Summary of solenoid issues

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Solenoid groups

- Target
- Pion Capture/Decay Channel
- Muon Drift
- Muon Cooling
- Muon Acceleration

Target Solenoid
General

- Resistive magnet nearest the beam for more efficient field production
- WC/H_2O shield between resistive and superconducting magnets
- Resistive-magnet housing removable as a unit from shield vessel and superconducting-magnet cryostat
- Assembly gaps fixed at minimum practical values

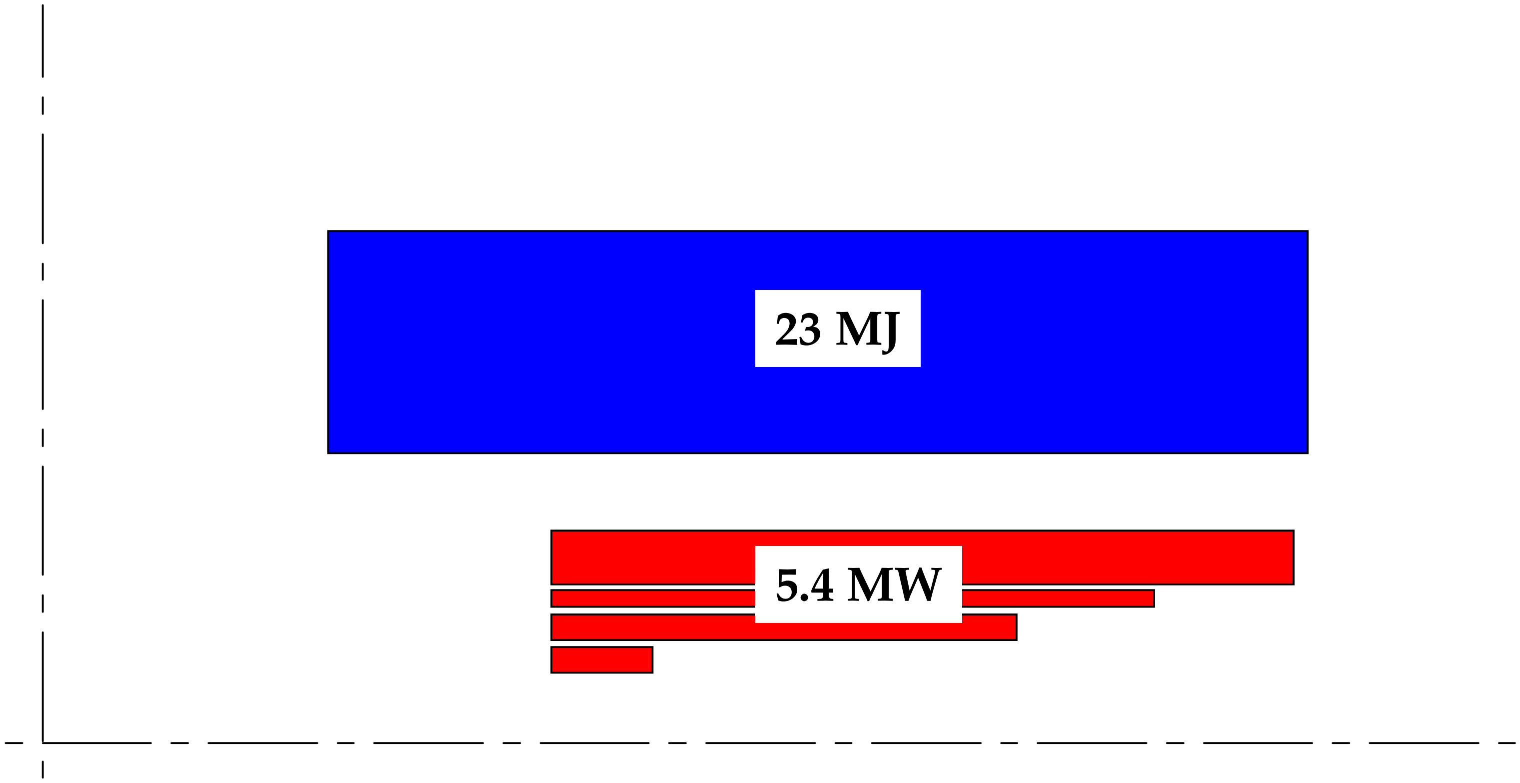
Target Solenoid: Resistive Insert

- Bitter-plate construction
- Hard-copper conductors
- “Ceramic” insulators
- 4-coil assembly

Target Solenoid Superconducting Outsert

- Single coil
- Force-cooled by supercritical He at 4.5 K
- CICC with 316LN jacket and MF-Cu/Nb_3Sn cable strands
- Pancake-wound construction with He inlets at the cross-over turns
- Radiation-tolerant epoxy-glass insulations applied after heat-treatment

Target Solenoid
Typical insert/outsert sizes



Muon Collaboration

Typical subcoil, Bitter-plate technology

QuickTime™ and a
Photo - JPEG decompressor
are needed to see this picture.

Water passage

Conductor stack,
one turn

Turn height

Insulation
layer

Parameters for a Bitter-coil set producing 10 T on axis

	Coil A	Coil B	Coil C	Totals
Inside radius (mm)	100	168	235	
Outside radius (mm)	165	232	300	
Height (mm)	320	404	538	
Number of turns	33	25	18	
Current (kA)	60	60	60	
NI (MA)	1.96	1.50	1.08	4.56
Voltage drop (V)	58	38	21	117
Power (MW)	3.5	2.3	1.3	7.1
Pack current density (A/mm^2)	125	67	36	
Voltage drop per turn (V)	1.74	1.56	1.17	
Δz_{turn} (mm)	9.7	16.5	29.6	
Δz_{insul} (mm)	~0.4	~0.45	~0.5	
$\Delta V/\Delta z$ across the insulation (V/mm)	~5	~4	~3	
Dia. of cooling holes (mm)	1.5	1.5	1.5	
Water velocity (m/s)	16	11	9	

Cooling (SFOFO) Solenoids

What kind of windings:

Ventilated windings – stable?

or

Impregnated windings – metastable?

Advantages of ventilated windings

- Will not quench or “train” under normal circumstances
- Much larger margin for tolerating off-normal events
- If there is a quench due to an off-normal event, most of the energy will typically be extracted, resulting in less time to recool

Disadvantages of ventilated windings

- Typically, larger conductors are desirable to avoid “wasted” space
- Active protection may be required
- A coil case is required
- A larger volume of conductor is required

Are these really disadvantages?

- Larger conductors useful in larger coils to reduce voltages during rapid discharge
- Passive protection more and more problematic for larger coils
- A rugged coil form will be required to distribute large fault forces
- The cost of larger coils is not so sensitive to conductor cost

  (in a ventilated design for SFOFO, the estimated conductor cost was ~10% of total)

Why is conductor volume not so critical in SFOFO?

$V = 2\pi \cdot a_1{}^3(\alpha^2 - 1)\beta$

where $\alpha = a_2 / a_1$, the ratio of outer and inner radii,

and $\beta = b / a_1$, the ratio of half - height and inner radius.

$$J = \frac{NI}{2a_1{}^2(\alpha - 1)\beta},$$

which yields

$$V = \frac{NI\pi \cdot a_1(\alpha + 1)}{J}.$$

For large, thin, modest - field coils ($\alpha \sim 1$), $V \propto \frac{1}{J}$.

For small, thick, high - field coils, $V \propto \frac{1}{J^2}$.

Why is helium in the windings good?

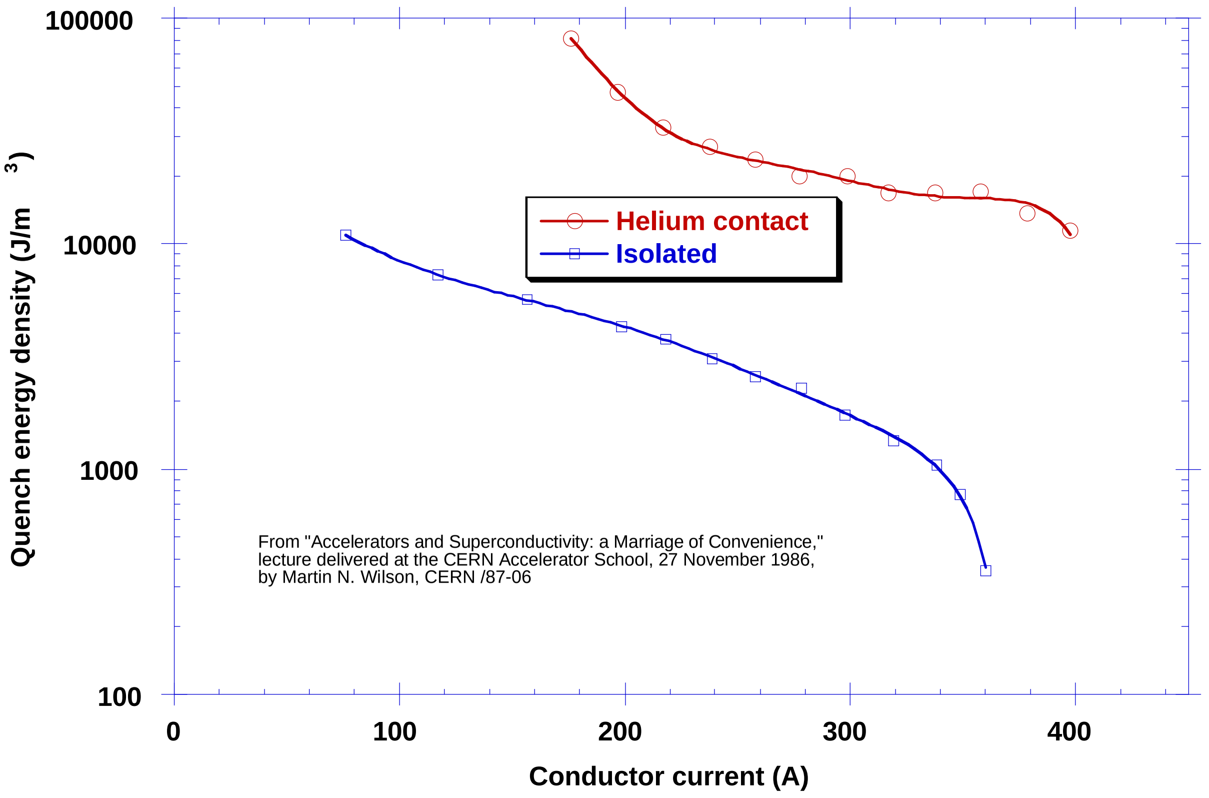
The energy density potentially deposited into a conductor by stick - slip - stop motion is given by $\frac{\Delta E}{\Delta V} = JB\Delta s$, where Δs represents motion $\perp$ both J and B.

Absorbing this energy results in a temperature rise, $\Delta T = \frac{JB\Delta s}{\sum_i f_i \rho_i \langle c_i \rangle}$,

where f_i, ρ_i, and $\langle c_i \rangle$ are the relative fractions, densites, and mean specific heats, respectively, of the constituents.

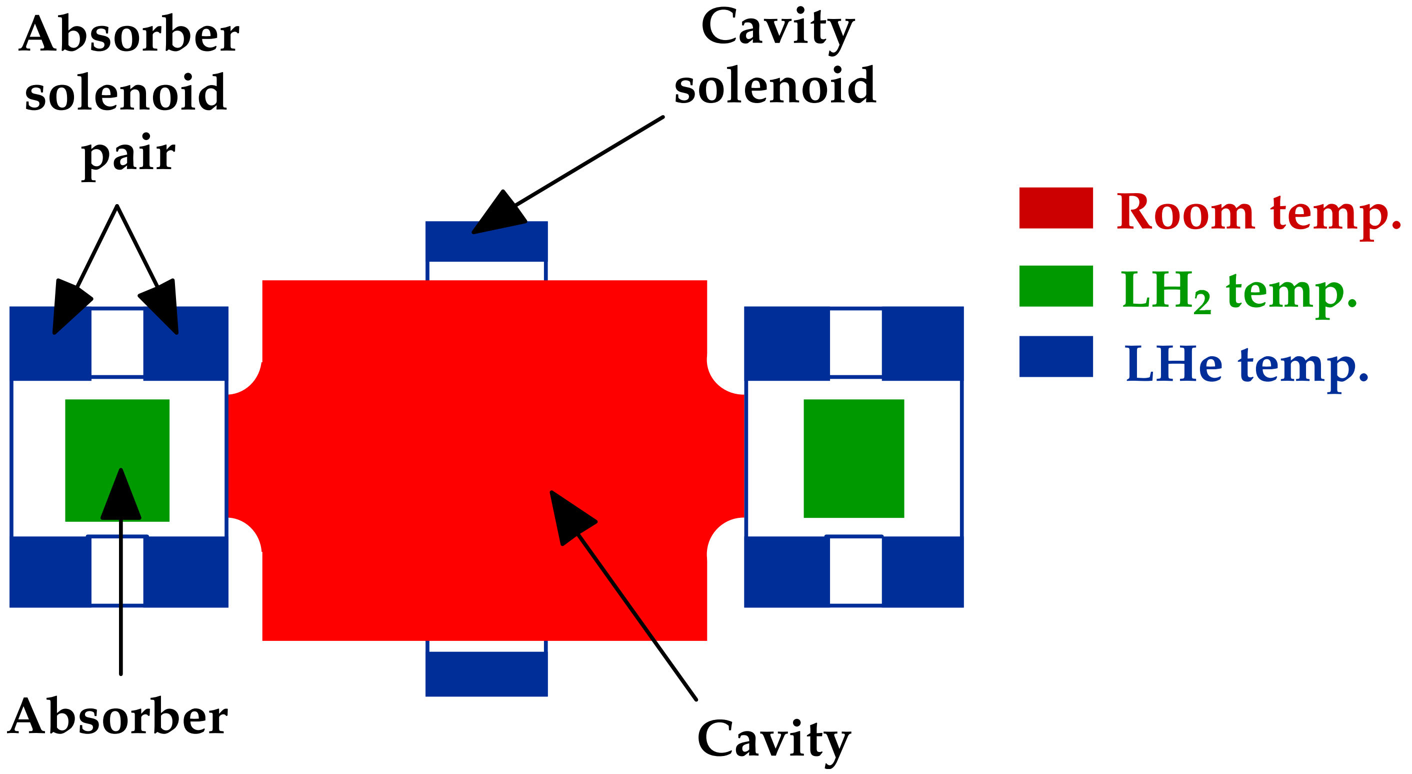
For a typical "dry" winding for SFOFO, 3-μm motion could result in $\Delta T = 0.9$ K, approximately the temperature margin of a conductor operating at 60% of its critical current at 6.4 T. That's because the heat capacity of the conductor is only about 2 kJ/m^3. Adding 10% LHe and taking credit for the latent heat of only 1/7 (6/7 expulsed by expansion), raises the local heat capacity of the windings to about 40 kJ/m^3.

Experimental results support this simple model



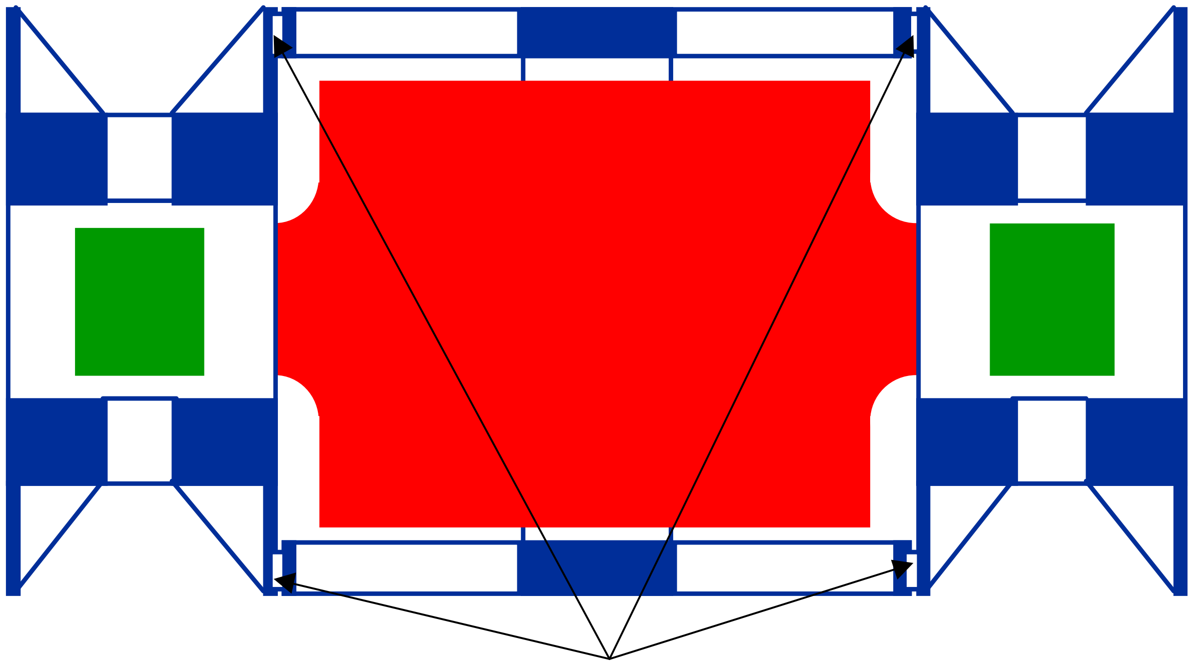
From "Accelerators and Superconductivity: a Marriage of Convenience," lecture delivered at the CERN Accelerator School, 27 November 1986, by Martin N. Wilson, CERN /87-06

Basic components requiring structural linking in the cryostat



Cold inter-coil structure

The potential fault forces on a set of coils are 2 orders
of magnitude greater than the gravity loads



Adjustable shims to compensate
for cooldown shrinkage