SPPC High Field Magnets - Preliminary Design Study and R&D Steps

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Chinese Academy of Sciences (CAS)

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  (Nb₃Sn Rutherford cabling, R&D status of high field HTS conductor, dummy coil fabrication, practice of shell-based structure,...)
• Summary
**Requirements of the SPPC Magnets**

### SPPC
- 50/100 km in circumference
- C.M. energy 70 TeV or higher
- Timeline
  - Pre-study: 2013-2020
  - R&D: 2020-2030
  - Eng. Design: 2030-2035
  - Construction: 2035-2042

### Main dipoles
\[ E[GeV] = 0.3 \times B[T] \times \rho[m] \]
- Field strength: 20 Tesla
- Aperture diameter: 40~50 mm
- Field quality: \(10^{-4}\) at the 2/3 aperture radius
- Outer diameter: 900 mm in a 1.5 m cryostat
- Tunnel cross section: 6 m wide and 5.4 m high

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The CEPC-SPPC ring sited in Qinhuangdao, 50 km and 100 km options.

6-m Tunnel for CEPC-SPPC. Left: SPPC collider. Right: CEPC collider (bottom) and Booster (top)

Refer to CEPC-SPPC Pre-CDR, Mar. 2015: [http://cepc.ihep.ac.cn/preCDR/volume.html](http://cepc.ihep.ac.cn/preCDR/volume.html)
Design Study of the SPPC Dipole Magnet

Q. Xu, K. Zhang, C. Wang et al.

20-T dipole magnet with common coil configuration
two Ø50 mm beam pipes; load line 80% @ 1.9 K

Integrated \( b_n/a_n \) Value (10\(^{-4}\))

<table>
<thead>
<tr>
<th>( b_n )</th>
<th>Value (10(^{-4}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>( b_3 )</td>
<td>0.14</td>
</tr>
<tr>
<td>( b_5 )</td>
<td>1.42</td>
</tr>
<tr>
<td>( b_7 )</td>
<td>-0.40</td>
</tr>
<tr>
<td>( a_2 )</td>
<td>-0.29</td>
</tr>
<tr>
<td>( a_4 )</td>
<td>-1.81</td>
</tr>
<tr>
<td>( a_6 )</td>
<td>0.03</td>
</tr>
</tbody>
</table>

**Design Study of the SPPC Dipole Magnet**

K. Zhang, Q. Xu, C. Wang et al.

Lorentz force per aperture:
- $F_{mag\_x} = 23.4 \text{ MN/m}$
- $F_{mag\_y} = 2.38 \text{ MN/m}$

Stress in coil after excitation

Stress in shell after excitation


R&D Steps for the SPPC Dipole Magnet

Q. Xu, K. Zhang, C. Wang et al.

With common coil configuration

1st step  ongoing
Fabrication of a 15-T Nb$_3$Sn or Nb$_3$Sn+HTS subscale magnet, to test the stress management method for Nb$_3$Sn & HTS coils and the quench protection method for HTS coils;

By the end of 2018.

2nd step
Fabrication of a 15-T Nb$_3$Sn or Nb$_3$Sn+HTS operational field dipole magnet with two $\Phi$50 mm beam pipes and $10^{-4}$ field quality, to test the field optimization method for HTS coils;

To be funded.

3rd step
Fabrication of the 20-T magnet with Nb$_3$Sn+HTS or only one of them, if we can get significant progress on the performance of Nb$_3$Sn or HTS superconductors, i.e., their Jc level is 3~6 times increased or even more, and the cost is significantly reduced. To be funded.

R&D Steps for the SPPC Dipole Magnet

C. Wang et al.

Comparison of different coil configurations

**Common coil vs Cos-theta**

**Common coil**

**Cos-theta**

**Different coil configurations for 20-T dipole magnet**

Left: Common coil

Right: Cos-theta

**Coil ends**
C. Wang, K. Zhang, Q. Xu et al.

1. A 14-T subscale magnet to be fabricated with Nb$_3$Sn and NbTi superconductors in 2016, to investigate the fabrication process and mechanical characteristics of Nb$_3$Sn coils.

For per meter of such magnet, the required length of the strand: Nb$_3$Sn: 4.48 Km; NbTi: 4.48Km.
C. Wang, K. Zhang, Q. Xu et al.

2-1. A 15-T subscale magnet to be fabricated with only Nb₃Sn superconductors but different cable dimensions, to test the stress management method of Nb₃Sn coils.

Main parameters of the cables

<table>
<thead>
<tr>
<th>Cable</th>
<th>Hight</th>
<th>Width-i</th>
<th>Width-o</th>
<th>Ns</th>
<th>Strand</th>
<th>Insulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>IHEPW1</td>
<td>5.8</td>
<td>1.5</td>
<td>1.5</td>
<td>14</td>
<td>IHEPWJC (Nb₃Sn)</td>
<td>0.15</td>
</tr>
<tr>
<td>IHEPW3</td>
<td>12</td>
<td>1.5</td>
<td>1.5</td>
<td>29</td>
<td>IHEPWJC (Nb₃Sn)</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Main parameters of the strands

<table>
<thead>
<tr>
<th>Strand</th>
<th>diam.</th>
<th>cu/sc</th>
<th>RRR</th>
<th>Tref</th>
<th>Bref</th>
<th>Jc@BrTr</th>
<th>dJc/dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>IHEPWJCJC</td>
<td>0.82</td>
<td>1</td>
<td>100</td>
<td>4.2</td>
<td>12</td>
<td>2400</td>
<td>400</td>
</tr>
</tbody>
</table>

For per meter of such magnet, the required length of the strand: Nb₃Sn in total: 9.12 Km.
2-2. A 16-T subscale magnet will be fabricated with HTS and Nb$_3$Sn superconductors, to test the stress management method and quench protection method of HTS coils.

For per meter of such magnet, the required length of the strand: YBCO: 1.44Km; Nb$_3$Sn: 4.48 Km
R&D Schedule for 2016-2018

C. Wang, K. Zhang, Q. Xu et al.

3. To fabricate a 14-T dipole magnet (with two apertures) with HTS and Nb$_3$Sn superconductors, to test the field optimization method of HTS & Nb$_3$Sn coils.

For per meter of such magnet, the required length of the strand: YBCO: 0.6 Km; Nb$_3$Sn in total: 9.12 Km
20-T Magnet Working Group in China

Northwest Institute for Non-ferrous Metal Research (NIN, Xi’an) & Western Superconducting Tech. Co, Ltd (WST, Xi’an)

Qualified $\text{Nb}_3\text{Sn}$ supplier for ITER; R&D and production of High $J_c$ $\text{Nb}_3\text{Sn}$ and Bi-2212 superconductors.

Shanghai JiaoTong U. & Shanghai Superconductor Tech. Co., Ltd (SSTC, Shanghai)

R&D and production of ReBCO superconductor.

Tsinghua U. & Innova Superconductor Tech. Co., Ltd (INNOST, Beijing)

R&D and production of Bi-2223 superconductor.

Institute of Plasma Physics, Chinese Academy of Sciences (IPP, Hefei)

Test stand with 12-T background field, $\text{Nb}_3\text{Sn}$ CICC cable fabrication;...

High Magnetic Field Laboratory, Chinese Academy of Sciences (CHMFL, Hefei)

Development of High field solenoids;...

Institute of High Energy Physics, Chinese Academy of Sciences (IHEP, Beijing)

30+ years R&D and production of conventional accelerator magnets, plus 10+ years R&D and production of superconducting magnets for particle detectors and industries.

and USTC, IMP, CIAE...

Welcome new members to join us!
20-T Magnet Working Group in China
20-T Magnet Working Group in China

Workshop on HTS & HFS Materials and Applications
http://indico.ihep.ac.cn/event/5946/

主办: 中科院高能物理研究所
协办: 上海交通大学
承办: 上海超导科技股份有限公司

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Development of $\text{Nb}_3\text{Sn}$ Rutherford Cable

Y. Zhu (WST) et al.

Collaboration between WST, Toly Electric, Changtong Electric and IHEP

Superconducting Rutherford Cable fabricated by Toly Electric with WST ITER type $\text{Nb}_3\text{Sn}$ strand

Superconducting Rutherford Cable fabricated by Changtong Electric with WST ITER type $\text{Nb}_3\text{Sn}$ strand
**Development of Nb$_3$Sn Rutherford Cable**

Y. Zhu (WST) et al.

**Collaboration between WST, Toly Electric, Changtong Electric and IHEP**

<table>
<thead>
<tr>
<th>Pitch length</th>
<th>Filling factor (%)</th>
<th>Ic degradation(%)</th>
<th>Average Ic degradation(%)</th>
<th>备注</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>90.6</td>
<td>9.39~16.04</td>
<td>12.48~12.67</td>
<td>损降最大</td>
</tr>
<tr>
<td>45</td>
<td>90.7</td>
<td>3.84~10.33</td>
<td>6.31~7.42</td>
<td></td>
</tr>
<tr>
<td>52</td>
<td>87.4</td>
<td>3.18~10.39</td>
<td>6.51~6.76</td>
<td>损降性能相当</td>
</tr>
<tr>
<td>52</td>
<td>83.7</td>
<td>0.33~6.2</td>
<td>3.13~3.60</td>
<td>损降最小</td>
</tr>
</tbody>
</table>

**不同磁场的Ic值**

<table>
<thead>
<tr>
<th>样品编号</th>
<th>节距60-90.6%</th>
<th>节距45-90.7%</th>
<th>节距52-87.4%</th>
<th>节距52-83.7%</th>
<th>原线</th>
</tr>
</thead>
<tbody>
<tr>
<td>12T</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13T</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14T</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
R&D of High Field ReBCO Tape by SSTC

**Architecture of type II superconductor from SSTC**

**Improved performance of SSTC tape at 4.2K**

3.3mm tape Ic:
>300A @ 12T, 4.2K

**Performance of SSTC tape at 4.2K and 12T**

**Improved performance of SSTC tape at 4.2K**

**Performance of SSTC tape at 4.2K and 12T**
R&D of Bi-2212 Superconductor by NIN

Fabrication of hundred meter level Φ1.0mm strands
4.2K, 0T: \(J_{ce} \ 920\text{A/mm}^2\), \(J_c \ 4400\text{A/mm}^2\).
4.2K, 20T: \(J_{ce} \ 270\text{A/mm}^2\), \(J_c \ 1200\text{A/mm}^2\).

An Over-pressure furnace is ready for heat treatment of strands

Bi-2212 stands and CICC conductor under development
Dummy Coil Fabrication

Kai Zhang, Chengtao Wang et al.

- **Racetrack coil**
- **Temperature controller**
- **Vacuum pump**
- **Magnetic Stirrer**
- **Epoxy tank**
- **Container**

Viscosity increase by time at 30°C (Huntsman epoxy):

- **Epoxy**: Huntsman epoxy & CTD-101K.
- 0.1 Mpa pressure be applied to the tank after epoxy filling.
- Preheat temperature: about 30°C
- Practice with copper Rutherford cables.
The present thickness of the shim and round tube of the bladder is 0.3 mm.

It’s obvious that the welding area between the shim and round tube is week where water leak always appear under high water pressure. We have increased the thickness of the shim and round tube to 0.5 mm, the new bladder will be tested soon.
Summary

• Design study of the SPPC high field magnets is ongoing.
• A series of 15T level model magnets will be fabricated in the next three years at IHEP, to investigate some fundamental problems for high field magnet R&D.
• Based on the collaboration between WST, Toly Electric, Changtong Electric and IHEP, development of high field Nb$_3$Sn Rutherford cable has got significant progress, almost ready for real cable fabrication.
• R&D of HTS superconductors for high field application is ongoing by SSTC and NIN.
• Preparation for the model magnet fabrication is ongoing at IHEP
• A national workshop on HTS materials and applications will be held at the end of this month in Shanghai.
• Next steps: model magnet development, funding application, international collaboration with LBNL, BNL and other interested labs).
From the Great Wall to the Great Collider
China and the Quest to Uncover the Inner Workings of the Universe

by Steve Nadis & Shing-Tung Yau

The story of the enchanting new physics that lies beyond the Higgs boson discovery — and the gargantuan particle accelerator that might get us there.

Thanks