Working point and space charge simulation studies for SIS100

V. Chetvertkova
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A little bit of history...

- Working point for Bunch Compression and Normal Operations
  - Qx=18.84
  - Qy=18.73

- Working point for Proton Operation (also optional for heavy-ion operation)
  - Qx=21.85
  - Qy=21.79

- Working point for slow extraction
  - Qx=17.32
  - Qy=17.3

(Blue star: before acceleration, Red star: slow extraction)
### SIS100 beam parameters & lattice

#### INJECTION

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<thead>
<tr>
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<th>Protons</th>
<th>U28+</th>
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<tr>
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<td>Ions per cycle</td>
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#### EXTRACTION

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<td>28.6</td>
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Momentum acceptance 5e-3

Warm quads: S52QD11 S52QD12

L = 1083.6m
SIS100 beta functions ($Q_x=18.84$, $Q_y=18.73$)

If SIS100 had only cold quadrupoles:

Horizontal aperture bottleneck: $3.8 \sigma_{x\text{RMS}}$

Vertical aperture bottleneck: $2.9 \sigma_{y\text{RMS}}$

2 warm quads (F & D) in sector 5:

Horizontal aperture bottleneck: $4.5 \sigma_{x\text{RMS}}$

Vertical aperture bottleneck: $3.2 \sigma_{y\text{RMS}}$

- "Beta-beating" between all-cold and actual lattice depends on the settings of the warm quadrupoles
## Magnet field errors and misalignments

### Displacement errors

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<td>eDS</td>
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### Relative systematic field errors

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### Relative random field errors

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### MADX notations:
- 0n – dipole
- 1n – norm quad
- 1s – skew quad
- 2n – norm sext.
- ...

### MADX notations:
- 0n – dipole
- 1n – norm quad
- 1s – skew quad
- 2n – norm sext.
- ...
Tune scan without space charge

- U28+ 200 MeV/u
- 3D Gaussian distribution truncated at 2 sigma, sigmas were chosen to ensure the RMS values after truncation:
  - Emittance\_x\_rms=8.8e-6; Emittance\_y\_rms=3.8e-6
  - RMS Bunch length: 14.5m
  - RMS Momentum spread: 0.5e-3
- Dipole errors are taken from the magnet measurements
- Quadrupole errors are taken from the model assumptions
- Tracking for 20000 turns
Tune scan without space charge, WP 18.55 – 18.95

Emittance growth for Qx=18.84, Qy=18.73 working point (One error set):
- Horizontal emittance growth: 12 %
- Vertical emittance growth: 3 %

Beam losses for Qx=18.84, Qy=18.73 working point (Several error sets):

0.1±0.1%
Tune scan without space charge, WP 18.55 – 18.95

MADX 5.04.02

STL

STL (diff. scale)

Gaussian beam cut at 2 sigma in all planes

Simulations for one error set

Gaussian beam cut at 3.4 sigma in longitudinal plane

[STL simulations: A. Oeftiger]
**Space Charge in SIS100**

- \( f_{\text{longitudinal}} \approx 1.5 \text{ kHz} \)  
  \( (T \approx 600 \text{ us}, Q \approx 0.005) \)

- \( f_{\text{transverse}} \approx 5 \text{ MHz} \)  
  \( (T \approx 0.2 \text{ us}, Q \approx 19) \)

Expected maximum Tune shifts

- \( \Delta Q_x = -0.2 \)
- \( \Delta Q_y = -0.31 \)

Challenge for SIS100 beam dynamics:

Resonance crossing due to space charge

[V. Kornilov. SIS100 high-intensity beam dynamics, MAC20 meeting, Nov. 2018]
Space Charge in MADX (1)


Allows to treat frozen space charge using beam-beam elements in a thin lattice.
The note gives descriptions of the following flags:

- Several flags (*options*) to be set to allow tracking with space charge:
  - bborbit
  - bb_ultra_relati
  - bb_sxy_update
  - emittance_update
  - exit_loss_turn

- Certain parameters to be set in BEAM and RUN commands
  - BEAM: N_particles, Ex_spch, Ey_spch,
  - RUN: N_part_gain, checkpnt_restart, sigma_z, track_harmon,
    delta_rms, deltap_max
Space charge, no errors
(Q_x=18.84, Q_y=18.73)

Phase advance analysis

Frequency analysis 128 turns

MAD-X

SixTrackLib + PyHT:
Space charge, no errors  
(Qx=18.95, Qy=18.94)

Phase advance analysis

2 turns  
MADX

1000 turns  
MADX

Frequency analysis 128 turns

MAD-X

SixTrackLib + PyHT:
Hidden flag (discovered when reading the source code): SC_CHROM_FIX

Possible options:

- Option, SC_CHROM_FIX = FALSE (default, original!)
  \[
  DPI = \frac{(z(6,i) - \text{orbit}(6))}{\text{betas}} \\
  z_{\text{part\_array}}(i) = (z(5,i) - \text{orbit}(5)) \times \text{betas}
  \]

- Option, SC_CHROM_FIX = TRUE (FRS add-ons)
  \[
  DPI = (z(6,i) - \text{orbit}(6)) \\
  z_{\text{part\_array}}(i) = (z(5,i) - \text{orbit}(5))
  \]

Comment in MADX source:

! Exact formulation might be too computational time costly:

! DPI=(sqrt((one+z(6,i)*betas)**2-gammas**(-2)))/betas-one
Space Charge in MADX (3)

No errors + Space charge in the working point region Qx, Qy: 18.55 – 18.95

MADX couldn’t find twiss along Qx=18.67

MADX couldn’t find twiss along Qy=18.76
Qy=18.77

sc_chrom_fix = false

sc_chrom_fix = true
Errors + Space charge in the working point region Qx, Qy: 18.55 – 18.95

MADX couldn‘t find twiss along Qx=18.67

MADX couldn‘t find twiss along Qy=18.76
Qy=18.77

sc_chrom_fix = false

sc_chrom_fix = true

• For the following studies sc_chrom_fix=true is set
SIS100 with errors and with frozen space charge

- U28+ at 200 MeV/u
- Particles per bunch 6.25e10

Tune scan for the Working Point region 18.55 – 18.95
Preliminary results of simulations with MADX 5.04.02

Space Charge: Beam losses for (18.84, 18.73) working point: 9±3%
SIS100 with errors and with space charge

[V. Kornilov. SIS100 high-intensity beam dynamics, MAC20 meeting, Nov. 2018]

Simulations with Elegant

With space charge

No space charge

[Simulations with Elegant: V.Kornilov]
Summary and outlook

- The model of SIS100 including magnet errors and misalignments is ready.
- Data on quadrupoles is still missing.
- SIS100 working point studies are still to be continued once the quadrupole data is available.
- Tracking with space charge:
  - Preliminary studies done with MADX: expected beam losses at WP $Q_x=18.84$, $Q_y=18.73$: $9\pm3\%$
  - Studies to be continued with STL (see presentation of A. Oeftiger).