Magnetic Insulation of RF (MIR)

R. B. Palmer, R. Fernow, J Gallardo (BNL)

Friday Meeting

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- Possible fix #1 with coils in irises
- Concept of magnetic Insulation of rf
- Simulations of simple pillbox with exact B direction
- Simulations with 1 degree miss direction of B
- Simulations of magnetically ionsulated cavity
- Experiments
- Conclusion
Fix # 1: Open 805 MHz cavity with coils in the irises

- For opposed coil currents
  - Electrons end in low field region, or
  - Return, but with low energy
  - This may, or may not, fix the problem

- Does not work for coils with same signs (see appendix 2 for fix)
The above suggests ‘Magnetitically Insulated rf’
Concept discussed for DC or slowly changing electric fields. e.g. RV Lovelace and E Ott Physics of Fluids 17, (1974)

Form cavity surface to follow magnetic field lines

• All tracks return to the surface, but
• Energies are very low
• No dark current, No X-Rays, no danger of melting surfaces
• Again does not work for same sign coils (see appendix 3 for fix)
Simulation of simple pillbox

CAVEL Simulation of 10 cm long simple 805 MHz cavity with 1 T magnetic field ⊥ axis

- Electrons move perpendicularly to field
- remaining close to surface
- Distance traveled depend on initial rf phase
Parameters versus time

1. Phase -80

Field (MV/m) KE 50 (eV)

2. Phase -40

Field (MV/m) KE 427 (eV)

3. Phase 0

Field (MV/m) KE 280 (eV)

4. Phase 40

Field (MV/m) KE 110 (eV)

5. Phase 80

Field (MV/m) KE 101 (eV)
• Energies (for 1T) are near maximum of secondary emission
• But no electron returns in following rf cycle
• So no build up of electrons (multipactering)
<table>
<thead>
<tr>
<th>Field (T)</th>
<th>Max E (eV)</th>
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</thead>
<tbody>
<tr>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
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<td>8</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
</tr>
</tbody>
</table>

- Energies and distances from surface $\propto \frac{1}{B^2}$
- At $B=1$ T secondary emission could be a problem
- But at $B \geq 4$ T the energies are too low ($\leq 20$ eV)
Sensitivity to angle of field
Simulate case with B at 91 degrees from cavity axis

- Situation is more complicated
- many tracks go to side walls
- But some return to surface with V enough for secondary emission

More studies needed to check multipactering
Magnetically insulated acceleration cavity

- This is NOT a good cavity
  \[ E_{\text{max}} = 3 \times E_{\text{acc}} \]
- But IS shaped to follow field lines

\[
\begin{align*}
J &= +55 \text{ A/mm}^2 \\
J &= -55 \text{ A/mm}^2
\end{align*}
\]
• Negative phases end with too high an energy for secondary emission
• But too low for damage
• Multipacting is less of a problem
Vs time

- Again muons end either at negative phases, or advance towards negative phases
- There will be no multipactoring
First Experiment in MTA
Using lab G Magnet and existing cavity at two angles
In next few weeks

- This is a test of "Fix #1" but not of "magnetically insulated rf"
- Note sensitivity to angle: if field lines focus to an iris, breakdown will not be suppressed
Possible next Experiment in MTA

- Using lab G Magnet and new simple pillbox cavity at multiple angles

This will be a better test of ’magnetic insulated rf

But angles should be good to a fraction of a degree, or adjustable over such a range, to see the senstitive angle dependence
Later test of Magnetically Insulated Cavity

Under discussion

- Use of double coil geometry allows condition to be tuned
Conclusion

• Ionization cooling for muon colliders require rf in magnetic fields
• But damage & gradient degradation seen with cavities in axial magnetic fields
• Coils in standard open cell irises offer possible solution # 1
  – Electrons end in low field regions
  – or return to source
  – but at lower energies

• By shaping cavity walls we can obtain solution "Magnetic Insulation"
  – Electrons are constrained to be near their sources
  – Dark current and X-Rays should be suppressed
  – Only possible problem is secondary emission

• Simulations of simple pill-box
  – If B exactly parallel to surface then no secondary emission problems because no carry-over to next cycle
  – But if error of 1 degree, situation more complicated

• Help from SLAC promised to study this
Appendix 1: Estimate of worst electron energy

<table>
<thead>
<tr>
<th>Energy</th>
<th>Cu range</th>
<th>Be range</th>
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</thead>
<tbody>
<tr>
<td>MeV</td>
<td>mm</td>
<td>mm</td>
</tr>
<tr>
<td>.13</td>
<td>.02</td>
<td>.07</td>
</tr>
<tr>
<td>0.25</td>
<td>0.05</td>
<td>.2</td>
</tr>
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<td>.5</td>
<td>0.19</td>
<td>.76</td>
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<tr>
<td>1</td>
<td>0.44</td>
<td>1.76</td>
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<tr>
<td>4</td>
<td>2.2</td>
<td>8.8</td>
</tr>
</tbody>
</table>

Thermal diffusion depth

\[ \tau_{201} = 200 \mu \text{sec} \quad \tau_{805} = 25 \mu \text{sec} \]

\[ \delta = \sqrt{\frac{2k\tau}{C_v}} = \sqrt{\frac{2 \cdot 4.01 \tau}{3.45}} \]

\[ = 0.2 \text{ (mm)} \quad \text{for 201 MHz} \]

\[ = 0.07 \text{ (mm)} \quad \text{for 805 MHz} \]

So \( \approx .5 \) (.2) MeV bad at 201 MHz for Cu (Be)

So \( \approx .3 \) (.13) MeV bad at 805 MHz for Cu (Be)

Be is better than Cu because the electrons go deep & \( \frac{dE}{dx} \) is less
This needs a real simulation, the above is only a qualitative argument
Appendix 2: Coil in iris solution for same sign currents

- Add outer coils with opposite currents
- Increase, somewhat main coils to regain field
- Fields on axis are not much different
Appendix 3: fix with non-alternating fields

- Note fields on the axis is little effected by outer coils
- Need experiments