Booster MDs

F. Schmidt: collecting PSB MD requests
At ABP we realize the special situation of the PSB:

We have therefore asked our fellow Jean-Baptiste Lagrange, who shall do SC experiments & simulations for all pre-injectors, to concentrate on the PSB for the time being. Presently, he is still in the process of benchmarking the new PyOrbit code with PTC-ORBIT that had been our workhorse up to now. To this end he will look at PSB runs.

We are looking forward to a new ABP colleague to work on the PSB and there is a flexibility post opened to this effect.

In the meantime, I will be the interim ABP link person.
During the last 2 years the SC team has started a more rigorous and systematic approach to the SC Studies. This has been applied to both the SPS and LEIR:

- In the past we have been relying on dynamic tune scans to find rough estimates of the strength of the resonances. However, a static scan is by far more trustworthy, albeit much more time-consuming.
- Lacking proper magnet measurements/modeling we need to measure effective models:
  - Non-linear parameters at largely different lattices (Integer part of tunes!) will help to fit such an effective model.
  - Driving-term Measurements
- The plan had been to apply these extended studies also at the PS and even more so in the present situation of the Booster!
- The topic concerns mainly MDs but I will touch on some of the required analysis and simulations studies.
Optics Machine Studies

Very systematic and detailed LIU PSB Optics Machine Studies similar to what we have already done at the SPS

a) Verify working point with optimal brightness

b) Loss Maps to identify destructive Resonance Lines:
   • Go beyond the purely empirical approach
   • Do static tune scans instead of the dynamic ones!

c) Driving terms with PSB full BPM system (16 PU each plane)
   • Quality of equipment (resolution, decoherence...) sufficient?
   • Kicked, miss-steered beams, AC dipole?
   • Global or local measurement?

d) Emittance Measurements and Evolution along the Cycle and wrt PS
   • Apparently the emittance is defined shortly after injection, can that be verified?
   • Can we trust the wirescanner reading throughout the cycle, in particular @injection?
Optics Simulation Studies I

The Optics Machine Studies must be accompanied with equally complete Optics Simulation Studies (Issue of Computing Resources!)

a) Complete PyOrbit/PTC-Orbit Bench-Marking
b) Improve Linear & Non-linear PSB Model, Parameter Scan
c) Predictive Simulation Studies of Beam in the PSB after Injection from Linac4, Full benchmarking with present multi-turn injection scheme ➔ Final Brightness Curve
d) Develop Strategy for PSB Resonance Compensation
e) Analysis and Tools for Realignment of the PSB (section 15)
Beam brightness

E. Benedetto

Simulations @ 50 MeV
Simulations @ 160 MeV WP=(4.33,4.55)
Simulations @ 160 MeV WP=(4.43,4.60)
Measurements
Scaled Measurements

(Ex+Ey)/2 [μm]

Np [e10]

PSB-MDs 28.03.17 F. Schmidt ABP
The Machine Studies must be accompanied with equally complete Simulation Studies (Issue of Computing Resources!)

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e) Analysis and Tools for Realignment of the PSB (section 15) ➔ P. Zisopoulos
Building linear / non-linear optics model

E. Benedetto, F. Schmidt

- Prepared a special cycle with at a lower working point (3.32, 3.81) and saved as an archive of the nominal MD user at 160 MeV
  - Measurements with two different optics allow for different sampling of errors

- Non-linear chromaticity measurements for the 2 optics: ~good agreement with our current MADX-PTC model

- MADX-PTC model: driving terms excited by main dipoles not negligible

<table>
<thead>
<tr>
<th>Q</th>
<th>Q’</th>
<th>Q''</th>
<th>Measured Q''</th>
<th>stdev</th>
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<tbody>
<tr>
<td>4.20</td>
<td>-3.35</td>
<td>45</td>
<td>15.1</td>
<td>5.7</td>
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<tr>
<td>4.30</td>
<td>-6.84</td>
<td>87</td>
<td>44.4</td>
<td>13.7</td>
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<tr>
<td>3.32</td>
<td>-2.81</td>
<td>78</td>
<td>48.3</td>
<td>3</td>
</tr>
<tr>
<td>3.81</td>
<td>-4.97</td>
<td>116</td>
<td>112</td>
<td>34</td>
</tr>
</tbody>
</table>

Tilts in the magnets not considered here!
resonance strength and phase:

\[ | h_{0030} | = \frac{1}{3} \frac{a_{y1}}{a_{y0}^2} \sin(|\hat{\phi}|) \]

\[ \psi_{0030} = \phi_{y1} + 2\psi_{y0} + \frac{\pi}{2} - \text{sgn}(\hat{\phi})(\frac{\pi}{2} - |\hat{\phi}|) \]

Phase and amplitude data obtained from Fourier spectra
$3Q_y = 16 – \text{compensated 2/2}$

**P. Urschütz thesis 2004**

---

**Beam intensity**

**Vertical beam position**

**Normalised phase space**

---

Results from the measurements:

\[
|h_{0030}| = 9.0 \pm 0.6 \times 10^{-3} \text{ mm}^{-1/2}
\]

\[
\psi_{0030} = -21^\circ \pm 14^\circ
\]

---

Calculated compensation currents (for two independent skew sextupoles):

\[
l_{XSK2L4} = -29.3 \text{ A}, \quad l_{XSK9L1} = +15.3 \text{ A}
\]

PSB-MDs 28.03.17  
F. Schmidt ABP

---

**Fourier spectrum**
Building linear / non-linear optics model

A. Valdiveso et al.

- Turn-by-Turn measurements with AC dipole excitation
  - Used a spare amplifier to drive Vertical TFB kicker at frequency close to the tune
  - Upgrade of the TFB kicker under way
  - Only 3 vertical PU available, only used for beta-beating, characterization of the system and validation of the method
  - Analysis ongoing
Collective Effects and Instabilities

a) Further Refinement of Impedance Model, T.L. Rijoff

b) Search for Source of Horizontal Instability, T.L. Rijoff

c) Upgrade of transverse Feedback (power for AC Dipole, robustness), A. Blas
LIU relevant Studies

a) Mitigating PSB SC Effects by “flat” distributions in the bucket (h=1+2+3), S. Albright

b) Transfer to PS, V. Forte

c) Emittance Blow-Up to mitigate PS SC, S. Albright, A. Oeftiger
2016 – Triple harmonic capture

Simulations suggest ~20% reduction in line density should be possible

S. Albright
Injector MD Days 2017
23/24 March
• The dispersion has been measured in the PSB and in the BT-BTP-PS line.
• The measured dispersion in the BTi-BTP line gave good agreement with the model, especially for outer rings (R1 and R4).
2016 – Emittance blow-up

Ring1:
RMS: 0.626 eVs
Area: 2.86 eVs
dp: 2.03E-3
Length: 224 ns

Ring2:
RMS: 0.559 eVs
Area: 2.74 eVs
dp: 1.92E-3
Length: 217 ns

Ring3:
RMS: 0.59 eVs
Area: 2.82 eVs
dp: 1.97E-3
Length: 222 ns

Ring4:
RMS: 0.567 eVs
Area: 2.83 eVs
dp: 1.95E-3
Length: 222 ns
Tomograms Over Process

kinetic energy programme (PSB)

ctime [ms]

kinetic energy [GeV]

A. Oeftiger
Injector MD Days 2017
23/24 March

PSB C573
before excitation

PSB C591
after excitation

PSB C800
after synchro, before extraction

CPS C171
after transfer
Other Studies

a) Tail Repopulation, P. Zisopoulos

b) Possibility of Chromaticity control in both planes???
   SC Team
Tail repopulation studies

M. Cielsak-Kowalska, E. Benedetto, will be finalized by P. Zisopoulos

- Tail repopulation MD
  - Shave large emittance beams
  - Goals: Diffusion coefficients, validation PyOrbit

At the time not possible to reproduce measurements w. Simulations
Figure 4.11: The tune spread (grey scatter plot) for different chromaticities: (a) \((\xi_x, \xi_y)=(-0.05, -3.17)\); (b) \((\xi_x, \xi_y)=(-0.8, -1.6)\); (c) \((\xi_x, \xi_y)=(-1.55, -0.12)\). The black dot is the bare tune at \((Q_x, Q_y)=(4.2, 4.31)\). The footprints are overlapped to the magnetic resonance lines, discussed in Chapter 1.
<table>
<thead>
<tr>
<th>Study</th>
<th>Deadline</th>
<th>People</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collective Effects</td>
<td>End 2017/8</td>
<td>T.L. Rijoff, A. Blas</td>
</tr>
<tr>
<td>ABP Link Person</td>
<td>End 2018</td>
<td>F. Schmidt, <em>(Flexibility Post)</em></td>
</tr>
<tr>
<td>LIU relevant Studies</td>
<td>End 2017/8</td>
<td>A. Oeftiger, S. Albright, V. Forte, SC Team,</td>
</tr>
<tr>
<td>Other Studies</td>
<td>End 2017/8</td>
<td>SC Team, P. Zisopoulos</td>
</tr>
</tbody>
</table>
Acknowledgements

The following people have helped with discussions, transparencies and/or their publications:

Reserve
Motivation

mitigate detrimental space charge impact at PS injection plateau

transverse direct space charge:

$$\Delta Q_{x,y}(z) \propto -\lambda(z) \int ds \frac{\beta_{x,y}(s)}{\sigma_{x,y}(s) (\sigma_x(s) + \sigma_y(s))}$$  \hspace{1cm} (1)

with (assuming a Gaussian in long. and horiz. plane)

$$\sigma_{x,y}(s) = \sqrt{\frac{\epsilon_{x,y} \beta_{x,y}(s)}{\beta \gamma} + D_{x,y}(s)^2 \delta_{\text{RMS}}^2}$$  \hspace{1cm} (2)

⇒ mitigate space charge (lower max $\Delta Q_{x,y}$) by

- line density depression $\lambda_{\text{max}} \sim \lambda(z_{\text{centre}})$
- increase momentum spread $\delta_{\text{RMS}}$
Non-linear effects & blow-up

E. Benedetto et al.

- PSB is equipped with a complete set of multipoles to correct (empirically) any higher order errors
- What if we include non-linearities in our model?

<table>
<thead>
<tr>
<th>Normal</th>
<th>Skew</th>
</tr>
</thead>
<tbody>
<tr>
<td>h3000 = 0.01</td>
<td>h2010 = 0.06</td>
</tr>
<tr>
<td>h2100 = 0.06</td>
<td>h2001 = 0.07</td>
</tr>
<tr>
<td>h1020 = 0.03</td>
<td>h1110 = 0.17</td>
</tr>
<tr>
<td>h0011 = 0.12</td>
<td>h0030 = 0.07</td>
</tr>
<tr>
<td>h0002 = 0.04</td>
<td>h0021 = 0.18</td>
</tr>
</tbody>
</table>

Additional emittance blow-up!
(knowing that eventually we can compensate resonances!)

Np=260e10

PSB-MDs 28.03.17  F. Schmidt ABP
New Shaving Scheme for the PSB
(E. Benedetto & M. Kowalska)

The beam shaving consists of scraping the beams at the PSB in order to modify beam intensity and emittance at values required for the optimal injectors performance.
The shaving takes place at the aperture restriction of the PSB (the Window Beam Scope).
The plane of interest is the vertical due to the chromatic independence of the distortions and the higher stability of the beam envelope.
It was shown that the old shaving scheme which used a single kick to produce closed orbit distortions, was very sensitive to the working point and steering errors. Enhanced beam losses around the PSB ring.
The new scheme (M. Kowalska, E. Benedetto) consists of creating a closed orbit bump at the WBS, by using two shavers. This operation localize the beam losses at the WBS. Significant reduction of the beam losses around the machine.
Asymmetric vertical beam profiles were also observed at injection. They were successfully reproduced with simulations in the presence of space charge and multipole Coulomb scattering.
The plots are taken from: M. Kowalska et al. “New Shaving Scheme for Low Intensity Beams in the PS Booster and Feasibility at 160 MeV” IPAC 2015, ”Interpretation of wire scanner assymetric profiles in a low-energy ring”, HB2016
Tails repopulation studies (MD 1955)  
(Elena Benedetto, Panos Zisopoulos, Magdalena Kowalska)  

At low energy, the PSB is strongly dominated by space charge which induces tails repopulation of the scraped distribution. It has been shown that after the transverse shaving of the beam the tails of the beam distribution repopulate. The effect can be shown by applying a second shave to the beam. An observed intensity drop marks the repopulation of the tails.

The goal of the MDs is to observe the evolution of the tails repopulation phenomenon, understand its connection to beam intensity and emittance and reproduce it in simulations.

- For the MDs two shavers are being used to create the closed bump. One shaver which was used in the old shaving scheme (Current function: green curve) and one from the new shaving scheme (Current function: yellow curve).
- The measurements of the intensity (red curve) by applying 2 consecutive shavings on the beam demonstrates the creation of the tails repopulation phenomena.
- The reproduction of the observations in simulations will enhance our understanding of the phenomenon.
Model used for comparisons with measured tune shift
the model includes:

- resistive wall
- indirect space charge
- vacuum pipe discontinuities
- ejection kicker including cables
- injection kickers (KSW)
- FINEMET cavities (only ring 4)

New configuration with new tune pickup and FINEMET cavities replacing the present RF cavities is already studied.
Additional components are being studied.

**T. Rijoff**
If the PSB transverse feedback is off
coherent instability in the horizontal plane

- at reproducible cycle time
  - first instable line 386 ms
- with an intensity threshold
- depending on bunch parameters

for short bunch and standard double rf
instability threshold $N_p = 500 \times 10^{10}$ ppb
Future plans and on working

- The impact of the new installations in the impedance model have been and will be taken into account (e.g. tune pickup, scraper, FINEMET).

- The impedance model will be refined with the present RF cavities.

- It will be interesting to perform some MD dedicated in ring 4 to understand the impact of the RF cavities on the horizontal instability.

- At 160 MeV the tune shift is driven by space charge. MD at high energy could allow to verify the impedance model where others components play a bigger role.

- It would be interesting continuing the studying started in 2013 about the dependency of the instability from the chromaticity.
PSB TFB **PRESENT** role =>
- Damping of transverse instabilities from 50 MeV to 1.4 GeV, with up to 1.1 E13 ppp and BW up to 13 MHz

PSB TFB **FUTURE** role =>
- Damping from 160 MeV to 2 GeV with up to 2.5 E13 ppp and BW up to 20 MHz
- Beam excitation for: blow-up, machine optics measurements and tune measurement
To fulfil the PSB **FUTURE** role only 2 upgrades are crucial:

- Increase of the **power amplifiers** from 100 W to 800 W
  - this implies:  
    - new **power supplies**
    - new **power loads**
    - new **electrical mains distribution**
- Design and install new PU **head amplifiers**

**Other approved upgrades:**

- Install a **PLC control** system for the power parts and the water system
- Install a new **water cooling** system
- Install an **Oasis** system
- **Reshuffle all the 14 electronic racks** for an improved ergonomy
- Upgrade the **CO crates**, modules and interface to the operation
- Design and install a new **digital loop processing** circuit
- New Fesa class and OP interface