An RF-$E \times B$-Dipole for Spin Manipulation at COSY
Prototype Commissioning and First Measurements

March 31, 2014 | Sebastian Mey for the JEDI Collaboration | Forschungszentrum Jülich
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Proposed Measurements

The RF-ExB-Dipole

Field Distribution and Compensation

First Measurements

Conclusion
Proposed Measurements

- Goal: disentanglement of EDM signal from false rotations induced by ring imperfections
- comparison of transverse rotations of invariant spin axis
  - solenoid field rotates spin axis in x-y-plane
  - radial dipole field rotates spin axis in y-z-plane, but transverse beam excitation \( \Rightarrow \) compensation with vertical E-field
- RF-B-field, \( \int \hat{B}_x \, ds = 0.3 \, \text{T mm} \), RF-E-field, \( \int \hat{E}_y \, ds = 46 \, \text{kV} \)
- spin-tune-frequency \( f_0 = f_{\text{rev}} |k + \gamma G|; \ k \in \mathbb{Z} \)
- \( d \) at 970 MeV/c: \( \gamma G = -0.16098; \ f_{\text{rev}} = 750 \, \text{kHz} \):

<table>
<thead>
<tr>
<th>( k )</th>
<th>( \nu_0 / \text{kHz} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>120</td>
</tr>
<tr>
<td>1</td>
<td>629</td>
</tr>
<tr>
<td>-1</td>
<td>871</td>
</tr>
<tr>
<td>2</td>
<td>1380</td>
</tr>
<tr>
<td>-2</td>
<td>1621</td>
</tr>
</tbody>
</table>
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**RF-B-Dipole**
- Ferrite blocks
- Coils: 8 windings, length 560 mm

**RF-E-Dipole**
- Two electrodes in vacuum camber
- Distance 54 mm, length 580 mm

**Shielding Box**
- Ceramic beam chamber
- Two separate resonance circuits

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The RF-ExB-Dipole

- **RF-B:**
  - watercooled copper tubing, $r = 3\, \text{mm}$
  - ferrite blocks in window frame configuration
  - $\mu_r = 240@1\, \text{MHz}$

- **RF-E**
  - electrodes 50 µm stainless steel foil
  - spanned over glass rods, $r = 3\, \text{mm}$
  - feedthroughs and leads mounted symmetrically
RF-B-Circuit

- parallel resonance circuit
- amplitude limited by losses \( \hat{I}_{\text{max}} \approx 5 \, \text{A} \)
- tuning to 50 \( \Omega \) with bidirectional coupler
- current in coil directly available via current transformer
RF-E-Circuit

- resonance circuit coupled to load by high ohmic balun transformer
- \( \hat{U}_{\text{max}} \approx 5 \text{kV} \) limited by high-voltage feedthroughs
- electrode voltage directly available via capacitive voltage divider
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Magnetic Flux Density

\[ \hat{I} = 1 \, \text{A} \]
\[ \hat{B}_x = 0.058 \, \text{mT} \]
\[ \int \hat{B}_x \, dz = 0.035 \, \text{T mm} \]

- distribution of radial component of magnetic flux density
- fields shown in central beam plane at \( y = 0 \)
Electric Field

\[ \hat{U} = 395 \text{ V} \]

\[ \hat{E}_y = 7594 \text{ V/m} \]

\[ \int \hat{E}_y \, dz = 4818 \text{ V} \]

- distribution of vertical component of electric field
Lorentz Force

\[ F_y = e(\hat{E}_y + c\beta \hat{B}_x) \]

- \( \beta \equiv \beta_z = 0.459; \quad \hat{l} = 1 \text{ A}; \quad \hat{U} = 395 \text{ V} \)
- optimization for integral compensation along beam path

\[ \int \hat{F}_y \, dz = 0 \text{ eV/m} \]
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First Measurement of Field Compensation

\[ f_{\text{RF-ExB}} = f_{\beta_Y} = 1186 \, \text{kHz} \]
\[ \hat{i} = 0.27 \, \text{A} \]
\[ \hat{U}_1 = 129 \, \text{V} \]
\[ \hat{U}_2 = 116 \, \text{V} \]

- measurement exactly on betatron frequency for max. sensitivity
- diagnosis with COSY beam current transformer
- pulsed mode of operation, 38 pulses, each 10 ms long
- compensation observed, minimum of 7% beam-loss achieved
- fringe fields and transient time behaviour have to be further studied

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First Measurement of Field Compensation

- set up well cooled beam
- orbit correction in the RF-dipole
- tune measurement
- fix one setting for the amplitude of RF-E-part
- vary amplitude and phase offset of RF-B-part to reach minimum beam loss

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Measurement at Spin Resonance Frequency

\[ f_{\text{RF-ExB}} = 871 \text{ kHz} \]
\[ \hat{i} = 3.38 \text{ A} \]

- \[ f_{-1} = f_{\text{rev}}| - 1 + \gamma G| \]
- relatively low current in RF-B-part already induces beamloss
- fields at \( \hat{i} = 3.38 \text{ A} \) : \( \hat{B}_x = 0.2 \text{ m T} \); \( \int \hat{B}_x \, dz = 0.12 \text{ T mm} \)
- required power \( \approx 120 \text{ W} \)
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Conclusion

To Do

- Simulations
  - simulations with true RF-fields to better understand losses due to eddy-currents
  - verify simulations with precise field measurements in the lab
- Measurements
  - spin dynamic measurements planned for September 2014 in JEDI-beam-time with polarized d-beam
- Hardware Development
  - prototype development for an upright, high-power RF-ExB-dipole based on a stripline design already under way
Thank You for Listening!

In case of additional questions contact s.mey@fz-juelich.de.

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Transient Time Behaviour

\[ \Delta t = 45 \text{ } \mu \text{s} \]
\[ \hat{i} = 0.27 \text{ A} \]
\[ \hat{U}_1 = 129 \text{ V} \]

- Wien-Filter condition not fulfilled during first \( \approx 15 \mu \text{s} \) of each pulse
- complete transient time lasts \( \approx 100 \text{ ms} \)
\( \Rightarrow \) rework of resonance circuit required
\( \Rightarrow \) ultimate precision needs feed forward control during activation cycle
\( \hat{I} = 1 \text{ A} \)

\( \hat{B}_y \approx 10^{-3} \hat{B}_x \)

in central field region

- vertical component dominated by fields from leads to the coil
\[ B_z \]

\[ \hat{i} = 1 \text{ A} \]

- Longitudinal component dominated by fields from the coil going around the beam chamber.
\[
\hat{U} = 395 \text{ V}
\]
\[
\hat{E}_x \approx 10^{-3} \hat{E}_y
\]
in central field region

- distribution of radial component of electric field dominated by fields from leads to the electrodes
\[ E_z \]

\[ \hat{U} = 395 \text{ V} \]

- distribution of longitudinal component of electric field dominated by fields from leads to the coil
\[ F_x \]

\[ \beta \equiv \beta_z = 0.459 \]
\[ \hat{i} = 1 \text{ A} \]
\[ \hat{U} = 395 \text{ V} \]

- \[ F_x = e(\hat{E}_x + c\beta \hat{B}_y) \]
\( F_z \)

\[ \hat{i} = 1 \text{ A} \]

\[ \hat{U} = 395 \text{ V} \]
Wave Impedance

\[ \hat{i} = 1 \text{ A} \]
\[ \hat{U} = 395 \text{ V} \]
\[ Z_{\text{theory}} = 173 \Omega \]

\[ Z = \frac{\hat{E}_x}{\hat{H}_y} = -\frac{\hat{E}_y}{\hat{H}_x} = \beta_z Z_0 \]
Orbit Corrections

\[ \Delta x = 0.7 \text{ mm} \]
\[ \Delta x' = 0.06 \text{ mrad} \]

- corrected orbit with closed bump at RF-Dipole
- BPM 14 and 15 at Dipole before and after RF-ExB
- distance \( \Delta z = 4.2 \text{ m} \)
Orbit Corrections

\[ \Delta x = 1.53 \text{ mm} \]
\[ \Delta x' = 0.13 \text{ mrad} \]

- corrected orbit with closed bump at RF-Dipole
- BPM 14 and 15 at Dipole before and after RF-ExB
- distance \( \Delta z = 4.2 \text{ m} \)