

## Optimization of the Slow Extraction Process from SIS300

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The Facility for Antiproton and Ion Research (FAIR) will house its two superconducting synchrotrons in the same tunnel. This singular feature results in non-standard phase-advances per FODO cell for SIS300 while SIS100 is based on standard design rules. A lattice with 'out of phase' elements is in general more prone to excite unwanted resonances. These resonances may eventually lead to coupling of the horizontal and vertical planes, reduction of the dynamic aperture (DA) and overall particle loss, unless a careful optimization of the sextupole strengths is performed. This important task has been realized by following the work on driving modes (also hamiltonian terms) from Bengtsson [1] and Streun [2]. The excitation of the different resonances driven by the chromatic and resonant sextupoles, together with the amplitude-dependent tune-shift coupling coefficient ( $\alpha_{xy}$ ), can be thus quantified and conveniently minimized by just resorting to an adequate functional. The lattice optimization as presented in this work has been carried out by requiring slow extraction to perform at high efficiency, the latter being evaluated through simulations realized with the code Elegant [3].

The studies on beam dynamics performed using the initial SIS300 lattice showed a small DA for particles with non-zero vertical amplitudes ( $y$ ) or angles ( $y'$ ). Those particles could not be extracted, as shown in Fig 1-left. The results for the 1<sup>st</sup> order geometric terms of the driving modes showed that the contribution from the chromatic sextupoles, ideally zero, was not negligible. Additionally, the resonant sextupoles, which should only excite the extraction resonance,  $3Q_x$ , excited the coupling resonance  $2Q_y + Q_x$  by one order of magnitude more. Similarly, the coupling coefficient,  $\alpha_{xy}$ , was as well one order of magnitude bigger than the horizontal term  $\alpha_{xx}$ .

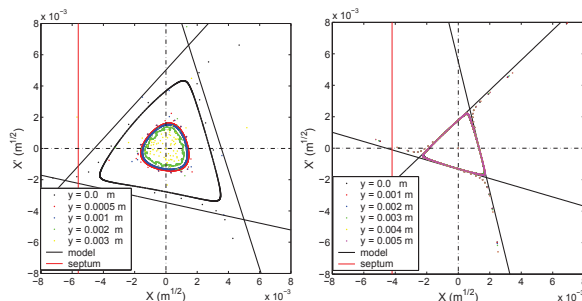


Figure 1: Phase-space plots for on-momentum particles at the entrance of the septum showing the characteristic triangular shape of slow extraction. The tracking simulations are compared with the 1D-analytical model from Pullia [4], before (left) and after (right) the optimization process.

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A functional was built having the strengths of the sextupoles as main variables, and whose optimization guaranteed the following requirements to be satisfied:

- Correction of the horizontal chromaticity to fulfill the Hardt condition (i.e. removal of the momentum dependence at the entrance of the septum in order to decrease the particle loss).
- Minimization of the unwanted resonances:  
 $h_{21000}(Q_x) \rightarrow 0$ ;  $h_{10110}(Q_x) \rightarrow 0$   
 $h_{10200}(Q_x + 2Q_y) \rightarrow 0$ ;  $h_{10020}(Q_x - 2Q_y) \rightarrow 0$
- Excitation of the 3<sup>rd</sup> integer resonance for extraction. The value needed depends on the tune distance ( $\varepsilon$ ) and on the emittance ( $\varepsilon_x$ ) of the beam:  
 $h_{30000}(3Q_x) \rightarrow 2\varepsilon/(3\pi\varepsilon_x/4\sqrt{3})$
- Minimization of the detuning coupling term:  
 $\alpha_{xy} \rightarrow 0$   
 The vertical chromaticity does not play any role and can be freely chosen.

A new working point, corresponding to a phase advance per FODO cell of  $\psi_x = 79.9^\circ$ ,  $\psi_y = 78.3^\circ$  was used, in order to generate a dispersion function with dispersion-free straight sections. By placing there the resonant sextupoles their contribution to the chromaticity is canceled. Additionally the chromatic sextupoles were repositioned with proper phase advances to avoid the excitation of resonances. After the redesign process the DA increased by more than one order of magnitude in the vertical axis. Tracking simulations performed on the new lattice of SIS300 show that all particles can be now extracted independently from their vertical amplitude as seen in Fig 1-right. The slow extraction efficiency of a uniformly distributed beam with an emittance of 2/1 mm-mrad (horizontal/vertical planes respectively) has a value of 92.02% for the optimized SIS300 lattice. The calculation was repeated for the case in which the chromaticity was not corrected to fulfill the Hardt condition. In this situation the slow extraction efficiency was reduced to a value of 75.95%

## References

- [1] J. Bengtsson. SLS Note 9/97, 1997.
- [2] A. Streun. Lectures at CAS, Zeuthen 2003.
- [3] M. Borland. APS LS-287, 2000.
- [4] M. Pullia. PhD thesis, October 1999.