AC LOSSES MODEL - PRD

Between 1D model and 3D real geometry, a demagnetization factor 2 is applied (relevant to rod-stab equivalence).

The ITER Central Solenoid (CS) has terminal butt-type joints called Coaxial joints. It was decided to study a design of this joint with rutherford shunts, and to build models for its resistive and inductive behaviors. In particular, the behavior of the joint under magnetic field transients is investigated with various analytical models that are compared with a FEM model. The key point of the study was to verify that the induced currents were reasonable and would not induce flux jumps in the rutherford. A prototype with simplified geometry was tested in the CEA Josefa facility under various field ramps. The results are presented and discussed.

AC LOSSES - LUD

The LUD design has a complete outer superconducting cylindrical shell. This implies a very good shielding of the perpendicular field variation. The composite (strand) model for AC losses* can be applied:

For a parallel screening by parallel rutherford, the usual composite model [see below] is not applicable. A model based on 1D magnetic diffusion is developed.

Eigentunction expansion

The mockup was tested in the Josefa Facility (CEA / up to 1 T). Model (dashed) is confronted to the experimental measurements (plain) in these induced voltage curves.

Model Losses Calculation for T=1s runs

Onset of instabilities is found at around 0.6T field variation:

CONCLUSION

Two coaxial joint designs are still being investigated. For both designs, an AC losses and induced currents assessment was necessary. For the PRD, the model is based on magnetic diffusion equation, and was confronted with experiment. For both designs, 0.1T/s field variation, axial and transverse, are acceptable.

AC LOSSES MODEL - PRD

A COMSOL FEM model was also developed to cross-check the values computed by the analytical model. Currents and field distributions are shown below. It was also used to compute axial field variation reactions.

**Note:**

The mockup was manufactured using rutherford cables soldered to a copper block with similar geometry.

**Diagram:**

Rutherford joint with magnetic field transients.

**Table:**

<table>
<thead>
<tr>
<th>Runs</th>
<th>I_{0,0} [A]</th>
<th>E_{of} [W]</th>
<th>E_{tot} [J]</th>
<th>T_{MAX} [K]</th>
<th>T_{MIN} [K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>B_{0}=0.1T</td>
<td>3.19</td>
<td>0.684</td>
<td>0.37</td>
<td>5.65</td>
<td>8.13</td>
</tr>
<tr>
<td>B_{0}=0.4T</td>
<td>12.8</td>
<td>1.35</td>
<td>0.64</td>
<td>8.00</td>
<td>12.4</td>
</tr>
<tr>
<td>B_{0}=0.6T</td>
<td>19.9</td>
<td>3.26</td>
<td>1.52</td>
<td>19.4</td>
<td>15.9</td>
</tr>
<tr>
<td>B_{0}=0.8T</td>
<td>25.6</td>
<td>5.40</td>
<td>2.51</td>
<td>32.1</td>
<td>18.1</td>
</tr>
</tbody>
</table>

AC LOSSES - LUD

The LUD design has a complete outer superconducting cylindrical shell. This implies a very good shielding of the perpendicular field variation. The composite (strand) model for AC losses* can be applied:

![Diagram of LUD design](image)

**Table:**

<table>
<thead>
<tr>
<th>Design parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint axial length</td>
<td>30 mm</td>
</tr>
<tr>
<td>Cable compacted diameter</td>
<td>20 mm</td>
</tr>
<tr>
<td>Residual void fraction</td>
<td>0.1</td>
</tr>
<tr>
<td>Cable twist pitch</td>
<td>450 mm</td>
</tr>
<tr>
<td>Max background operating field</td>
<td>3.9 T</td>
</tr>
</tbody>
</table>

**Diagram:**

- External Sc shells (soldered)
- 2 layers of twisted strands (120mm)

**Diagram:**

Parallel Rutherford Design (PRD)

- Straight copper shells
- Parallel rutherford

**Diagram:**

Laced Union Design (LUD)

- 2 layers of twisted strands [120mm]
- Straight copper shells
- Parallel rutherford

**Diagram:**

Field transient 0.1T/s during 1s + plateau

Computed power and induced currents

$$ P = \frac{2 \pi B_0 I_L^2}{\mu_0} \text{[W/m]} $$

$$ I_L = B_1 \left( \frac{L_1}{\mu_1} \right) \frac{B_2}{\mu_2} \frac{1}{\rho_0} \text{[m]} $$