Fast Orbit Feedback at the SLS

2nd Workshop on Beam Orbit Stabilisation
(December 4-6, 2002, SPring-8)

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Outline

- Noise Sources at SLS
- Stability / System Requirements
- Fast Orbit Feedback Implementation
- Digital BPM System
- Status
- Outlook
Noise Sources at SLS

conditions:
- spectra measured with DBPM system
- normal work day
- booster ramping with 3 Hz for top-up operation
- no ID movements

<table>
<thead>
<tr>
<th>known noise sources</th>
<th>not yet identified noise sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Hz: booster ramping</td>
<td>85 Hz, 209 Hz</td>
</tr>
<tr>
<td>20-35 Hz: girder vibrations</td>
<td></td>
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<tr>
<td>50 Hz and harmonics: net line</td>
<td></td>
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</tbody>
</table>
**Noise Sources at SLS**

**Integrated Vibration Spectrum (0.5 - 300 Hz)**

- **Horizontal**
  - **Total**: 1.7 µm RMS
  - **Noise (DBPM)**: 1.2 µm RMS
  - **Beam Osc. (globally @ BPM)**: 1.2 µm RMS (scaled with $\sqrt{\beta_x(\text{mean})/\beta}$)
  - **Beta ($\beta_x$)**: 10 m
  - **Beta ($\beta_y$)**: 11 m

- **Vertical**
  - **Total**: 1.8 µm RMS
  - **Noise (DBPM)**: 1.2 µm RMS
  - **Beam Osc. (globally @ BPM)**: 0.9 µm RMS (scaled with $\sqrt{\beta_y(\text{mean})/\beta}$)
  - **Beta ($\beta_y$)**: 21 m

**Noise Levels**

- **Horizontal**
  - **Integrated RMS**: 0.4 µm RMS
  - **Local RMS**: 0.9 µm RMS
  - **Local RMS**: 0.6 µm RMS

- **Vertical**
  - **Integrated RMS**: 0.5 µm RMS
  - **Local RMS**: 0.5 µm RMS
  - **Local RMS**: 0.6 µm RMS

**Notes**

- $\beta_x \approx 10$ m (at location of pickup)
- $\beta_y \approx 21$ m (at location of pickup)

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Stability Requirements

- position stability: 1/10th of vertical beam size at location of insertion devices
  \[ \Rightarrow 1 \, \mu m \text{ RMS in vertical plane (1\% coupling)} \]
  
  but:
  \[ < 1 \, \mu m \text{ RMS in vertical plane (<1\% coupling)} \]

- suppress oscillations up to 100 Hz by factor of 5

- fast compensation of orbit distortions due to user controlled ID movements
Theoretical Noise Suppression with Feedback:

- PID controller
- bandwidth of vacuum chamber, corrector magnet including eddy currents: 120 Hz

-10 dB reached at:
  \[ f_s = 1 \text{ kS/s}: \quad 20 \text{ Hz} \]
  \[ f_s = 2 \text{ kS/s}: \quad 45 \text{ Hz} \]
  \[ f_s = 4 \text{ kS/s}: \quad 100 \text{ Hz} \]

Transfer function of feedback loop still to be measured...

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Power Supply Resolution / RMS Orbit Distortion

Residual vertical RMS orbit after orbit correction as seen by the monitors:

RMS Girder Error: 0.001 mm

- 60 ppm: $y_{rms} = 0.75 \mu m$
- 30 ppm: $y_{rms} = 0.5 \mu m$
- 15 ppm: $y_{rms} = 0.25 \mu m$

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Slow Orbit Feedback

central processing unit:
- calculate inverted response matrix (SVD)
- read all BPM values
- calculate correction
- set new corrector settings
- use control system network

Fast Orbit Feedback

\[ A^I = \begin{bmatrix} 1 & \text{bpm} & 72 \\ \text{corr.} & 72 & 1 \end{bmatrix}_{72x72} \]

- processing decentralized and integrated in the 12 BPM stations (6 BPMs and 6 corrector magnets per station)
Fast Orbit Feedback Hardware Layout

DBPM System

- BPM pickups
- RF Front End
- Digital Down Converter
- Timing signal
- SHARC link ports (40 MB/sec)

FOFB System

- Fiber optic links to adjacent sectors (40 MB/sec)
- Fiber optic links
- DSP1, DSP2
- Serial interf.
- EPICS
- LAN (TCP/IP)

VME Bus
Digital BPM System Resolution

- Minimum turn-by-turn resolution (1 MS/s) at SLS < 20 µm
- Minimum closed orbit / feedback resolution (4 kS/s) < 1.2 µm
- Minimum "ramp-250ms" resolution (30 kS/s) at SLS < 3 µm

Power Level [dBm]

Beam Current [mA]

Resolution [mm]

Constant gain levels of:
- 60000
- 50000
- 40000
- 33000
- 30000
- 25000
- 20000
- 15000
- 10000
- 6000

- Turn-by-turn mode
- "ramp-250ms" mode
- Closed orbit / feedback mode
### Implemented Modes:

<table>
<thead>
<tr>
<th>Mode</th>
<th>Digital Down Converter Output Rate (kHz)</th>
<th>Passband BW (kHz)</th>
<th>Resolution RMS (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. turn by turn</td>
<td>1041</td>
<td>416</td>
<td>19</td>
</tr>
<tr>
<td>2. “250 ms mode”</td>
<td>32</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>3. “500 ms mode”</td>
<td>16</td>
<td>6</td>
<td>2.1</td>
</tr>
<tr>
<td>4. closed orbit mode</td>
<td>4</td>
<td>1.5</td>
<td>1.2</td>
</tr>
</tbody>
</table>

alternative FOFB modes (?):
- 4 kHz DDC output rate, 0.5 kHz analogue BW?
- 8 kHz DDC output rate and decimation on DSP, 1.5 kHz analogue BW?  .....
Fast Orbit Feedback

Properties:
- update rate: 4 kHz
- BPM data exchange only between adjacent sectors over point-to-point fibre optic links (40 Mbytes/s) (reflecting the localized structure of the inverted response matrix)
- direct control of magnet power supplies (by-passing control system)
- decentralized structure of feedback ⇒ can continuously run even if not all BPM data are available for the current cycle (link breakdown etc...) ... still to be proven

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Status

- feedback running in “passive mode” (3 Hz)
- processing times:
  - digital down-conversion and decimation: \( \sim 250 \, \mu s \)
  - digital x/y calculation: \( \sim 70 \, \mu s \)
  - “global” data exchange: \(< 8 \, \mu s \)
  - feedback algorithm: \( \sim 40 \, \mu s \)
  - data transfer to PS controller: \(< 30 \, \mu s \)

  total delay: \( \sim 150 \, \mu s \)
  + 250 \, \mu s
  ("ADC integration")

- Digital down-converter firmware upgrade needed to synchronize all BPMs (but: presently priority to multibunch feedback system...
Dispersion Correction

- available BPM information per DBPM station:
  18 position readings per plane

Dispersion Function:

\[ x = x_\beta + D_x \cdot \left\langle \frac{dp}{p} \right\rangle \]

\[ \left\langle \frac{dp}{p} \right\rangle = \frac{1}{N} \cdot \sum \frac{x_i}{D_{xi}} \]

- \(|dp/p| < 2 \cdot 10^{-5}\) by central frequency control (BD application)
- maximum dispersive contribution:
  \[ \left| D_x \cdot \left\langle \frac{dp}{p} \right\rangle \right| \leq 4 \mu m \]
dp/p Calculation

measurement: 24 November 2002

local fit: averaged over 100 samples

global fit: averaged over 3 samples

⇒ dispersion orbits (path length changes) will not be corrected by fast orbit feedback
Conclusion / Outlook

- "fast orbit feedback" (FOFB) scheme running in 3 Hz passive mode to check functionality and integration
- dp/p correction possible even if decentralized
- final decision about BPM bandwidth and DDC output rates to be made
- planned start of 3 Hz FOFB in active mode: Jan. 2003
- planned start of 4 kHz FOFB: ~ spring 2003 (firmware upgrade of BPM system)
BPM Operation Modes

Batch Processing Mode “250 ms mode” (present operation mode):

\[ \langle \text{average position} \rangle \uparrow \]

- 64 samples
- \( = 2 \text{ ms} \)
- 320 ms
- \( = 252 \text{ ms} \)
- (3.125 Hz injection trigger)

Real Time Processing Mode (future operation mode):

\[ \langle \text{position} \rangle \uparrow \]

- 8192 samples
- \( = 252 \text{ ms} \)
- 250 µs
- (4 kHz sample rate)