HIGH INTENSITY NONLINEAR DYNAMICS IN SIS100

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Abstract

Beam loss control in the planned SIS100 is relevant for the design of collimators and for maintaining vacuum quality. We present the status of the studies of beam degradation, due to space charge and magnet imperfections during the accumulation at injection energy. The impact of magnet misalignment on resonances and beam trapping/scattering effects is discussed.

INTRODUCTION

In the SIS100 synchrotron of the FAIR project at GSI [1] bunches of U^{28+} ions are stored for a time of the order of a second. Controlling radiation damage [2] and containing the negative effects of beam loss on vacuum and magnets – which rely on NEG coating [3] and on a dedicated new halo collimation concept [4] – require a maximum acceptable beam loss of (much) less than 10% over the total accelerator cycle. We study here the incoherent space charge (SC) effect during the 1 s long injection flat-bottom for working point 1 (WP1): $Q_{x/y} = 18.84/18.73$.

STATUS OF BEAM LOSS PREDICTION

In SIS100 the nonlinearities are given by standard multipoles in sc dipoles, conveniently described via an elliptic coordinate transformation [5, 6], and by the multipoles for sc quadrupoles taken from [7]. Chromatic correction sextupoles are ignored. The purely systematic multipoles yield a short term dynamic aperture (10^3 turns) of 4.8σ for a reference beam of 8.75 mm-mrad rms emittance with the beam magnetic rigidity at injection of 18 Tm. Magnet random errors are introduced through a $\pm 30\%$ fluctuation for all multipoles of the sc dipoles [8]. In this modeling we take into account a possible residual closed orbit distortion (COD), after correction. After a numerical study in which we apply shifts to the quadrupoles, we correct the COD and in Fig. 1a we show an example with two residual closed orbit distortions for two types of positioning errors. For safety we consider a reference residual COD of 1mm vertical rms COD (1.6 mm horizontal) see Fig. 1a, which contains 95% of the associated COD distribution. The feed down of magnets components, for $d_{x,rms} = d_{y,rms} =$ 0.32 mm, yields an average DA of 3.3σ with a variance of 0.21σ. See in Fig. 1b for the dependence of DA from the level of rms COD. We model the bunched beam with a Gaussian transverse distribution truncated at 2.5σ in amplitudes as result of a controlled beam shaping during transfer from SIS18 to SIS100. Two sets of reference emittances (2σ) are defined. Beam1: $\epsilon_{x/y} = 35/15$ mm-mrad (edge at $2.5\sigma <$ DA=3.1σ), which assumes no dilution within

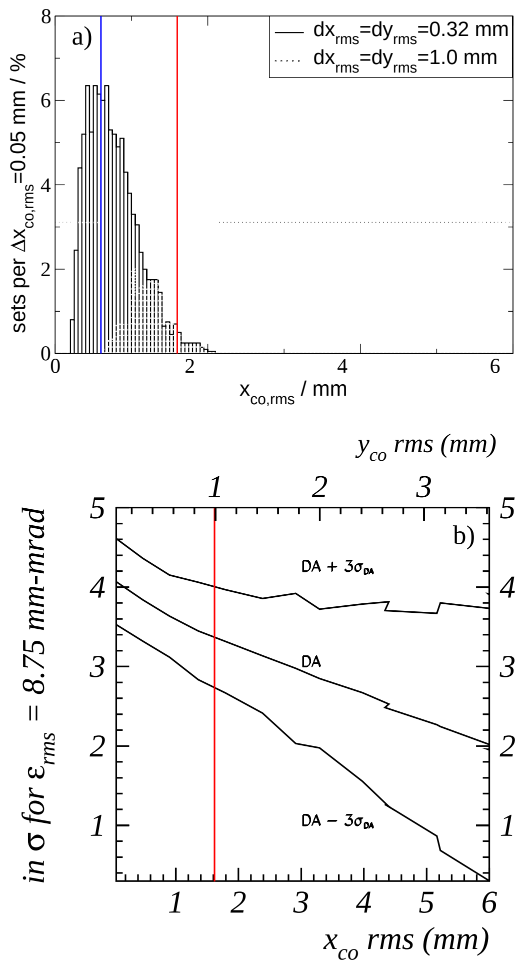

Figure 1: a) Closed orbit distortion after correction for two sets of closed orbit errors: the normal positioning error of 0.32 mm, and for example for the enhanced level of 1 mm; b) DA computed for several error seeds defining an rms COD.

the SIS18 acceleration cycle; Beam2: $\epsilon_{x/y} = 50/20$ mm-mrad (edge at $2.98\sigma <$ DA=3.1σ), which allows for some dilution getting closer to the dynamic aperture limitation, but reducing the SC tune shift. Including all systematic and random terms so far discussed we explored 27 error seeds consistent with the standard 1 mm vertical rms COD. The beam loss was computed over 10^4 turns, and we singled out a "standard error case" with the moderately pessimistic beam survival of 99% (Fig. 2a extends prediction till 10^5 turns). Simulation results for the "standard error case" including chromaticity show that up to 10^5 turns (0.6 s) the Beam1 exhibits a beam loss up to about 1%, while

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for Beam2 we find 6% of beam loss. This statistical effect of COD is analyzed for a wide range of working points in Fig. 2b. For each WP we plot DA affected by the "standard error seed" on sc dipole errors as well as by the 1mm level of vertical rms COD.

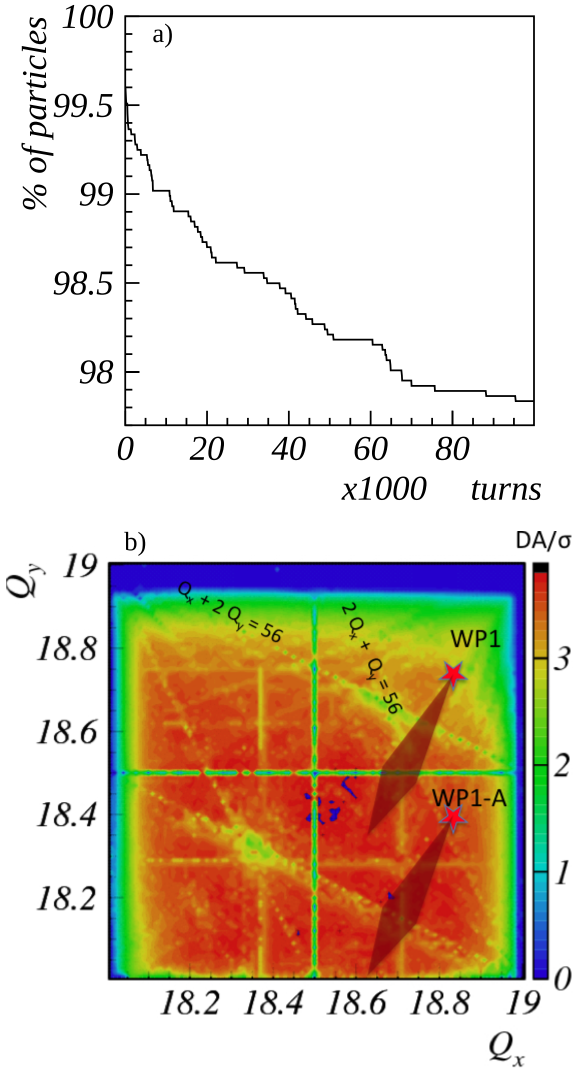

Figure 2: a) Beam2 for the standard error case. b) SIS100 dynamic-aperture scans for the "standard error seed". Red marker: proposed working point WP1.

We then evaluated the effect of the chromaticity in a bunched beam with rms momentum spread of $\delta p/p = 5 \times 10^{-4}$ consistent with a bunch length of $\pm 90^0$ (bunching factor of 0.33) and linear synchrotron period of 233 turns (RF voltage of 53 kV if SC is ignored). Simulations with SC are made with MICROMAP including all previously discussed effects for the "standard error case". The SC is computed with a frozen model, which incorporates the local beam size defined by the beam optics [9]

For the maximum nominal intensity of a total of 6×10^{11} of U^{28+} in 8 bunches the SC tune spread is -0.31 / -0.47 for Beam1 and -0.21 / -0.34 for Beam2. In Fig. 3c,d we present results for Beam1/Beam2 at 1.2×10^5 turns (0.7 s storage) for half nominal intensity, which helps avoiding the half-

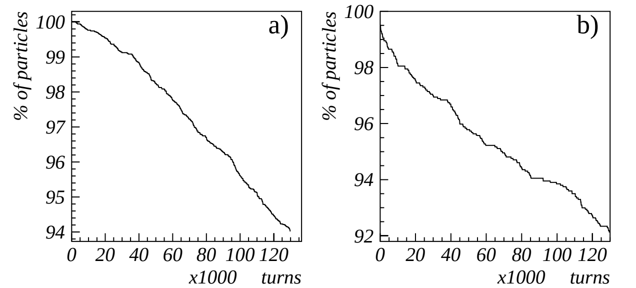

Figure 3: SIS100 beam loss with space charge for Beam1 a) and Beam2 b) for an intensity of 3×10^{11} ions.

integer resonance. In comparison with the case without SC the Beam1 is dominated by SC as losses increase from 1% to 6% when SC forces are included. For Beam2 the loss is dominated by the DA and chromaticity, and adding SC only leads to an increase of the loss from 6.5% to 8%. The SC dominated loss for Beam1 at half nominal intensity can be understood as a result of the periodic crossing of the tune footprint with the third order error resonance $Q_x + 2Q_y = 56$, possibly also with $3Q_y = 56$. The nominal intensity for the same set of parameters (and the same error set) results in a more than proportional increase of the loss. At maximum intensity many more particles cross the resonance $Q_y + 2Q_x = 56$ and become candidates for loss. We have therefore investigated an alternative working point (WP1-A): $Q_{x/y} = 18.84/18.40$, which is exposed to the apparently weaker third order resonance $2Q_x + Q_y = 56$. Results for beam survival over the full cycle are obtained by the sum of all the beam loss accumulated by each of the 8 bunches injected over 1 second. In this process the first bunch is stored 1 s, the second 0.875 s, the third 0.75 s and so on. Each of these bunches will have the same time survival pattern just time shifted according to the injection time. As simulations show that, in good approximation, the beam loss pattern is linear (see Fig. 3), we find that the total beam loss over one second relative to the total injected ions is just half of the relative beam loss for the first injected bunch. The beam survival for the full cycle is presented in Table 1. The loss is improved for full intensity, but slightly

Table 1: Beam survival averaged over full SIS100 cycle.

WP	(18.84, 18.83)		(18.84, 18.40)	
ϵ_x/ϵ_y	35/15	50/20	35/15	50/20
Part. 6×10^{11}	75%	78%	87%	86%
Part. 3×10^{11}	97%	96%	95%	91%

worse for half intensity, possibly because of the proximity of the line $Q_x + 2Q_y = 56$. It should be noted here that the simulation model employed in this study lacks dynamical self-consistency. This is not expected to matter for losses at or below the few percent level, but for larger losses inclusion of full self-consistency (e.g. updating the SC force as a consequence of losses) could easily enhance or diminish the loss rate.

BEAM LOSS CODE BENCHMARKING

The complexity of the long term beam loss prediction becomes particularly critical when all effects from a realistic and complete modeling are included, in particular all type of misalignments, nonlinear error distributions along the ring, and variations of beam distribution. It becomes therefore desirable to establish a benchmarking of the robustness of the beam loss (emittance growth) prediction for SIS100. We report here a preliminary benchmarking with an extended version of MADX, i.e. MADX+fsc3d [10], which was developed in ITEP, where the beam-beam MADX capabilities are used in algorithms for simulating frozen space charge.

SIS18 emittance growth code benchmarking

Clearly the complexity of a similar benchmarking should follow firstly a relatively simple code benchmarking, which allows a first code validation. Then after a verification of this "simplified" scenario the full SIS100 code benchmarking can take place. To this purpose the code benchmarking on trapping phenomena presented in Ref. [11] can be followed. This benchmarking was performed in 2006 between SIMPSON and MICROMAP, and the result of the benchmarking were found very good. All 9 steps described in [11] have been repeated with MADX+fsc3d, and the main result is shown in Fig. 4 (larger oscillation pattern in MICROMAP stems from the emittance diagnostic which was made on a space domain rather than detecting the beam distribution in the position monitor location).

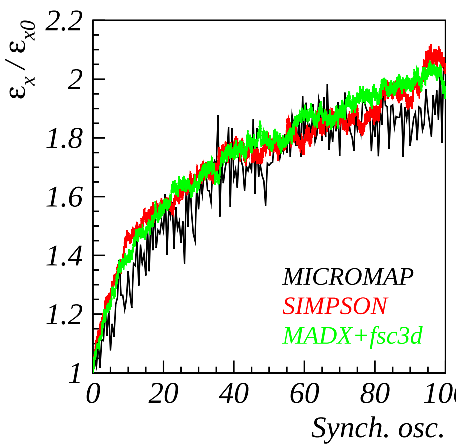

Figure 4: Emittance growth versus synchrotron oscillations in 3 different codes.

The result confirms the correct implementation of space charge algorithms and the correct retrieving of the long term effect on the beam emittance due to space charge trapping/scattering effects.

Preliminary SIS100 beam loss benchmarking

The beam dynamics with space charge is obtained by fixing a number of interaction region between the beam space charge and the beam particles. As a preliminary calculation we applied the MADX+fsc3d to SIS100 for the case of beam2. The sequence of seed for magnet random errors is not taken equal to those used in the simulation for Table 1. Clearly this result represents a specific sequence of errors and a particular COD which set some more pessimistic condition to the beam dynamics. In fact the dashed curve in Fig. 5 shows that over 3×10^5 turns $\sim 6\%$ of particles are lost contrarily to the 1.5 % found in Fig. 2a. The retrieved and more pessimistic beam loss is shown by the black solid curve in Fig. 5.

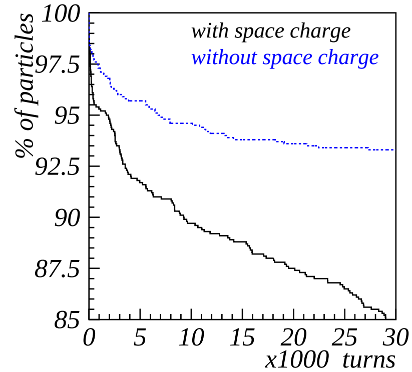

Figure 5: Long term beam loss for SIS100 beam2 including space charge (black) and without (blue).

CONCLUSION/OUTLOOK

These studies confirm that the working regime of SIS100 is enough sensitive to random variation of magnet components and COD deformation. A large scale investigation on all effects enhancing space charge induced long term beam loss is in progress. Parallel to these studies of the intrinsic limits with the present design, strategies of resonance measurements and control are under development, leaving for future studies their robustness in presence of space charge.

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