Application of Phase Space Beam Position and Size Monitor for Synchrotron Radiation

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Plan

- Motivation
- The system
- Results
- Optimization
  - APS-U simulations
- Conclusion
- References
Motivation: Source monitoring & Data Correction

- New generation light sources with small emittance
- MBA Lattice
  
  \[ \varepsilon \propto \frac{E^2}{(N_s N_d)^3} \]
  
  \[ \varepsilon_y \propto \sigma_y \sigma_y \]

  Ns: # sectors in the ring
  Nd: # dipoles/sector

- Beam stability and source size measurements challenging and important.
Double Crystal Monochromator

Double Crystal Monochromator (DCM), Creates a nearly monochromatic beam

\[ \theta_k \]
DCM @ K-edge Absorption

Some of the beam above and some of the beam below the edge energy
What the Beam Looks Like?

<table>
<thead>
<tr>
<th>y &amp; y'</th>
<th>What the beam looks like</th>
<th>Beam</th>
<th>Edge</th>
</tr>
</thead>
<tbody>
<tr>
<td>y=0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>y'=0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
What Happens When the Beam Moves?

<table>
<thead>
<tr>
<th>$y &amp; y'$</th>
<th>What the beam looks like</th>
<th>Beam</th>
<th>Edge</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y=0$</td>
<td></td>
<td><img src="image1" alt="Beam" /></td>
<td><img src="image2" alt="Edge" /></td>
</tr>
<tr>
<td>$y'=0$</td>
<td></td>
<td><img src="image3" alt="Beam" /></td>
<td><img src="image4" alt="Edge" /></td>
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<tr>
<td>$y&gt;0$</td>
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<td><img src="image5" alt="Beam" /></td>
<td><img src="image6" alt="Edge" /></td>
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<td><img src="image7" alt="Beam" /></td>
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<tr>
<td>$y=0$</td>
<td></td>
<td><img src="image9" alt="Beam" /></td>
<td><img src="image10" alt="Edge" /></td>
</tr>
<tr>
<td>$y'&gt;0$</td>
<td></td>
<td><img src="image11" alt="Beam" /></td>
<td><img src="image12" alt="Edge" /></td>
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<tr>
<td>$y&gt;0$</td>
<td></td>
<td><img src="image13" alt="Beam" /></td>
<td><img src="image14" alt="Edge" /></td>
</tr>
<tr>
<td>$y'&gt;0$</td>
<td></td>
<td><img src="image15" alt="Beam" /></td>
<td><img src="image16" alt="Edge" /></td>
</tr>
</tbody>
</table>
The System - Extracting Information

\[-\ln \Rightarrow \frac{d}{dy} \Rightarrow \sigma_{\text{edge}}\]

\[\gamma_{\text{beam}} \Rightarrow \sigma_{\text{beam}} \Rightarrow \gamma_{\text{edge}}\]
Source position and angle

Beam Side – no filter

\[ y_{\text{beam}} = y + Dy' \]

Edge Side – contrast filter

\[ y_{\text{edge}} = y \]

\[ y = y_{\text{edge}} \quad \& \quad y' = \frac{y_{\text{beam}} - y_{\text{edge}}}{D} \]
Moving the Electron Beam **Position** (mostly)

### Position

<table>
<thead>
<tr>
<th>BPM Value</th>
<th>Beam Position y (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-60</td>
<td>-150</td>
</tr>
<tr>
<td>-40</td>
<td>-100</td>
</tr>
<tr>
<td>-20</td>
<td>0</td>
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<tr>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>40</td>
<td>150</td>
</tr>
<tr>
<td>60</td>
<td>+ photon beam position</td>
</tr>
</tbody>
</table>

- least squares fit

**Theory**

Slope = 1.807 µm/BPM Value

### Angle

<table>
<thead>
<tr>
<th>BPM Value</th>
<th>Beam Angle y (µradians)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-60</td>
<td>-150</td>
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</table>

- least squares fit

**Theory**

Slope = 0.0301 µradians/BPM Value

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Measurements made while the beam stability was improved
Correcting Experimental Data

Measurements made while a beam motion with 10 Hz frequency and different amplitudes was put in the ring.

The Dashed line show the predicted value based on a machine optics simulation.

The System - Extracting Size Information

\[-\ln\]
\[\frac{d}{dy}\]
\[\sigma_{\text{edge}}\]
\[\gamma_{\text{beam}}\]
\[\sigma_{\text{beam}}\]
Beam size and Divergence - Emittance

The Vertical Emittance Comes from the Widths

Contributions to the K-Edge Width

\[ \sigma_{beam}^2 = (D \sigma_{\text{y}'_{\text{res}}})^2 + \sigma_{\text{y}'_{\text{source}}}^2 + (D \sigma_{\text{y}'_{\text{mono}}})^2 \]

What we measure

Contributions to the Unfiltered Beam Width

\[ \sigma_{edge}^2 = \sigma_{\text{y}'_{\text{source}}}^2 + (D \sigma_{\text{y}'_{\text{edge}}})^2 \]

What we want

What we need to figure out
Measurements of Emittance

\[ \sigma_y = \sqrt{\sigma_{edge}^2 - (D \sigma_{y'_{K-edge}})^2 - (D \sigma_{y'_{mono}})^2} \]

\[ \sigma_{y'} = \frac{1}{D} \sqrt{\sigma_{beam}^2 - \sigma_y^2 - (D \sigma_{y'_{Ph}})^2} \]

\[ \mathcal{E}_y \propto \sigma_y \sigma_{y'} \]
Changing the Electron beam Size (mostly)


![Graph showing the relationship between XSR σ_y and BMIT σ_y](chart.png)

**Slope** = 1.13 ± 0.04
Ps-BPM Outputs

\[ \gamma \]
\[ Dy' \]

\[ \gamma \]
\[ Dy' \]

Power spectrum

\[ \sigma_y \]
\[ D\sigma_y \]

Power spectrum

Optimization Process

- The monochromator
  - crystal material
  - reflection geometry
  - choice of lattice planes

- The K-edge filter
  - sets the energy
  - the K-edge width
  - the concentration and thickness of the filter element

- The system geometry and
  - the only relevant distance is the source to the detector distance.

- The detector
  - pixel size in the diffraction plane

Ray-Tracing and Modelling

Simulations done in ShadowOui package in the OASYS environment

The nominal electron beam size: $\sigma_{\text{source}} = 4.9 \ \mu\text{m}$ and $\sigma'_{\text{source}} = 2.8 \ \mu\text{rad}$.

APS-U BM source

APS-U source with zero-emittance

Example of ps-BPM for APS-U Source

- APS-U
- Si (111)
- Single Bragg
- Barium K-edge
- 37.441 keV
- 10 m from the source
- 10 μm detector

Conclusion

- **Beamline**
  - BPM
  - Correcting Experimental Data

- **Machine**
  - BPM
  - Control and Feedback System
  - Emittance Measurements

- Real-time capability of beam position and size monitoring
- The data can be used for both source and beamline diagnostics
- The system has the sensitivity to be used at small-emittance sources.
Reference


Thank you!

Questions?