Shell-based support structure for the 45 GHz ECR Ion Source MARS-D

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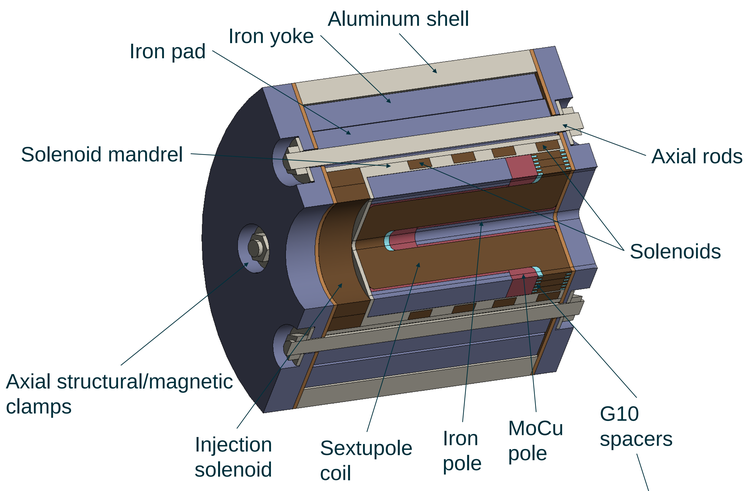
Background

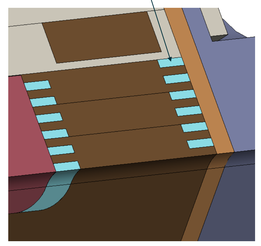
Superconducting electron cyclotron resonance ion sources (ECRISs) using NbTi coils and optimized for 28 GHz resonant heating have been successfully operated for almost two decades. Moving to higher heating frequencies requires increased magnetic fields, but traditional racetrack-and-solenoid ECRIS structures are at their limit using NbTi. Rather than moving to a superconductor untested in this field, the Mixed Axial and Radial field System (MARS) being developed at Lawrence Berkeley National Laboratory employs a novel closed-loop-coil design that more efficiently utilizes conductor fields and will allow the use of NbTi in a next-generation, 45 GHz ECRIS. This presentation shows the design status of the shell-based support structure central to the MARS-D magnet design, as well as structural analysis of its components and optimization of pre-load parameters that will guarantee its successful operation.

Man Parameters	
Microwave frequency f_{rf}	45 GHz
Resonant heating field B_{ECR}	1.6 T
Injection confinement field B_{inj}	5.7 T
Extraction confinement B_{extr}	3.4 T
Radial confinement field B_{rad}	3.1 T
Stored energy E	560 kJ

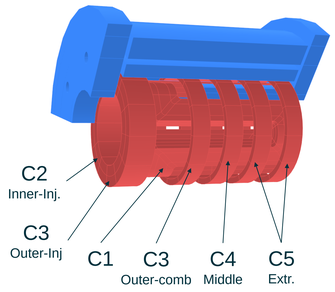
Mechanical Structure



- Shell-based mechanical structure will use bladder-and-key technique for magnet assembly and preload.
- Axial clamps will provide axial-preload and magnetic shielding.
- Coil together with structural and magnetic poles will be epoxy impregnated inside the solenoid mandrel.
- Coil subassembly will be surrounded by protective aluminum plates and inserted into mechanical support structure



Magnetic Analysis

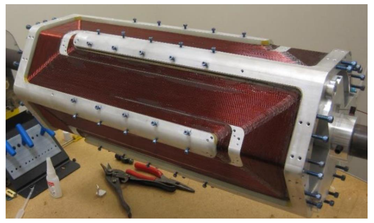


Coil-Section	J_{eng} (A/mm²)	I_{op} (A)	B_{cond} (T)
C1-Inner	140	365.4	8.16
C1-Outer	210	548.2	7.80
C2-Inner-Inj	140	365.4	8.04
C3-Outer-Inj	180	469.9	5.46
C3-Outer-Comb	180	469.9	5.95
C4-Middle	-200	521.1	5.68
C5-Extr.	180	469.9	5.94

Conductor

Rectangular NbTi wire	
Bare wire	1.84 mm x 1.16 mm
Cu/Sc	~1.3
RRR	99
Twist	58 mm
Insulation	35 um

Short sample	
B (T)	Ic (A) at 4.2 K
7.0	1337
8.0	960
8.8	618
9.5	350

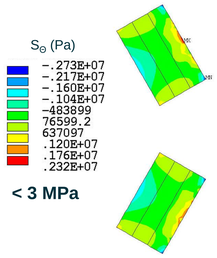


A test dry-winding was performed using copper wires to explore the fabrication of a MARS closed-loop coil

Structure Stress Optimization (2D)

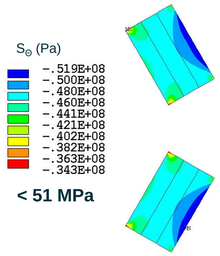
Sextupole conductor – Azimuthal Stress

Room temperature



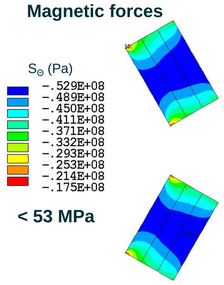
< 3 MPa

Cool-down



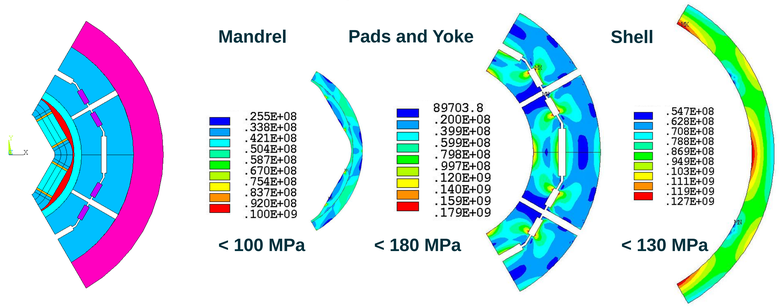
< 51 MPa

Magnetic forces



< 53 MPa

Structure components – Von Mises Stress

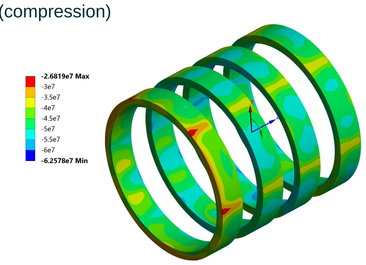


Conclusions

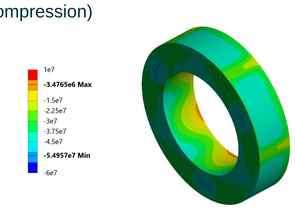
- Novel close-loop-coil enables using NbTi conductor for building the next generation 45 GHz ECRIS.
- Winding process was developed and tested using copper conductor coil.
- Shall based structure utilizing bladder-and-key assembly and pre-load technic was developed.
- Optimized pre-load parameters allow to keep all coils compressed and well below material limits.

Coil Stress Analysis (3D)

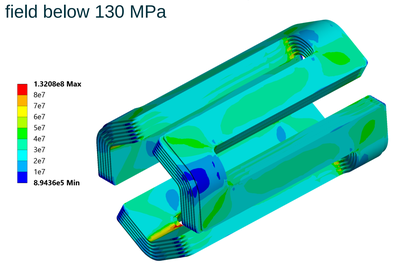
Hoop stress in solenoids at nominal field
In the range of **-62 to -27 MPa**
(compression)



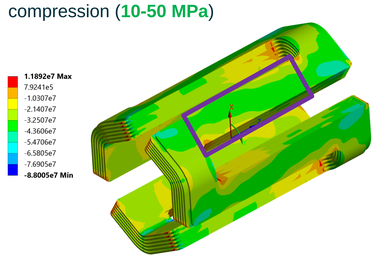
Hoop stress in injection solenoid at nom. field
In the range of **-55 to -3.5 MPa**
(compression)



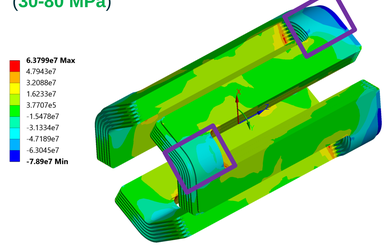
Von Mises stress in the sextupole at nominal field below 130 MPa



Sextupole **azimuthal stress** at nominal field
Coil straight section remain under compression (**10-50 MPa**)



Sextupole **axial stress** at nominal field
Sextupole coil-ends remain compressed (**30-80 MPa**)



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