Beam jitter in the PIP2IT MEBT

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PIP-II Technical Meeting
12th Sept, 2017
Outline

• Introduction
  – Noise in BPM data
  – Goals
• SVD
• Results and comparison with beam trajectories from OptiM
• Effect of LEBT Solenoid currents on BPM noise
• Summary
Introduction

• There are large fluctuations in BPM readings
  – Rms deviation is up to $\sigma \sim 160 \ \mu m$, significantly larger than the expected BPM electronic noise

• Beam centroid motion (jitter)
  – Significantly affects accuracy of beam measurements
  – restricts efficiency of scraping system
  – May affect rms emittance (see report on 7th March, 2017)

• Goals for the study
  – Differentiate between the BPM noise and beam motion
  – Locate the source of beam motion to eventually eliminate it
The main tool: SVD

• Singular Value Decomposition (SVD) of BPM matrix is used to distinguish between the beam jitter and electronics noise.
  – E.g. MIA with BPM correlations matrices, SLAC-PUB-7863
  – Beam motion component is defined by optics
  – BPM noise is either uncorrelated or correlated differently (e.g. through a common ground).

• BPM data were analyzed for several configurations of MEBT
  – The most important features are the same
  – Picture becomes much clearer with larger number of BPMs and larger pulse samples
  – Most of results to be presented are for the present assembly
    • MEBT-3.0, 10 pairs of BPMs
SVD

• The BPM data: $p$ # of pulses recorded from $m$ # of BPMs are arranged into $p \times m$ matrix $B$

• The matrix is decomposed as $B_{p \times m} = USV^T$
  
  – $U$ and $V$ are the temporal and spatial eigenvectors.
  
  – $S$ is diagonal matrix consisting of eigenvalues.
  
  – $V$ (Spatial vectors) are repeatable for different ensembles of pulses for a given lattice.
  
  – $U$ (Temporal vectors) will change from ensemble to ensemble.
  
  – # of non-zero eigen values represents the degrees of freedom

• The sign of a beam jitter
  
  – An eigenvector that resembles a possible trajectory in MEBT
  
  • Or part of eigenvector if the perturbation is inside of the MEBT
BPMs in MEBT-3.0

- Rms deviation of BPM signals
  - 20 channels; 20 Hz repetition rate; 35 min.
  - 25th Aug, 2017

<table>
<thead>
<tr>
<th>BPMs</th>
<th>P:M00BXM</th>
<th>P:M10BXM</th>
<th>P:M20BXM</th>
<th>P:M30BXM</th>
<th>P:M40BXM</th>
<th>P:M50BXM</th>
<th>P:M60BXM</th>
<th>P:M70BXM</th>
<th>P:M80BXM</th>
<th>P:MX2BXM</th>
</tr>
</thead>
<tbody>
<tr>
<td>σ (µm)</td>
<td>31.17</td>
<td>12.21</td>
<td>32.86</td>
<td>39.24</td>
<td>11.17</td>
<td>30.10</td>
<td>38.54</td>
<td>18.26</td>
<td>19.48</td>
<td>27.70</td>
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</table>

<table>
<thead>
<tr>
<th>BPMs</th>
<th>P:M00BYM</th>
<th>P:M10BYM</th>
<th>P:M20BYM</th>
<th>P:M30BYM</th>
<th>P:M40BYM</th>
<th>P:M50BYM</th>
<th>P:M60BYM</th>
<th>P:M70BYM</th>
<th>P:M80BYM</th>
<th>P:MX2BYM</th>
</tr>
</thead>
<tbody>
<tr>
<td>σ (µm)</td>
<td>21.36</td>
<td>207.92</td>
<td>76.43</td>
<td>99.58</td>
<td>140.82</td>
<td>72.35</td>
<td>145.36</td>
<td>42.42</td>
<td>160.31</td>
<td>103.44</td>
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</table>
SVD results

- There are only a few significant eigenvalues
  - The main one becomes more prominent in larger data sets
- Mostly in vertical plane

In the plot, eigenvalues are normalized by the value of the largest component.

BPM rms deviation calculated for the raw data set and after subtraction of the first one and two components, $N_{p \times m} = B_{p \times m} - USV^T$, where $S$ is calculated by changing all other eigen values to zero.
Comparison with beam motion in MEBT: OptiM trajectories

- 4 trajectories in the MEBT are simulated for orthogonal initial conditions with OptiMX
  - E.g. \((x, x') = (1,0)\) and \((0,1)\)
- An eigenvector is fitted to a linear combination of displacement of these trajectories in BPMs

Trajectories in the MEBT with orthogonal initial conditions simulated with OptiMX.
Eigenvectors fitting

- First two eigen vectors are fitted very well with beam trajectories given by OptiM
  - There are no indication of a large source of the beam jitter in the MEBT

Eigenvectors amplitudes (orange) and their fitting to Optim Trajectories (blue).
Frequency components

- FFT of the dominant line shows a strong 1.09 Hz line
  - Frequency is repeatable in different measurements

Results of FFT analysis for two measurements: August 15 (left, at 10 Hz) and August 25 (right, at 20 Hz).
Source of the jitter?

- Not MEBT => upstream
  - RFQ, LEBT, or Ion Source
  - Initial thought: jitter primarily in vertical plane indicate to RFQ
- Test: check whether LEBT solenoid settings affect the jitter plane
  - All solenoids are connected to rotate in the same direction
  - Rotation angle is proportional to the total number of Amp·turns
    - \(~5\ \text{mrad}/\text{A}\)
We studied the variation of BPMs noise by changing the LEBT solenoid current.

We varied the solenoid currents to have same transmission through RFQ ~97 %.
BPMs rms deviations at different solenoid currents

• The noise changes significantly!
  – The jitter plane clearly rotates
Numerical comparison of rotation

- The jitter plane is defined for each case
  - The first eigenvector is fitted with OptiM trajectories
  - Actions for X and Y are calculated using Twiss parameters from OptiM
  - The plane angle is deduced from their ratio (no sign)
- The found rotation is similar to calculated from solenoid currents => the source is upstream

<table>
<thead>
<tr>
<th>Date</th>
<th>Sol2</th>
<th>Sol3</th>
<th>Total current</th>
<th>Rotation</th>
<th>Difference with nominal</th>
<th>Theta</th>
<th>Difference (beam jitter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15/8/2017</td>
<td>130.00</td>
<td>226.90</td>
<td>356.90</td>
<td>97.85</td>
<td>0.00</td>
<td>81.18</td>
<td>0.00</td>
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<tr>
<td>15/8/2017</td>
<td>70.00</td>
<td>216.90</td>
<td>286.90</td>
<td>78.66</td>
<td>-19.19</td>
<td>64.11</td>
<td>-17.07</td>
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<tr>
<td>15/8/2017</td>
<td>195.00</td>
<td>238.40</td>
<td>433.40</td>
<td>118.82</td>
<td>20.97</td>
<td>56.52</td>
<td>-24.66</td>
</tr>
</tbody>
</table>
Summary

• The beam jitter is the main contribution for large variation in the measured BPM signals.

• No sources of a significant beam jitter are found in the MEBT.

• Beam jitter is originated upstream of 2nd solenoid of LEBT.