Revised Q2pF Return End for updated turn-to-turn spacing

Ramesh Gupta
March 12, 2024
Updated Return End

➢ Cross-section was updated to accommodate a significant change in turn-to-turn spacing (from 0.12 mm to 0.0965 mm).

➢ While turn distribution in inner layer remained same (31+4=35), it changed in the outer from (21+13=34) to (19+15=34) in the outer layer. Therefore, the end design needs to be updated.

➢ Need to assure a good field quality (end harmonics) and low peak fields with desired layout of end turns (Min. tilt angle 70 degrees).

Final optimization after the feedback from the single turn winding trials
Revised X-section with Symmetric Wedges
(as presented last week)

- Uses EIC Quad Cable
- Field Quality Optimized
- Peak field Optimized
- Poles of Outer and Inner aligned
- Wedges made exactly symmetric
- Collaring process should provide a good pre-stress
  (note: wedge shape at poles)

(same number of turns as before: inner 35 and outer 34, but turn distribution in outer layer changed)

Looks good mechanically
Peak Field Calculations in Q2pF Cross-section

Non-linear iron
Peak Field: 6.387 T
Gradient: 38.27 T/m

Peak Field Enhancement:
6.387T/5.358T = 19.2%

Mirror iron calculations (saves time, however, expect higher field at the same current)

Peak Field: 6.89 T
Gradient: 41.498 T/m

Peak Field Enhancement:
6.89T/5.81T = 18.6%
(ratio about the same)

Mirror iron calculations takes significantly less time
Important in 3-d calculations; used during the optimization
Return End for updated turn-to-turn spacing (min tilt angle 70°)

➢ End turns of the outer layer and the inner layers aligned
Additional Peak Field Enhancement in the Ends

End configuration iterated for smaller peak fields in the ends. Final optimization after the winding trials.

ROXIE calculations with mirror iron

• Peak field in 2-d: 6.89 T
• Peak field in 3-d: 7.09 T

Only about ~2.9% higher peak field than that in the x-section (what are the calculation errors?)

Turn #34 is the pole turn in the outer layer
Integrated harmonics (3-d) in the Return End

A reasonable end design:
- All integrated field harmonics are well within 1 units (mirror iron).
- Final optimization to be performed after the winding trials and with non-linear iron.

End configuration iterated for lower integrated harmonics in the ends.
Renderings of the Inner Layer of the Return End

Looks reasonably ok; to be examined more carefully
Renderings of the Outer Layer of the Return End

Looks reasonably ok; to be examined more carefully
Renderings of Both Layers of the Return End

Looks reasonably ok; to be examined more carefully
Field along the z-axis at a radius of 100 mm on the horizontal axis and vertical axis

By (T)

$$\begin{align*}
\text{B}_x \\
\text{B}_y \\
\text{B}_z
\end{align*}$$

(symmetric return end)

Next set of runs with the separate lead end
Field harmonics $B_6$ and $B_{10}$ along the z-axis

(symmetric return end)
Summary

➢ Initial return end design completed for the updated turn-to-turn spacing
➢ The present solution has a reasonable peak field enhancement in the ends and reasonable integral harmonics
➢ Next : Update the Lead End
➢ Final finer optimization to be performed after the winding trials in case parameters have to be adjusted
Extra Slides
# Comparison with the Previous Design

## Previous Design

<table>
<thead>
<tr>
<th>Block Data 2D</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>Type</td>
<td>NCab</td>
</tr>
<tr>
<td>1</td>
<td>Cos</td>
<td>31</td>
</tr>
<tr>
<td>2</td>
<td>Cos</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Cos</td>
<td>21</td>
</tr>
<tr>
<td>4</td>
<td>Cos</td>
<td>13</td>
</tr>
</tbody>
</table>

## New Design

### Previous value of insulation

<table>
<thead>
<tr>
<th>Block Data 2D</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>Type</td>
<td>NCab</td>
</tr>
<tr>
<td>1</td>
<td>Cos</td>
<td>31</td>
</tr>
<tr>
<td>2</td>
<td>Cos</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Cos</td>
<td>19</td>
</tr>
<tr>
<td>4</td>
<td>Cos</td>
<td>15</td>
</tr>
</tbody>
</table>

### New value of insulation

| Optimization algorithm || Extrem |  |
|------------------------|---------|----------|
| No | X | Y | No | X | Y | No | X | Y | No | X | Y |  |
| 1  | 0,5 | 1,3 | 0,5 | 0,5 | 0,46 | 0,46 | 0,46 | 0,46 | 0,46 | 0,46 | 0,46 | 0,46 |
| 2  | 0,45 | 1,3 | 0,46 | 0,46 | 0,46 | 0,46 | 0,46 | 0,46 | 0,46 | 0,46 | 0,46 | 0,46 |
| 3  | 2 | 9 | 6,6685 | 6,6685 | 6,6685 | 6,6685 | 6,6685 | 6,6685 | 6,6685 | 6,6685 | 6,6685 | 6,6685 |
| 4  | 2 | 12 | 10,3535 | 10,3535 | 10,3535 | 10,3535 | 10,3535 | 10,3535 | 10,3535 | 10,3535 | 10,3535 | 10,3535 |
| 5  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
Cross-section (ROXIE)

➢ Symmetric wedges

Ramesh Gupta
Revised Q2pF Return End for updated turn-to-turn spacing