Development of High Field Wide Bore Superconducting Magnets for Research Applications

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UHFNMR & MRI: Science at Crossroads
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Timeline for Superconducting Magnet (Solenoids) Development

- **1962**: NbTi
- **1970**: NbTi @ 4.2 K
- **1983**: NbTi+ Nb3Sn @ 2.2 K
- **1990**: NbTi+ Nb3Sn+ RRP® @ 2.2 K
- **1995**: 22.5 T LTS+HTS(@4.2 K), 23.9 T (2.2 K)
- **2000**: 22.3 T 950MHz
- **2005**: NbTi/Nb3Sn+ RRP®+HTS? @ 4.2 K-2.2 K
- **2010**: 24 T@ OI 2 K
- **2015**: 32 T ? @ NHMFL
- **2020**: Bi-2212, Bi2223 YBCo

Flux Density (T) vs. Proton NMR Frequency (MHz)
Challenge of HF magnets large stored energy and size - Need Compact Systems

Increase in B or Bore → increase in size

22T @ 2.2K

22.5T @ 4.2K
Critical elements for Development of High Field/Wide Bore SC magnets

SC Materials /Design
- LTS <23T
- HTS >23T
- Conductor design
- Filament size
- Multi-filament/wire/tape conductors

Coil Technology
- Compact magnets
- Coil structure
- Cooling techniques
- Low vibration (if cryofree®)
- Low em noise

System Integration
- Integrating coils with different wires including LTS+HTS
- Design Tools
- Quench management
- Instrumentation

Customer + Materials + Engineering
## New class of HF magnets for Research

### 15T_250mm @ 4.2K LTS

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Specifications</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flux density homogeneity</td>
<td>&lt; 0.0143 over a 10 mm DSV</td>
<td>0.0144 over a 10 mm DSV</td>
</tr>
<tr>
<td>Energisation rate</td>
<td>&lt; 1 hours</td>
<td>59.55 min</td>
</tr>
<tr>
<td>Stored energy</td>
<td>7.3 Mjoule nominal</td>
<td>6.95 MJoule</td>
</tr>
<tr>
<td>Static Helium Boil off (No insert coil)</td>
<td>&lt; 3.2 L / hour</td>
<td>1.2 L / hour</td>
</tr>
<tr>
<td>Helium Capacity</td>
<td>300 L nominal</td>
<td>313 L</td>
</tr>
</tbody>
</table>

### 19T_150mm @ 4.2K LTS

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Specifications</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flux density homogeneity</td>
<td>&lt; 0.04 % over a 10 mm DSV</td>
<td>&lt; 0.04 % over a 10 mm DSV</td>
</tr>
<tr>
<td>Energisation rate</td>
<td>&lt; 2 hours</td>
<td>&lt; 2 hours</td>
</tr>
<tr>
<td>Stored energy</td>
<td>5.7 Mjoule</td>
<td>5.7 Mjoule</td>
</tr>
<tr>
<td>Static Helium Boil off (No insert coil)</td>
<td>&lt; 3.2 L / hour</td>
<td>0.86 L / hour</td>
</tr>
<tr>
<td>Helium Capacity</td>
<td>240 L</td>
<td>240 L</td>
</tr>
</tbody>
</table>
15T_250mm system – Quench management

- Peak coil currents during a Q from NbTi coil
- Peak coil temperatures during a Q from NbTi coil

Time step in %

Coil1_data
Coil2_data
Coil3_data
Active Heaters
Vcoil1
Vcoil2
Vcoil3

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LTS and HTS Integration – demonstrated 2011

Different HTS inserts developed from Bi-2212 wind & react coils and tested in a 20T LTS magnet

- Set 1, pair of 6 layer coils **100mm** long
- Set 2, single 14 layer coil **100mm** long
- Set 3, pair of 6 layer coils is **300mm** long

1.5mm round wire (15x85 fil.)

22T (2.2K) 20T @4.2K, 78 mm cold bore solenoid
## MRI magnet coverage

<table>
<thead>
<tr>
<th>Clinical MRI</th>
<th>Laboratory MRI</th>
<th>Special and Future MRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>• 1.5T-3T</td>
<td>• 7-9T</td>
<td>• &gt;11.4 T–20 T?</td>
</tr>
</tbody>
</table>

### Current and proposed MRI systems

- **Clinical**
- **Split Pair**

**In-vivo observation of metabolism**

- **NMR Frequency (MHz)**
- **Magnet Bore (mm)**
Summary

• Engineering of SC magnets up to 23T (narrow bore) is well understood and can be offered commercially as products.

• New generation of **HF compact magnets** is possible with different **bore sizes** (15T/160mm, 19T/150mm and 15T/250mm) and **cooling methods** (wet, cryofree and recondensed).

• Magnet development of **HF systems >25T** is now possible with compact wide bore LTS outserts to accommodate **HTS insert coils**.

*Thank you*