Design of tunable magnets for 12 MeV Race - Track Microtron

10 November 2011

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1.- 12 MeV Race – Track Microtron of the UPC.

- The Technical University of Catalonia (UPC), the Skobeltsyn Institute of Nuclear Physics (SINP - Moscow State University) and CIEMAT are building a race-track microtron (RTM).

- A possible future application of this RTM is Intraoperative Radiation Therapy.

### Race – Track Microtron components,

1. Electron gun,
2. Linac,
3-4. End magnets,
5. Quadrupole,
6. Extraction magnet,
7. Extracted beam.

### Technical Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energies</td>
<td>6, 8, 10, 12 MeV</td>
</tr>
<tr>
<td>Operating frequency</td>
<td>5712 MHz</td>
</tr>
<tr>
<td>End magnet field</td>
<td>0.8 T</td>
</tr>
<tr>
<td>Maximum beam current</td>
<td>&lt;2.5 μA</td>
</tr>
<tr>
<td>RTM head dimensions</td>
<td>670x250x210 mm</td>
</tr>
<tr>
<td>RTM head weight</td>
<td>&lt; 100 kg</td>
</tr>
</tbody>
</table>
Vacuum chamber and pumping tube assembly.

Supporting platform with linac installed.
2.- End magnet design.

- The end magnet function is to provide the beam recirculation in the RTM.
- As a source of the magnetic field in the end magnets the rare earth permanent magnet (REPM) material is used (M1-M13). The permanent magnet are necessary because:
  1. Complicated magnetic field profile.
  2. Compatible with high vacuum.
  3. Permit a compact design.
End magnet external dimensions.

• The end magnet is formed by:
  One 180º - dipole (main pole) (0),
  One reverse field magnet (1)
  Two additional dipoles (2,3).
• Reverse field magnet: Compensate the defocusing effect by the fringe field.
• Additional dipoles: Reflect the first orbit back to the linac axis.

Beam trajectory for first orbit.
End magnet field profile in the orbit plane.

The residual magnetization of REPM blocks are:

\[ B_{rM1} = B_{rM2} = B_{rM3} = 1.06 \, \text{T} \]
\[ B_{rM4} = B_{rM5} = 0.0663 \, \text{T} \]

Design requirements,

\[ \frac{\Delta B_0}{B_0} = 10^{-3} - 10^{-4} \]
\[ \frac{\Delta B_{1,2,3}}{B_{1,2,3}} = 10^{-2} - 10^{-3} \]
3.- End magnet tuning system.

- The magnetic systems must reproduce the field found in beam dynamics simulations with:
  - Field Uniformity: $10^{-3}$
  - Absolute field value: $5 \times 10^{-4}$
  - Equality of field of two magnets: $10^{-4}$

- In electromagnets: the magnetic field adjustment is achieved by varying the current in the coils.

- In permanent magnets some tuning mechanisms are used:
  1. Magnetization and demagnetization.
  2. Tuning with plungers.
  3. Tuning with rotating blocks.

For the tuning of the RTM end magnet we decided to use a system of plungers.
Tuning process.

\[ V_0 = \frac{gB_0}{2\mu_0} \]

\[ \mu = \infty \]
3.1. - Simulation of tuners.

3.1.1. - Main pole tuning system.

- The main pole tuning system consists of a cylindrical plunger that moves in a channel in the end magnet (M2 block).
- To avoid the plunger saturation, Vanadium – Permendur material is used.

The maximum magnetic field variation is \( \frac{\Delta B_0}{B_0} = 0.037 \).
3.1.2.- Reverse pole tuning system.

- Reverse pole tuning: a system of six tuners that moves horizontally to the reverse pole.
- The M4 height was reduced to allow the motion of the plungers.

The maximum magnetic field variation is \( \frac{\Delta B_2}{B_1} = 0.086 \).
3.1.3.- Additional pole tuning system.

- Additional poles tuning: a system formed by five tuners (diameter 4.5mm) that move vertically in the REPM blocks M7 and M11.
- To allow tuners movements we perform a channels in REPM blocks M7 and M11.

The maximum magnetic field variation is \[ \frac{\Delta B_2}{B_2} = 0.0473 \].
3.2.- Tuning ranges and interdependence.

In the ANSYS simulations it was obtained that a variation of the position of the main pole plunger affects the magnetic field in the reverse pole.
And vice versa, a variation of the position of the reverse pole plunger, $h_2$, changes the magnetic field in the main pole.
3.3.- Tuning procedure.

By means of ANSYS simulations it was found that the nominal values of the magnet field:
- \( B_0 = 0.79826 \, \text{T} \)
- \( B_1 = 0.116 \, \text{T} \)

are obtained at the median tuner positions:
- \( H = 5.0 \, \text{mm} \)
- \( h_2 = 2.5 \, \text{mm} \)

for the residual magnetizations:
- \( B_{rM1} = B_{rM2} = B_{rM3} = 1.0628 \, \text{T} \)
- \( B_{rM4} = B_{rM5} = 0.1278 \, \text{T} \)
4.- Summary results and conclusions.

- The results obtained in the ANSYS simulations are,

| Pole          | $|\Delta B_n / B_n|$ |
|---------------|---------------------|
| Main Pole     | 0.037               |
| Reverse Pole  | 0.086               |
| Additional Poles | 0.047               |

- For magnetic field tuning we must use a combination of the demagnetization technique and tuning with plungers. The procedure is the following:
  - magnetize REPM to maximum level of $Br=1.1 – 1.2$ T.
  - measure field level and in 1-2 steps by applying demagnetizing field reduce the field level to the range found in ANSYS simulations with respect to the nominal level.
  - By moving the plunger, make the most difficult step, to adjust the magnetic field level.

- Future work: Once the magnets are manufactured, apply this tuning process.
Thank You