Review of Operating Currents, Forces and Torques for the BEPC-II IR Magnets

Presented by
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## BEPC-II Superconducting IR Magnet Coil Parameter Summary

<table>
<thead>
<tr>
<th>BEPC-II Magnets 12-May-03</th>
<th>B, G (T), (T/m)</th>
<th>( R_{in} ), ( R_{out} ) (mm)</th>
<th>From IP (mm)</th>
<th>Coil Length (mm)</th>
<th>Magnetic Length (mm)</th>
<th>Operating Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS1</td>
<td>-</td>
<td>95.1~105.9</td>
<td>630~933</td>
<td>303</td>
<td>-</td>
<td>1120*</td>
</tr>
<tr>
<td>AS2</td>
<td>-</td>
<td>115.4~119.0</td>
<td>1035~1381</td>
<td>346</td>
<td>-</td>
<td>1120**</td>
</tr>
<tr>
<td>AS3</td>
<td>-</td>
<td>95.1~105.9</td>
<td>1474~1590</td>
<td>116</td>
<td>-</td>
<td>1120**</td>
</tr>
<tr>
<td>SCQ</td>
<td>18.744</td>
<td>95.1~108.1</td>
<td>961~1457</td>
<td>496</td>
<td>400</td>
<td>460</td>
</tr>
<tr>
<td>SCB (HCD)</td>
<td>0.543 0.056</td>
<td>108.5~111.8</td>
<td>633~1307</td>
<td>674</td>
<td>400</td>
<td>495 (50)</td>
</tr>
<tr>
<td>VCD</td>
<td>0.059</td>
<td>111.9~113.5</td>
<td>904~1514</td>
<td>610</td>
<td>380</td>
<td>24</td>
</tr>
<tr>
<td>SKQ</td>
<td>0.937</td>
<td>113.6~115.2</td>
<td>954~1464</td>
<td>510</td>
<td>400</td>
<td>45</td>
</tr>
</tbody>
</table>

*Best estimate as of 22-May-03. Previous was 1140 A.*

**AS2 and AS3 are in series with AS1 but can have their own independent trim currents.
BEPC-II Anti-Solenoid Design Parameter Summary

1/2 BES-III Detector with Anti-Solenoid

- $I_{\text{main}} = 1120 \text{ A}$
- $N_{AS1} = 732 \text{ turns}$
- $N_{AS2} = 260 \text{ turns}$
- $N_{AS3} = 280 \text{ turns}$
- $N_{\text{Tot}} = 1272 \text{ turns}$
- $L_{\text{Tot}} = 78 \text{ mH}$
BEPC-II Anti-Solenoid Layout & Wiring Schematic

Left Side

\[ \Delta I_{13L} \quad \Delta I_{12L} \quad \Delta I_{\text{Main}} \]

Right Side

\[ \Delta I_{12R} \quad \Delta I_{13R} \]

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Trim circuits will allow fine tuning of the anti-solenoid compensation scheme as well as left/right adjustment.

But given skew-quadrupole winding, is fine tuning really needed? (Need answer from IHEP.)

And if needed is +/-65 A enough? (Need answer from IHEP.)
Anti-Solenoid Longitudinal Force Diagram

Net Longitudinal force on right and left sides is equal in magnitude and opposite in direction since current flows with the same handedness on right/left sides but the BES-III radial field reverses on right and left sides.
**Anti-Solenoid Longitudinal Force Calculation**

\[
\vec{F} = \int J \times \vec{B} \, dV
\]

**Longitudinal Force**

@ 1120 A = 10 kN
(2300 lbs)

@ 1250 A = 12 kN
(2600 lbs)

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**Integration over region 15**
Total current (integral J ds) = 313547.9999
Integral of potential (integral 2 pi r A ds) = 39.20040494
Stored energy (integral pi^2 r A J ds) 529.4310071
Stored energy (integral pi^2 r B.H ds) 383.8888169
Force (integral 2pi r J x B ds) = (-10246.0471, -1036.414008)
Integral of 2*pi^2*r^2 BR

**Integration over regions 16 to 17**
Total current (integral J ds) = 291923.9999
Integral of potential (integral 2 pi r A ds) = -0.00434887
Stored energy (integral pi^2 r A J ds) = 0.57622490
Stored energy (integral pi^2 r B.H ds) = 115.1053607
Force (integral 2pi r J x B ds) = (-102215.022, -122.274303)
Integral of 2*pi^2*r^2 BR

**Integration over region 18**
Total current (integral J ds) = 019000.9997
Integral of potential (integral 2 pi r A ds) = 153.0181385
Stored energy (integral pi^2 r A J ds) = 30774.95335
Stored energy (integral pi^2 r B.H ds) = 994.5991522
Force (integral 2pi r J x B ds) = (-35116.18962, 10411.81516)
Integral of 2*pi^2*r^2 BR

**Integration over regions 15 to 18**
Total current (integral J ds) = 1424444.9999
Integral of potential (integral 2 pi r A ds) = 392.216889
Stored energy (integral pi^2 r A J ds) = 23486.73773
Stored energy (integral pi^2 r B.H ds) = 1467.59236
Force (integral 2pi r J x B ds) = (-19944.9112, 10381.52677)
Integral of 2*pi^2*r^2 BR

Component: 2*pi^2*r^2 BR
-30716.38
1097.763
32911.91

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There is a net torque on a dipole in a solenoidal field (but not on quadrupole due to symmetry). Magnitude of torque is \( I_{\text{Dipole}} \cdot A_{\text{Proj}} \cdot B_{\text{BES-III}} \).

Even though anti-solenoid changes the field seen by the dipole, a net torque remains on cold mass!

\[
\vec{\tau}_{\text{Dipole}} = \vec{\tau}_{\text{BES-III}} + \vec{\tau}_{\text{Anti}} = 0
\]

means that

\[
\vec{\tau}_{\text{Anti}} = - \vec{\tau}_{\text{BES-III}}
\]
Calculation of Torque on Cold Mass Due to the BES-III Solenoidal Field

Take $B_{\text{BES-III}}$ to be 1 T uniform field then...

**Case 1: Vertical Dipole Corrector (VDC) $A_{\text{Proj}} = 59.5 \, \text{m}^2$**

For $I_{\text{op}} = 24 \, \text{A}$, torque is $1430 \, \text{N} \cdot \text{m} (1050 \, \text{ft} \cdot \text{lbs})$ and

$I_{\text{Max}} = 65 \, \text{A}$ torque is $3870 \, \text{N} \cdot \text{m} (2850 \, \text{ft} \cdot \text{lbs})$

in the horizontal plane.

**Case 2: Horizontal Dipole Corrector (HDC) $A_{\text{Proj}} = 26.6 \, \text{m}^2$**

For $I_{\text{op}} = 50 \, \text{A}$, torque is $1330 \, \text{N} \cdot \text{m} (980 \, \text{ft} \cdot \text{lbs})$ and

$I_{\text{Max}} = 65 \, \text{A}$ torque is $1730 \, \text{N} \cdot \text{m} (1280 \, \text{ft} \cdot \text{lbs})$

in the vertical plane.

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Calculation of Maximum Allowable Torque and a Strong Warning

With VDC and HDC both at 65 A, can add torques in quadrature to get:

\[ \sqrt{3870^2 + 1730^2} = 4240 \text{ N} \cdot \text{m (3130 ft} \cdot \text{lbs)} \]

But must be sure that HDC (i.e. SCB) is never run at 550 A with the BES-III Solenoid turned on (e.g. Synrad mode)!

In that case we would have 550 A \cdot 26.6 \text{ m}^2 \cdot 1 \text{ T} = 14,600 \text{ N} \cdot \text{m (10,800 ft} \cdot \text{lbs)} from HDC!

Note: If the anti-solenoid were on, then once the cold mass gets out of line the torque would increase due to mutual repulsion with BES-III.
Need decision whether to provide trims for later anti-solenoid fine tuning (Ok to omit?).

Have assumed 1250 A, 550 A and 65 A power supplies (see G. Ganetis talk) for calculating forces and torques (Are these values ok?).

Checked that support at end can is adequate?

Must interlock SCB current with BES-III to avoid accident (Or make stronger supports with increased heat leak?)!