

Verification of the applicability of the Hardt condition to the slow extraction of SIS18

N. Pyka, 31st May 2007

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Participants	N. Pyka, U. Scheeler, operating team
Beam	Ar ¹⁸⁺ at 300 MeV
Extraction target	HHD

Result

It has been demonstrated for the first time that the Hardt condition (suppression of the momentum dependence of the separatrices and superposition of the extraction separatrices) can be applied beneficially to the ion optics of SIS18 for slow extraction. Six sextupole magnets were activated in order to excite the resonance and all twelve sextupole magnets were used to restrain the chromaticity to small values. **The observed extraction efficiency yields 93% compared to a best value of 83% with the slow extraction scheme used so far in SIS18.**

Normal slow extraction

First, for comparison, a slow extraction scheme has been realized which has been used so far at SIS18. The extraction efficiency obtained was 83% (extracted 5.2×10^8 ions, circulating: 6.3×10^8 ions).

Momentum spread

A quick Schottky measurement revealed roughly a frequency width of $\Delta f_h = 6$ [kHz] FWHM at $f_{hc} = 25.34$ [MHz]. In order to estimate the momentum spread dp/p the measured width is multiplied by a factor of 1.7. This factor represents $\pm 2 \sigma$ of a Gaussian distribution comprising 95.5% of the particles. With a transition energy of SIS18 of $\gamma_T = 5.6$ and $\gamma = 1 + 300/931.5 = 1.322$ the correction factor η is derived as $\eta = \gamma^2 - \gamma_T^2 = 0.54$. Hence, it follows that $dp/p = 1.7 \times \eta^{-1} \times \Delta f_h / f_{hc} = 7.5 \times 10^{-4}$.

Beam loss calculations

What will be the minimum beam loss for the so far used slow extraction scheme? In other words, what may one expect to gain by applying the Hardt condition. To answer this question one has to know the physical coordinates of the septum and the momentum spread of the beam. With these parameters one can calculate the angular width of the separatrices at different momenta which are cut in phase space at the electrostatic septum.

For the ion optical simulation with MIRKO the presumed position of the electrostatic septum has been at $X = -55$ [mm] with an angle of $X' = -9.0$ [mrad]. These values were confirmed by U. Blell. The tune for the simulation was taken as $Q_x=4.31$, $Q_y=3.29$.

In contrast, the displayed tune at the accelerator control panel was $Q_x=4.3044$, $Q_y=3.29$. This tune has to be corrected by $+0.02$ and -0.03 (GSI_Acc_Note-2005-02-001, Franchetti et al.). Hence, the effective tune has been $Q_x=4.324$, $Q_y=3.26$.

The simulation result of the normal slow extraction yields an angular distribution at the position of the electrostatic septum of $\Delta X' = 0.47$ [mrad] at the given momentum distribution of $dp/p = 7.5 \times 10^{-4}$ and a tune of $Q_x=4.31$, $Q_y=3.290$. The "effective" thickness of the septum wires at a length of the septum of 1500 [mm] are thus 0.71 [mm]. Hence the extraction loss due to the finite momentum spread, presumed a jump length of 7 [mm] of the unstable particles, should be at least $0.7/7$ equals 10 %. Other lost mechanisms may further reduce the extraction efficiency. In contrast, a minimum beam loss at the electrostatic septum due to the finite wire thickness of 0.1 [mm] accounts for $0.1/7 = 1.4$ %. That means, applying the Hardt condition one may gain about 8 to 9%.

In fact, one may gain even more because the uncorrected beam delivers a whole bunch of jump lengths of the unstable particles due to the momentum dependent sizes of the separatrices. Hence, some particles may sense higher beam loss, other may jump too far to be on a reliable extraction path.

Ion optical adjustments to fulfill the Hardt condition

The chromaticity had to be corrected from about $\xi = -1.5$ in both planes to about $\xi = -0.06$. This needs sextupole magnet excitations of up to 63 [A] compared to a maximum of 8 [A] for the normal extraction.

After having driven the sextupole magnets to the calculated currents, already an extraction efficiency of about 50% has been observed. In order to optimize the flight path, several parameters had to be changed considerably. At the end of the optimization process, the beam trajectory was centered during the whole extraction time. Unfortunately, no detailed optimization of the sextupole phase could be made.

Eleven measurements of the number of particles have been taken to determine the extraction efficiency. The mean value for the circulating beam was 6.05×10^8 particles, the mean value for the extracted beam was 5.63×10^8 particles which yields an extraction efficiency of 93%.

Beam loss monitors

The beam loss monitors S04DL1 & -2 around the electrostatic septum as well as the beam loss monitors S06DL3R & -3L around the magnetic extraction septum displayed rather low losses after optimization of the beam trajectory.

Outlook

The observed results are very promising and should be confirmed and optimized by using substantially different start conditions. In particular by using an Uranium beam and adjusting the sextupole phase. A more precise Schottky measurement on momentum spread should be taken and the obtained chromaticity should be determined experimentally by BTF measurements. The tune in the simulations will be corrected taking the above mentioned systematic tune error into account in order to excite the sextupole magnets with the correct current. Finally, as cross-check, the situation on the beam loss monitors at the electrostatic and magnetic septa should be compared for the "so far used" slow extraction and for the ion optical alignment fulfilling the Hardt condition.

In view of the FAIR project, one should of course apply in a further step also knock-out extraction instead of running into the resonance with fast quadrupole magnets.

Observations

The exchange of data between the SIS Expert Mode and the normal SIS mode was seriously hampered. In some situations it was not clear which data were really taken into account and which were simply ignored, e.g the sextupole phase seemed to be ignored.

Sometimes data had to be transferred "by hand", which meant to transfer each element of a spreadsheet after each other. The try to transfer the whole spreadsheet ended in overwriting the desired data with a prescribed data set. The same occurred with a change of the sextupole phase.

The sextupole magnets labeled "1C" at the end changed sign when being transferred between Expert and SISMODI, while sextupole magnets labeled "3C" at the end underwent no change. Nevertheless, the assigned currents turned out to be correct.

In order to figure out a reliable data set for routine operation, the clearance of the data exchange seems to be indispensable before continuation of the proposed experiments.