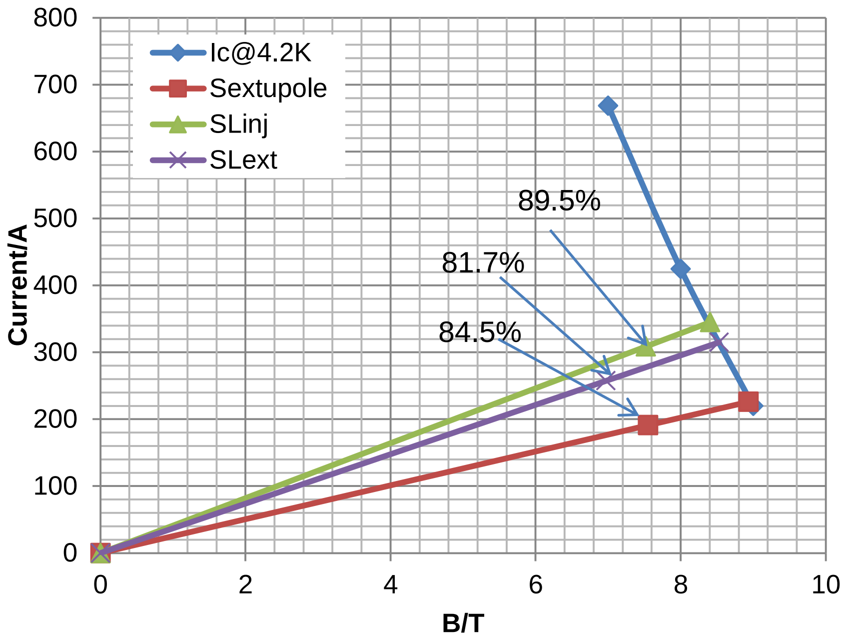
Contraction coeffecient From 293K to 4K:

- Iron：0.198%
- Al：0.414%
- Cu/NbTi：0.265%

Magnet design - coil winding

Conductor parameters

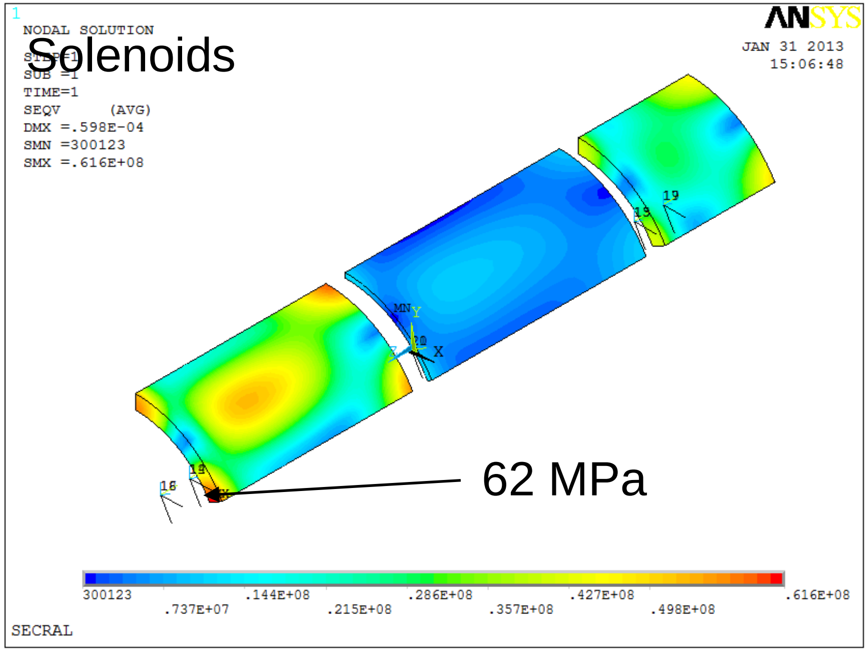
SC material	NbTi/Cu
bared size (mm)	1.20×0.75
insulated size (mm)	1.28×0.83
Cu/ Non Cu	1.3:1
Cu RRR	>100
number of filaments	630
Ic @4.2 K,7T (A)	668.7
Ic @4.2 K,8T (A)	424.8
Ic @4.2 K,9T (A)	219.6

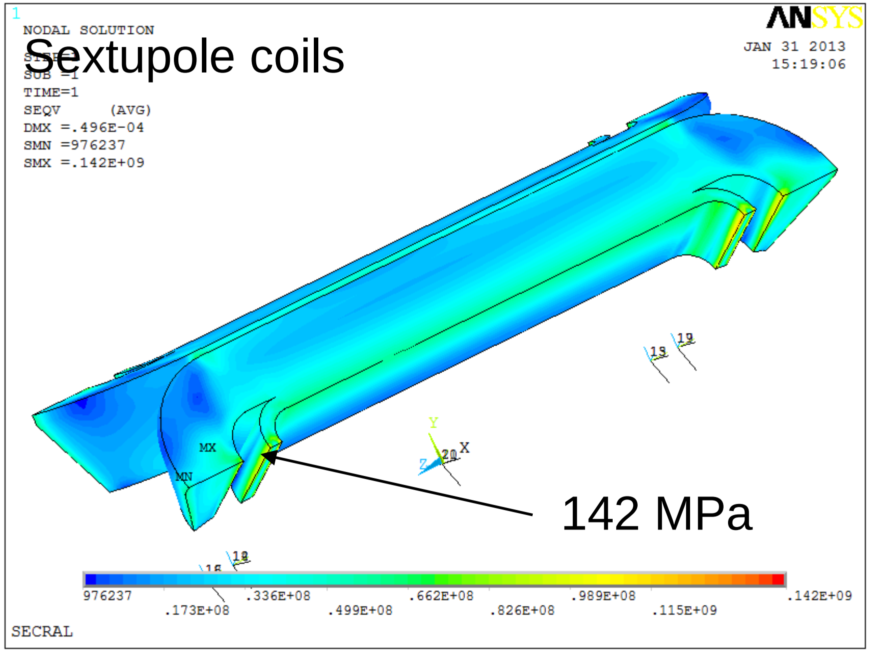


Parameters	SLinj	SLmid	SLext	Sextupole
Inner radius(mm)	90	100	90	116
Outer radius(mm)	105	105	105	212
Length(mm)	200	225	115	724
Bpeak on coil(T)	7.52	6.61	6.97	7.55
Turns	2480	696	1424	3617
Current(A)	308.7	62.2	257.4	191
Load line	89.5%	/	81.7%	84.5%
Conductor length(m)	1525	454	881	5229,each coil

Magnet design - structural analysis

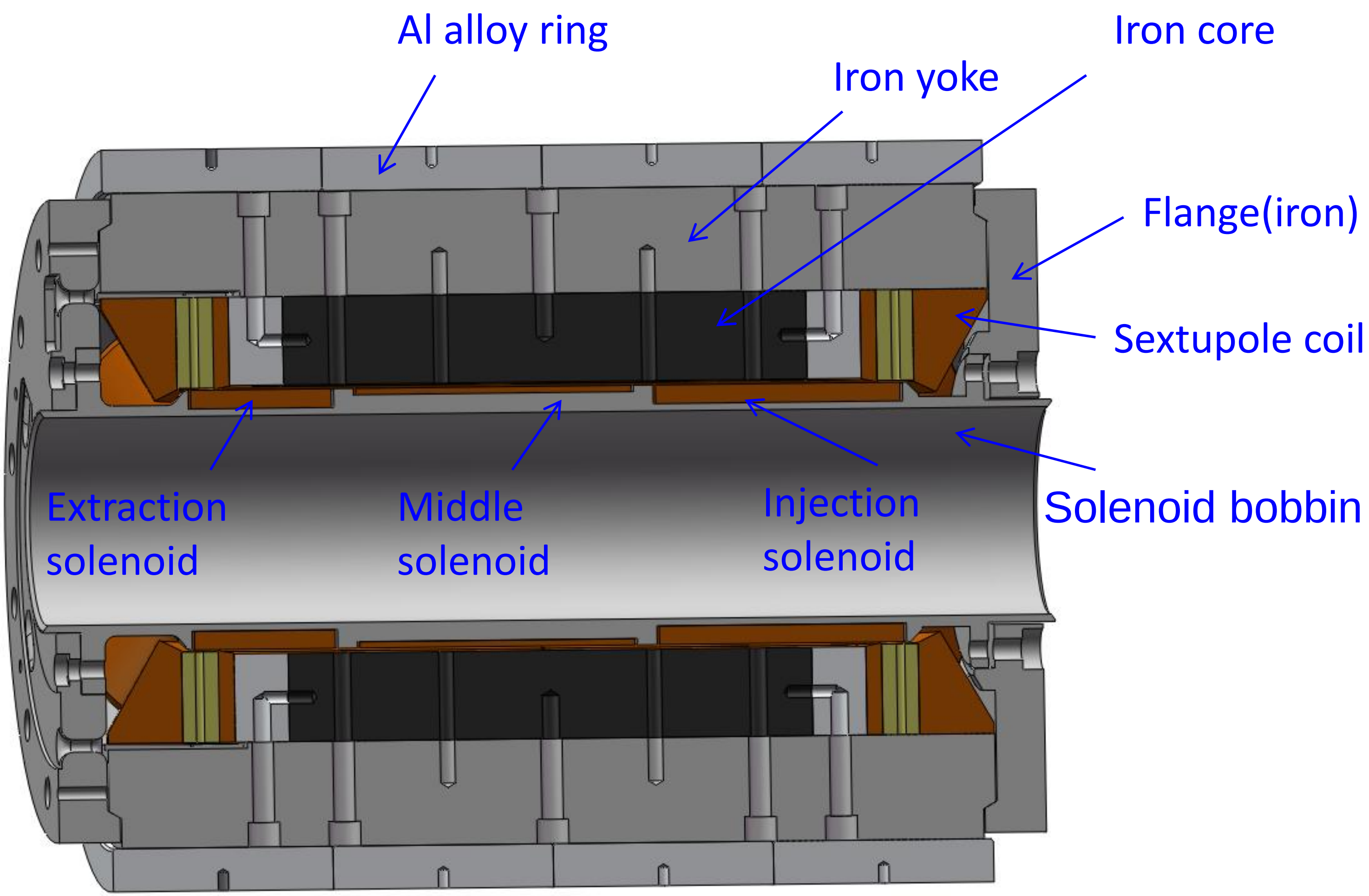
Stress under Lorentz force





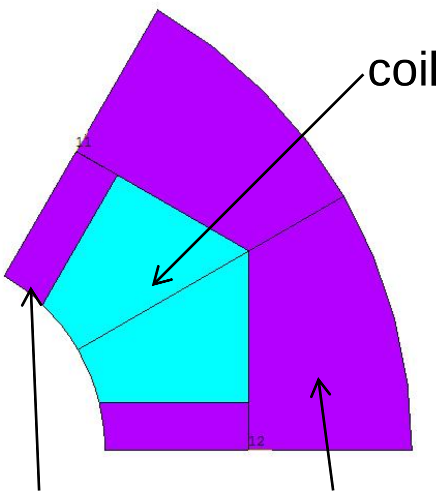
The maximum stress on coils is 142 MPa

Magnet design - cold mass assembly

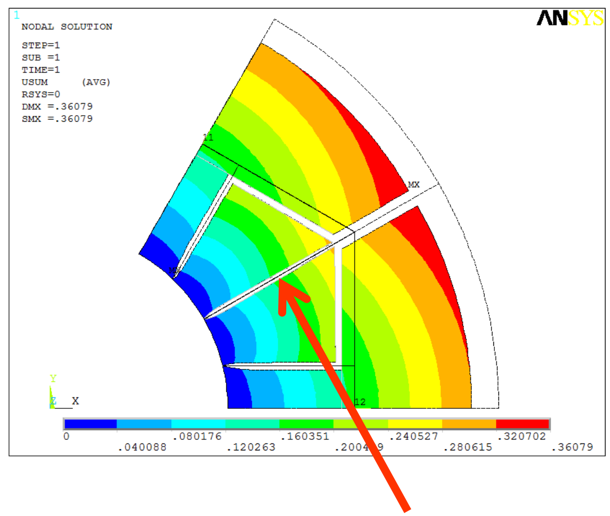


Magnet design - Low temperature shrinkage

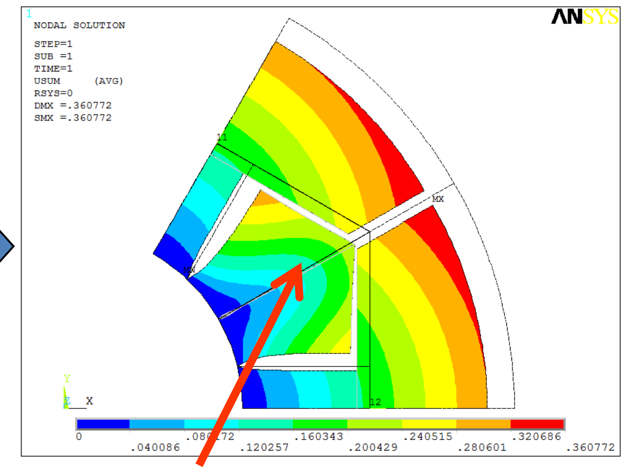
300 K



4.2 K



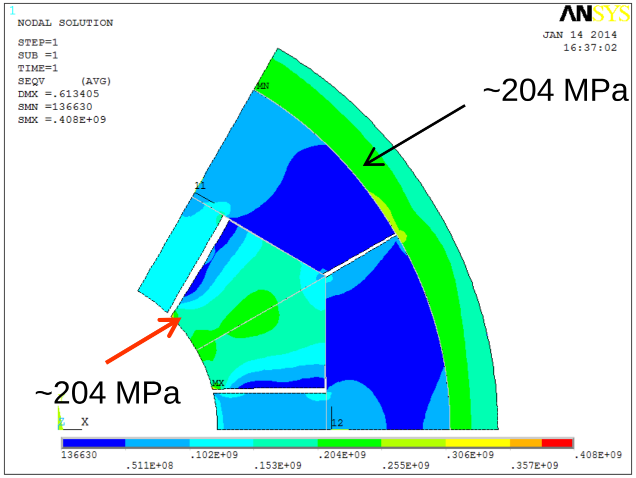
Charged



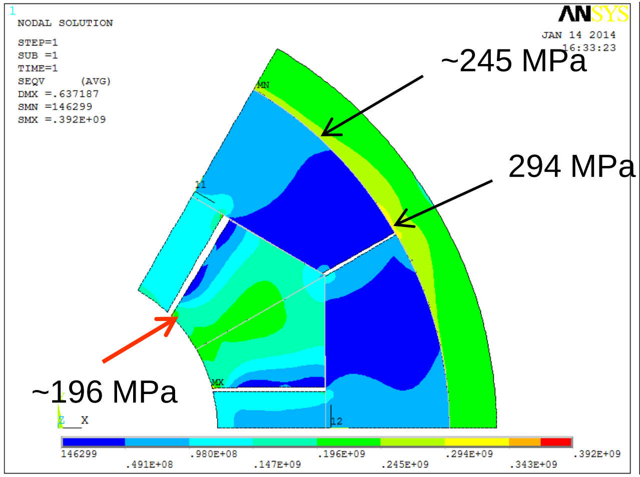
- Pre-stress must be applied to reduce movement of the sextupole coils under Lorentz force!
- two options:
  - Using bladder between adjecent sextupole coils (VENUS);
  - ✓ Compress with shrink Al alloy rings around iron (SECRAL)

Magnet design - pretention design with Al ring

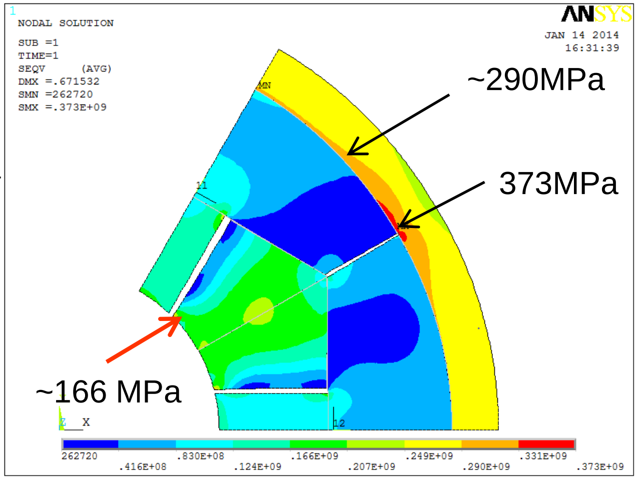
ΔD: Shrink range of Al rings



ΔD = 0.1 mm

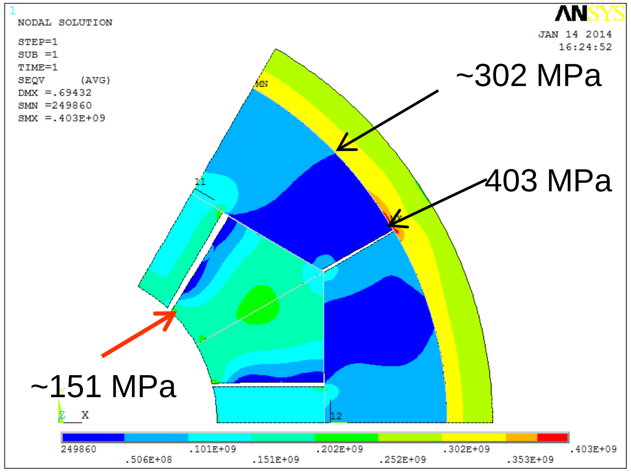


ΔD = 0.3 mm

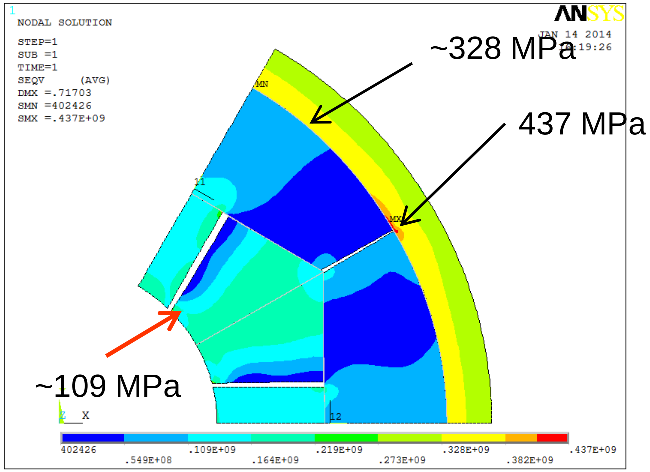


ΔD = 0.6 mm

Final design



ΔD = 0.8 mm

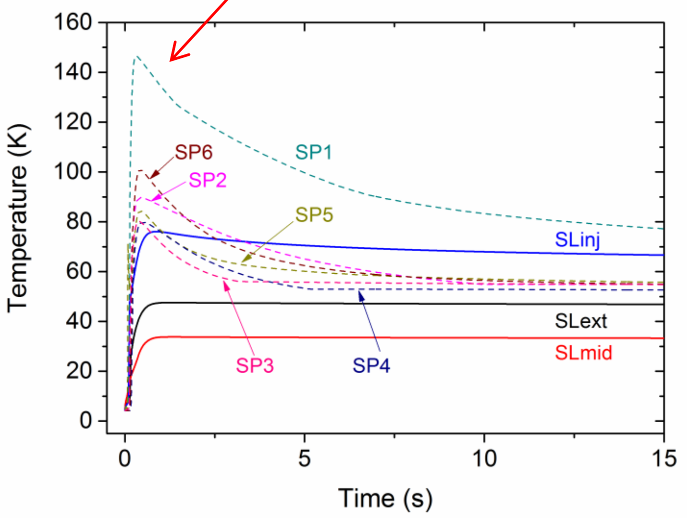


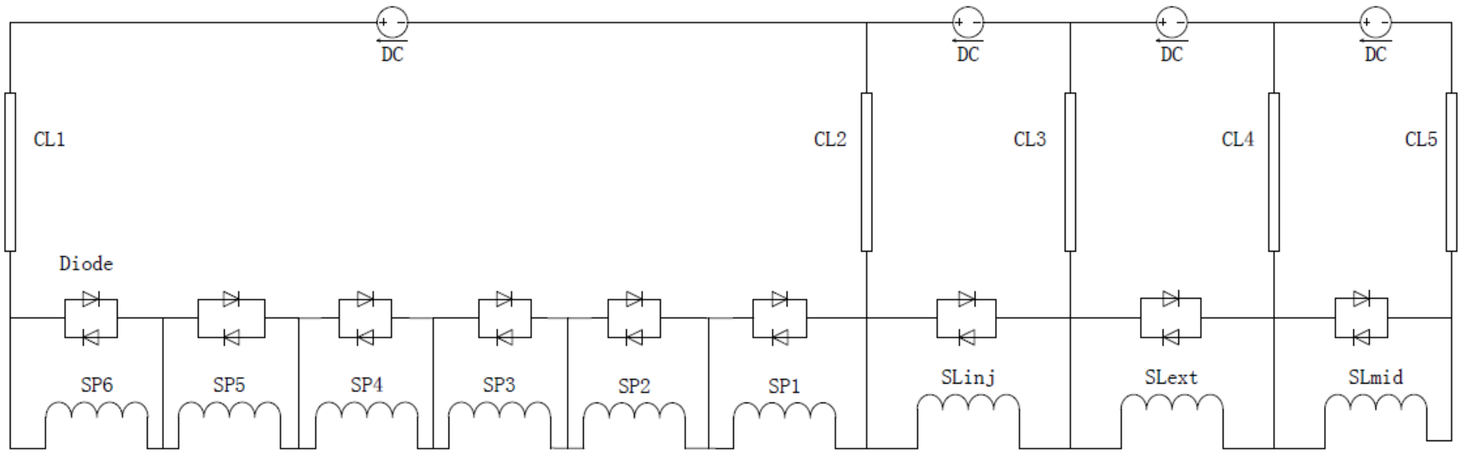
ΔD = 1.0 mm

Magnet design - quench protection and power scheme

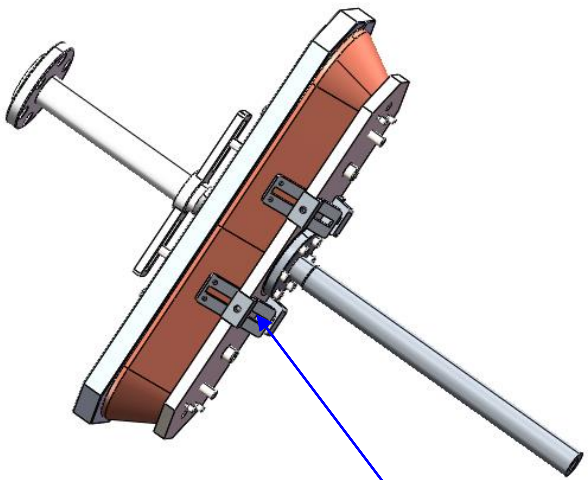
- Quench calculated using Opera Quench program
- Cold diode for quench protection
- 3 solenoid and sextupole powered independently
- 5 HTS current leads used to reduce heat load

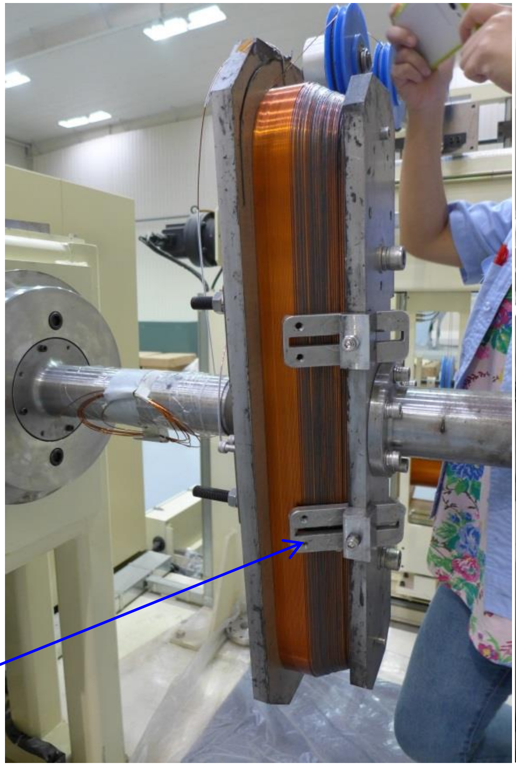
hot spot temperature under 150 K

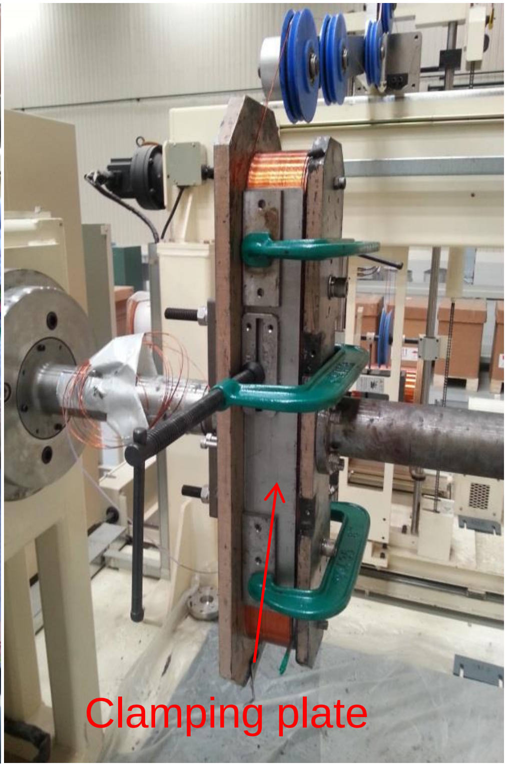




Construction - sextupole coil winding



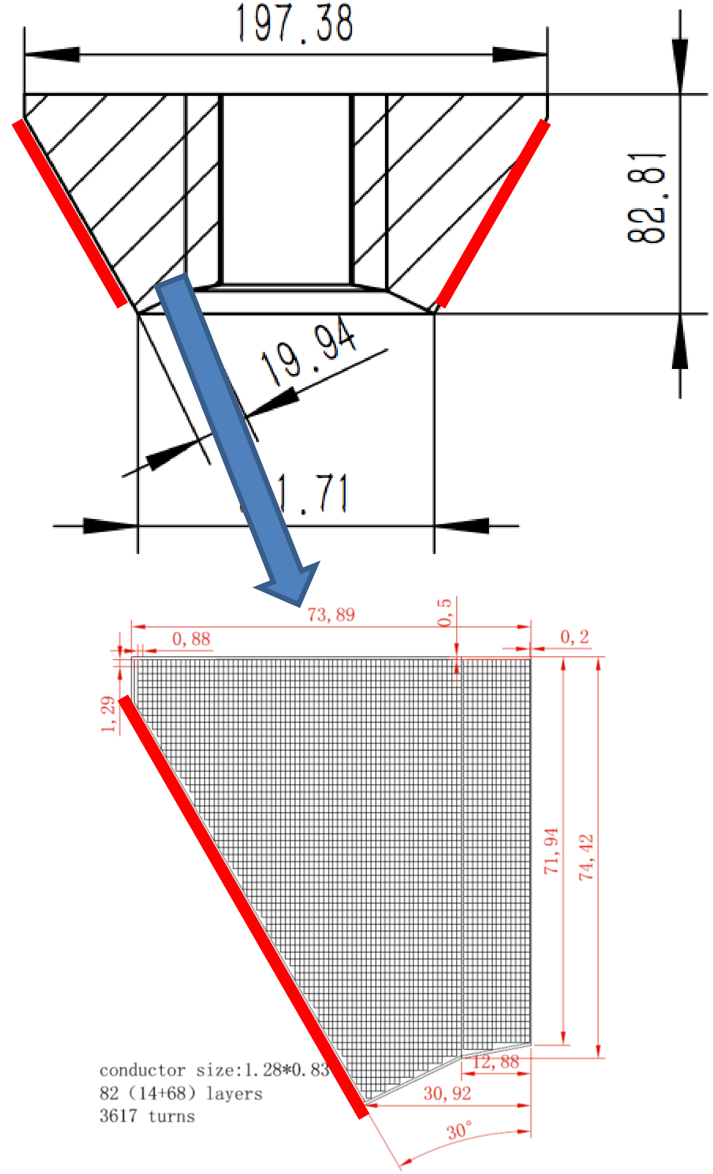




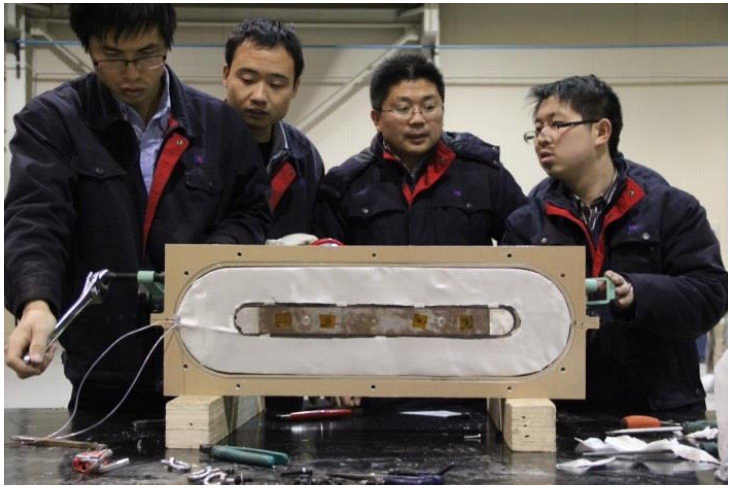
- Wet-wound with stycast 2850FT epoxy
- Four sliders to ensure the angle of the coil
- After winding 2 layers, clamping and curing the coil with two plates

Construction - shape control of sextupole coil

- The angle of hypotenuse of the coil is most important for the assembly of six sextupole coils;
- The tolerance of the final size should be within 0.1 mm
- It is difficult to control the size in winding process
- VPI used to get a good shape of sextupole coil

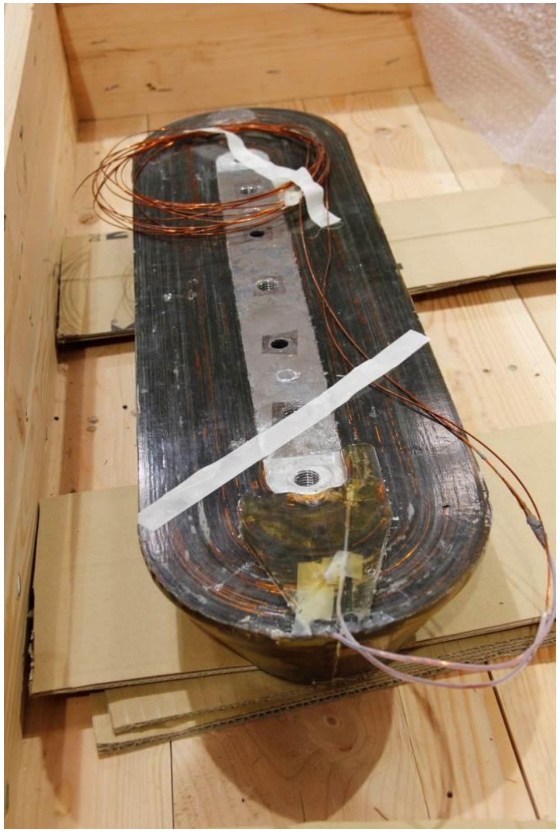


Construction - sextupole coil impregnation



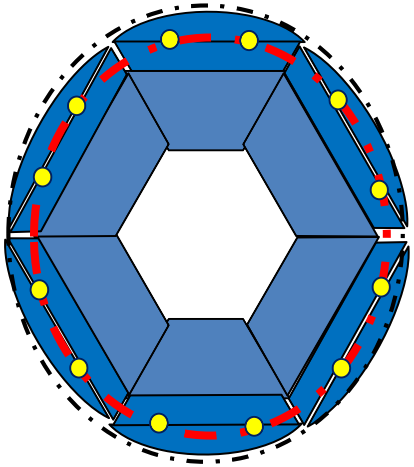
- Glass fiber cloth wrapped around the coil

- Impregnating with CTD101K epoxy

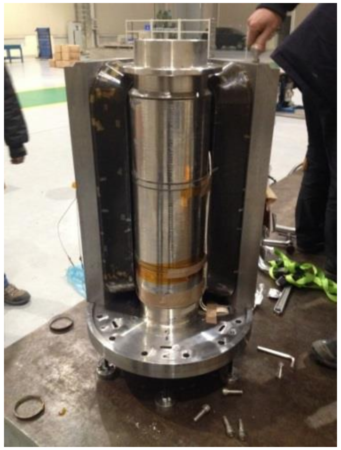


- Coil finished Impregnating

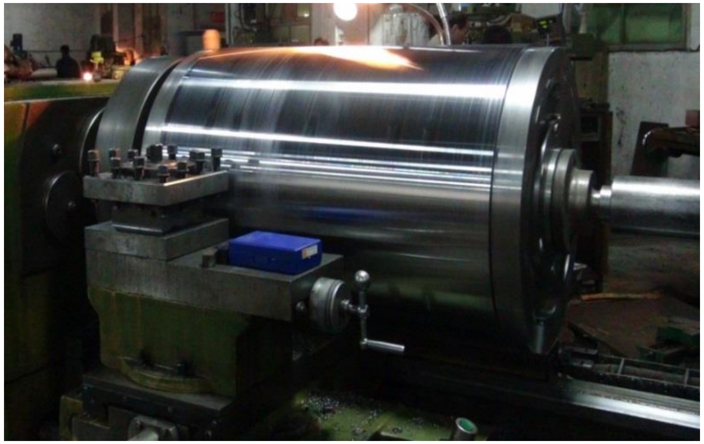
Construction - Cold mass assembly



roundness of the assembly



trial assembly



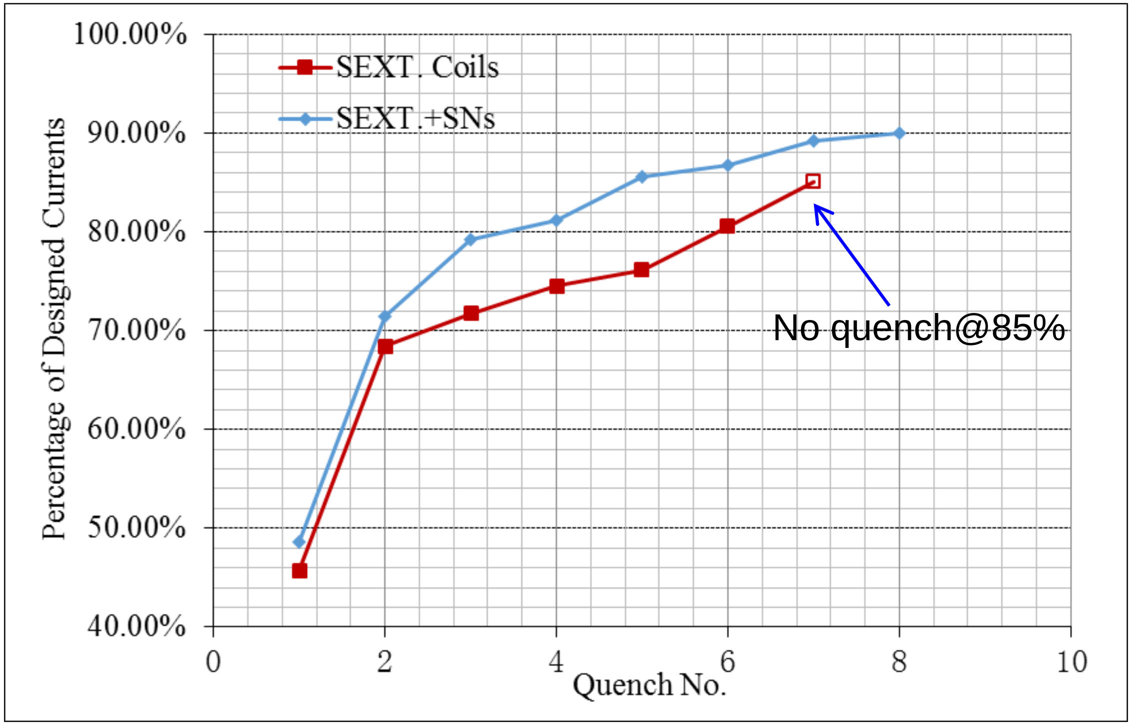
Repair roundness

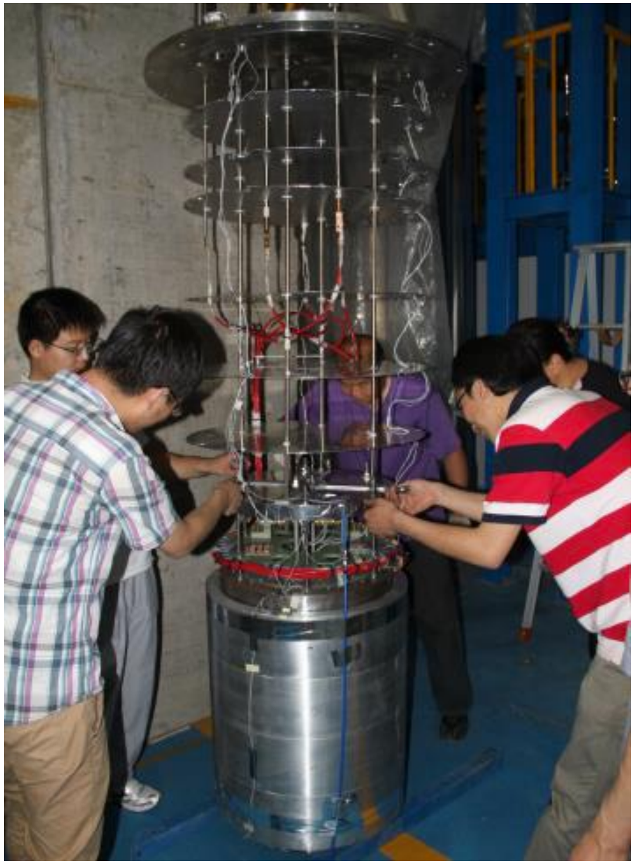
- The roundness of the assembly has not reached requirement after trial assembling
- The yoke assembly(removing coils) was repaired through turning machine
- Four Al rings were assembled one by one after heated to 150 ℃
- Magnet finishing fabrication and assembling in June 2014

Al rings assembling

Finished assembly

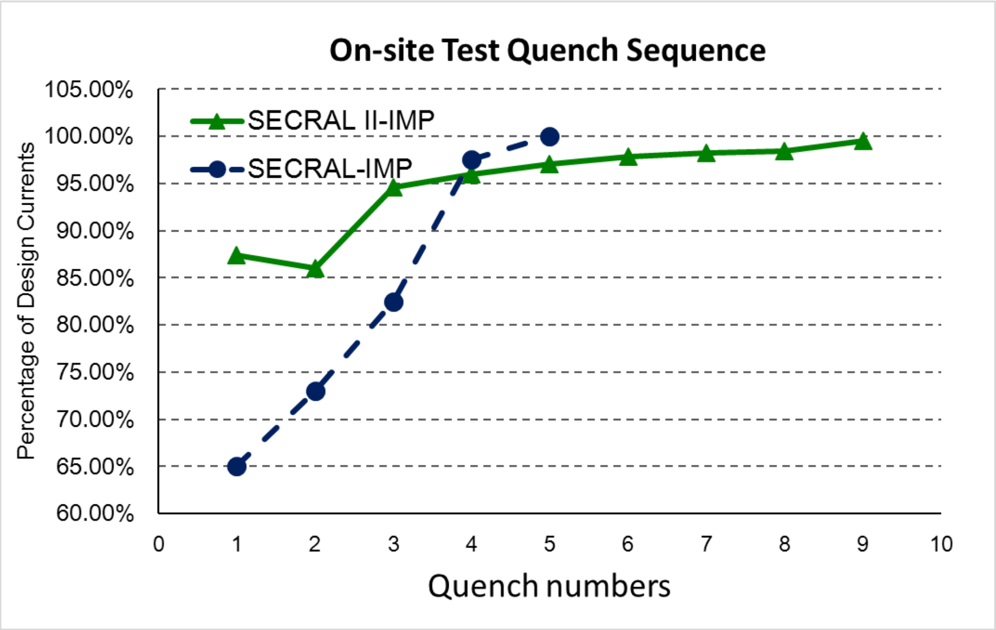
Magnet test – cold mass test in test dewar





- Sextupole coils ramped to 85% with 6 quenches
- All coils ramped together to 90% with 8 quenches

Magnet test – user's site test



Finish user's site test in Dec. 2015

- 3 quenches to reach 95% design currents
- 9 quenches to reach 100% design currents
- No quench happens during beam commissioning

Conclusion

- A fully superconducting ECR magnet for SECRAL II has been successfully developed within 3 years
- Structural analysis of cold mass was performed using ANSYS
- Winding tool of sextupole coil has been developed
- Pre-tension of sextupole coil has been applied through thermal fit Al rings
- Design and fabrication of ECR magnet with the reversed structure is a matured technique now

Acknowledgements

- Thanks to Dr. Detlef Krischel, Dr. Satoshi Ito and Dr. Daniel Xie for giving fruitful suggestions in magnet design and fabrication

- Thanks to XSMT inc. for magnet fabrication

Thanks for your attention!