COSY orbit control

EDM kick-off meeting
March 13, 2017 | C. Weidemann
Reminder:
- Use of spin-filter method (talk by Frank Rathmann)
- EDMs introduce vertical spin component in a horizontally polarized beam

\[
\frac{d\hat{S}}{dt} = \left( \hat{\Omega}_{MDM} + \hat{\Omega}_{EDM} \right) \times \hat{S} = \left( \frac{q}{m\gamma} \gamma G \bar{B} + \frac{q\eta}{2m} \vec{\beta} \times \bar{B} \right) \times \hat{S}
\]

- Measurement of vertical polarization buildup $S_y$
- Misaligned magnets/distorted orbit leads to polarization buildup (fake signal)

Quadrupole shifts ($\sigma < 1 \text{ mm}$) & no EDM

**EDM Signal**

\( \eta = 10^{-4} \)

50000 turns $\approx 66ms$
Precursor experiment at COSY - Systematics

Correct orbit to minimize polarization buildup

\[ \eta = 10^{-4} \approx 3.5 \times 10^{-19} \text{ e cm} \]

Today

Goal

\[ (\hat{B} L)_{WF} = 0.06 \text{ Tmm} \]

Courtesy: M. Rosenthal
**COSY**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Circumference</td>
<td>183.47 m</td>
</tr>
<tr>
<td>Particles</td>
<td>(Un)polarized $p$ and $d$</td>
</tr>
<tr>
<td>Type of injection</td>
<td>$H^-$, $D^-$ stripping injection</td>
</tr>
<tr>
<td>Current at source exit</td>
<td>Polarized: 15 $\mu$A</td>
</tr>
<tr>
<td></td>
<td>Unpolarized: 100–200 $\mu$A</td>
</tr>
<tr>
<td>Momentum range</td>
<td>0.3–3.65 GeV/c</td>
</tr>
<tr>
<td>Betatron tune range</td>
<td>3.55–3.7 in both planes</td>
</tr>
<tr>
<td>Phase-space cooling</td>
<td>Electron and stochastic</td>
</tr>
<tr>
<td>Beam position monitors</td>
<td>31 (horizontal and vertical)</td>
</tr>
<tr>
<td>Steerers</td>
<td>23 (horizontal), 21 (vertical)</td>
</tr>
<tr>
<td>Straight sections</td>
<td>Length: 40 m</td>
</tr>
<tr>
<td></td>
<td>4 x 4 quadrupole magnets</td>
</tr>
<tr>
<td></td>
<td>4 sextupole magnets</td>
</tr>
<tr>
<td>Arc sections</td>
<td>Beam pipe diameter: 0.15 m</td>
</tr>
<tr>
<td></td>
<td>Length: 52 m</td>
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<tr>
<td></td>
<td>3 x 4 dipole magnets</td>
</tr>
<tr>
<td></td>
<td>3 x 4 quadrupole magnets</td>
</tr>
<tr>
<td></td>
<td>5 sextupole magnets</td>
</tr>
<tr>
<td></td>
<td>Beam pipe in dipole magnets:</td>
</tr>
<tr>
<td></td>
<td>height: 0.06 m, width: 0.15 m</td>
</tr>
</tbody>
</table>
Orbit correction

Orbit response matrix measurement

\[ M_{ij} = \frac{\sqrt{\beta_i \cdot \beta_j}}{2\sin(\pi v)} \cdot \cos(|\varphi_i - \varphi_j| - \pi v) \]

- Beam position at BPMs
- ORM
- Corrector magnet strength

\[
\begin{pmatrix}
\hat{x} \\
\hat{y}
\end{pmatrix}
= M
\begin{pmatrix}
\theta_x \\
\theta_y
\end{pmatrix}
\]

SVD analysis for matrix inversion

\[
\Delta \begin{pmatrix}
\theta_x \\
\theta_y
\end{pmatrix}
= M^{-1} \begin{pmatrix}
\hat{x} \\
\hat{y}
\end{pmatrix}_{uncorrected}
\]

- Automatic ORM measurement set up
- ORM derivation from model calibrated
Orbit correction - Limitations

- Iterative correction allows to achieve rms values of 1.6mm

**Limitations:**

- Positioning of quadrupole magnets
  (misalignment of 0.3-0.5 mm already explains current correction limits)

Simulated $\Delta y_{RMS}$ in the presence of misaligned quadrupole magnets. These misalignments are randomly generated assuming different Gaussian widths $\sigma_y$.

- Realignment of dipole and quadrupole magnets in progress
Orbit correction - Limitations

- Iterative correction allows to achieve rms values of 1.6mm

Limitations:

- Positioning of quadrupole magnets
- Precision of COSY model (if ORM is deduced from model)
- (minimal steerer change might be of relevance for lowest energies)
- BPM resolution

- Tedious effort for calibration
- Electronics EOL
- BPM system found to not fulfill the JEDI requirements, especially close to 0 position.

Courtesy: F.Hinder
BPM Electronic Replacement

Libera Hadron

- Ready-to-use system, based on 250 MHz ADCs and FPGA fast data processing.
- Used within the FAIR-project, knowledge has to be in-house anyway, software development & upgrades through FAIR-project possible
BPM Electronic Replacement

Libera Hadron

- Ready-to-use system, based on 250 MHz ADCs and FPGA fast data processing.
- Used within the FAIR-project, knowledge has to be in-house anyway, software development & upgrades through FAIR-project possible.
- Parallel developments before commissioning:
  1. Common signals paths (Trigger, RF-ref, Sync)
  2. Network Connection
  3. Pre/Main Amplifiers and Cabling
  4. Control system integration

- Commissioning Beam Time preliminary scheduled in July 2017
Control System Upgrade

- Current COSY Control System completely self developed
  - No community support or shared development
- Therefore decision was made to upgrade Control System
  - First only for new systems like orbit control
- EPICS / Control System Studio was chosen
- Decision was made to speed up the progress by contracting a company
  - Technical design report for COSY upgrade

- Staged approach:
  0) Orbit feedback using old COSY components (beam stability)
     - Analog BPM system integration
     - Correction dipole function generators integration
     - New control system
       - Archiver incl. interface and database
       - Git service for release management
       - GUI (Control System Studio)
  - Training
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- Staged approach:
  0) Orbit feedback using old COSY components
  1) Details to be negotiated
    - Upgrade to LIBERA BPM readout
    - Timing system?
Orbit Feedback incl. GUI
Orbit Feedback incl. GUI

Correction of artificially created local orbit bump

Original orbit (golden orbit)

Orbit with local bump

Back to original (golden) orbit
Orbit Feedback

Correction magnet strength during correction

some startup steerer settings (with beamloss)

activation of feedback

continuation in next COSY cycle
Orbit Feedback

Orbit RMS shown for each correction step
Orbit Feedback

Correction towards 0-orbit

\[ x_{RMS} = 11.1 \text{ mm} \]

\[ x_{RMS} = 10.2 \text{ mm} \]

Cut value not adjusted
Steerer at maximum
**Orbit Feedback**

**Correction towards 0-orbit**

- Feedback works in principle
- Adjustment of parameters required
- Limitations for correcter settings
- Exclusion of false orbit measurement
- Limitation due to BPM offset
  - Libera BPM readout

\[ x_{RMS} = 2.5 \text{ mm} \]

Cut value adjusted
Steerer excluded
Summary

- EDM experiment requires a beam orbit RMS < 100 μm
- Realignment of quadrupole magnets in progress
- Existing BPM electronics is struggling to deliver this accurate information, especially around 0 position
- Upgrade using commercial system LIBERA Hadron
- Along upgrade of the control system using EPICS
- Implementation of an orbit feedback in CSS
  - Almost finished for the existing BPM system
- Once LIBERA system is commissioned, replacing BPM measurement module in orbit control system
- Planned to be fully functional late 2017

Control system for other subsystems

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