An RF Wien Filter as Spin Manipulator
MT Student Retreat 2015

Hamburg, February 23, 2015 | Sebastian Mey | Forschungszentrum Jülich
Content

The RF-ExB Dipole

Spin Motion in an RF-Wien-Filter

Measurements

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The RF-ExB Dipole

RF-B Dipole
- ferrite blocks
- coil: 8 windings, length 560 mm
- two electrodes in vacuum camber
distance 54 mm, length 580 mm

RF-E Dipole
- shielding Box
- ceramic beam chamber
- two separate resonance circuits

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RF-B Circuit *

- amplitude limited by losses \( \Rightarrow \hat{i}_{\text{max}} \approx 5 \, \text{A} \) @ \( P_{\text{in}} \approx 90 \, \text{W} \)
- matching to 50 \( \Omega \) with bidirectional coupler
- frequency range 630 kHz - 1170 kHz
- current in coil directly available via current transformer

[* A. Schnase, “RF-Dipole System at COSY for spin-flipping experiments”, IKP Annual Report 2002]
RF-E Circuit

- $\hat{U}_{\text{max}} \approx 2 \text{kV} \ @ \ P_{\text{in}} \approx 90 \text{ W}$
- frequency range 630 kHz - 1060 kHz
- electrode voltage directly available via capacitive voltage divider
Lorentz Force Compensation

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

- \( \beta \equiv \beta_z = 0.459; \quad \hat{I} = 1 \text{ A}; \quad \int \hat{B}_x \, dz \approx -0.035 \text{ T mm} \)
- \( \hat{U} = 395 \text{ V}; \quad \int \hat{E}_y \, dz = 4818 \text{ V} \)
- simulated optimization for integral compensation along beam path
  \( \int \hat{F}_y \, dz = 0 \text{ eV/m} \)

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Thomas-BMT Equation in Case of a Wien-Filter

- consider device with pure radial magnetic and vertical electric field
- adjust net Lorentz force to zero
  \[ \frac{\vec{E}}{c} = -\vec{\beta} \times \vec{B} \]
- Thomas-BMT Eq.: 
  \[ \frac{d\vec{S}}{dt} = \frac{e}{m} \vec{S} \times \vec{\Omega}_{MDM} \]

\[ \vec{\Omega} = (1 + \gamma G)\vec{B}_\perp + (1 + G)\vec{B}_\parallel - \left( \frac{\gamma}{\gamma+1} + \gamma G \right) \frac{\vec{\beta} \times \vec{E}}{c} \]

\[ = \left(1 - \frac{\beta^2 \gamma}{\gamma+1} + (1 - \beta^2)\gamma G \right) \vec{B} = \frac{1+G}{\gamma} \vec{B} \]
Spin-Resonance Strength of an RF-Wien-Filter *

- particles sample localized RF field once each turn at orbit angle $\theta$
  \[ b(\theta) = \int \hat{B} \, dl \cos(\frac{f_{RF}}{f_{rev}} \theta + \phi) \sum_{n=-\infty}^{\infty} \delta(\theta - 2\pi n) \]

- intrinsic resonance strength given by spin rotation by turn, calculate with Fourier integral over driving fields along orbit*:
  \[
  |\epsilon_k| = \frac{f_{spin}}{f_{rev}} = \frac{1+G}{2\pi \gamma} \int \frac{b(\theta)}{B \rho} e^{iK\theta} \, d\theta \\
  = \frac{1+G}{2\pi \gamma} \int \frac{\hat{B} \, dl}{B \rho} \sum_{n=-\infty}^{\infty} \cos(2\pi n \frac{f_{RF}}{f_{rev}} + \phi) e^{i2\pi Kn} \\
  = \frac{1+G}{2 \cdot 2\pi \gamma} \int \frac{\hat{B} \, dl}{B \rho} \left( \sum_{n} e^{\pm i\phi} \delta(n - K \mp \frac{f_{RF}}{f_{rev}}) \right)
  
Resonance Condition

- Spin tune given by $\gamma G$, resonance at every sideband with
  $$K = \gamma G = n \pm \frac{f_{\text{RF}}}{f_{\text{rev}}} \iff f_{\text{RF}} = f_{\text{rev}}|n - \gamma G|; \ n \in \mathbb{Z}$$

- $d$ at 970 MeV/c: $\beta = 0.459; \ \gamma = 1.126; \ G = -0.142\ 987$;
  $$\Rightarrow f_{\text{rev}} = 750\ \text{kHz}; \ \gamma G = -0.16098$$

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<th>$n$</th>
<th>$f_{\text{RF}} / \text{kHz}$</th>
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<tr>
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</tbody>
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Polarimetry and Beam Setup

- massive carbon target with slow extraction
- polarization $\Rightarrow$ rate asymmetries in $^{12}\text{C}(\vec{d}, d) : P_y \propto \frac{N_{\text{left}} - N_{\text{right}}}{N_{\text{left}} + N_{\text{right}}}$
- use Cross Ratio to suppress offset and first order systematic errors

$$CR_y = \frac{r - 1}{r + 1} ; \quad r^2 = \frac{L(\uparrow)R(\downarrow)}{L(\downarrow)R(\uparrow)}$$
Field Compensation

- measurement on betatron frequency for max. sensitivity
- polarimeter target directly above beam-pipe-center as defining acceptance
  ⇒ exited part of beam is removed
  ⇒ diagnosis with COSY beam current transformer
- determination of amplitudes and phase corresponding to Lorentz force compensation down to permille!
Measurement of Resonance Strength

- total spin flip only on resonance $\Rightarrow$ average polarization $\rightarrow 0$
- minimum of vertical polarization oscillation frequency
- resonance strength $\varepsilon = \frac{f_{Py_{\text{min}}}}{f_{\text{rev}}}$
Preliminary result of Fixed Frequency Scans

- RF-solenoid: \( f_{Py} \propto \frac{1+G}{4\pi} \frac{\int B_\parallel dl}{B\rho} \)
- RF-Wien-Filter: \( f_{Py} \propto \frac{1+G}{4\pi \gamma} \frac{\int B_\perp dl}{B\rho} \)
- RF-dipole: \( f_{Py} \propto \frac{1+\gamma G}{4\pi} \frac{\int B_\perp dl}{B\rho} + \text{interference from beam oscillations} \)
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- RF-ExB dipole acting on MDM with minimal disturbance has been successfully commissioned
  - RF-B amplitude: $\int \hat{B}_x \, dz \approx 0.18 \, \text{T mm} \, @ \, \hat{i}_{\text{max}} = 5 \, \text{A}$
  - RF-E amplitude: $\int \hat{E}_y \, dz \approx 24 \, \text{kV} \, @ \, \hat{U}_{\text{max}} = 1975 \, \text{V}$
  - $\pm 1$ spin harmonics at 629 kHz and 871 kHz available for studies
- Field strengths necessary for spin manipulation ($\approx 0.01 \, \text{T mm}$) available at very low input powers ($\approx 10 \, \text{W}$)
- Wien filter as RF spin manipulator is a concept that works
- High precision version with stripline layout scheduled for commissioning in September 2015

[* see talk given by J. Slim]
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