Beam Loss And Longitudinal Emittance Growth In SIS

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Abstract. Beam losses of several percent occur regularly in SIS. The onset occurs during the RF capture of the beam. Previous studies have revealed that the losses can come from the RF bucket at the start of acceleration being over filled due to the longitudinal bucket acceptance being too small, or due to the mismatch between the mean energy from the UNILAC and synchronous energy of the SIS [1]. The beam losses as measured by a DC beam transformer however show in addition to the sharp initial drop, for the above reasons, a much slower decay in the beam intensity. The speculated cause comes from the incoherent transverse tune shift of the bunched beam, which forces particles into transverse resonant conditions. The emittance growth is also another important issue for SIS. Past measurements from Schottky-noise pick-ups have shown a factor of 3-5 increase in the emittance depending on the extraction energy; a large factor when compared against expectations from theory. These factors were calculated from the ratio between the normalized relative momentum spread of the DC beam before RF capture and after debunching. In this present work, tomographical techniques have been used to reconstruct the phasespace from a series of bunch profile measurements from a Beam Position Monitor (BPM). Therefore one can find the rate of growth in the emittance from a series of high resolution BPM measurements along the RF ramp. Furthermore the initial phasespace density matrix from these reconstructions has been used to generate the initial population of macroparticles for the ESME longitudinal dynamics Particle-In-Cell code [2], thereby enabling a comparison between the emittance growth of the beam under ideal conditions and that of the experiment. The emittance growth (rms) during the acceleration (~540ms) was approximately 20%, and that during the RF capture was estimated to have an upper limit of about 40%. Later measurements have also been performed from emittance evaluation of the DC beams during the injection and extraction plateaus of the machine cycle. It was found that a blow-up factor of ~270% occurred in the emittance and that this could not be reproduced in the simulation, which yielded a factor of ~50%.

INTRODUCTION

The FAIR project at GSI demands a vast increase in the output intensity from the present SIS, which shall operate as a booster synchrotron for the future SIS100 synchrotron. Reduction of the total beam loss and emittance growth which are presently regularly observed are thus important issues. We present the findings from two machine experiments; the beams were $^{40}Ar^{10+}$ and $^{40}Ar^{18+}$, however the losses and emittance growth seem to first order to be independent of the ion species. Cures to the beam losses and emittance growth are discussed in the conclusions.

RESULTS AND DISCUSSION

Beam Loss During RF Capture

The injected beam from the UNILAC (Universal Linac) fluctuates during the experiment causing considerable emittance growth during bunching (i.e. RF capture). If the mean energy offset relative to the synchronous energy of the SIS is severe enough or the energy spread is sufficiently large then beam loss may occur if the bucket area is too small when the RF is ramped. The time scale for this kind of loss mechanism is relatively short (~1ms in figure 1) compared to that often observed (~100ms in figure 2). The slower loss profile may be due to space-charge detuning of the bunched beam. What is more particles outside the separatrix of a stationary bucket remain in close longitdinal phasespace orbits, yet beam loss occurs.

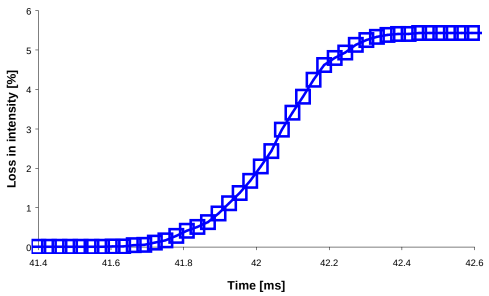

FIGURE 1. Beam loss profile of $^{40}Ar^{10+}$ beam taken from a DC transformer.

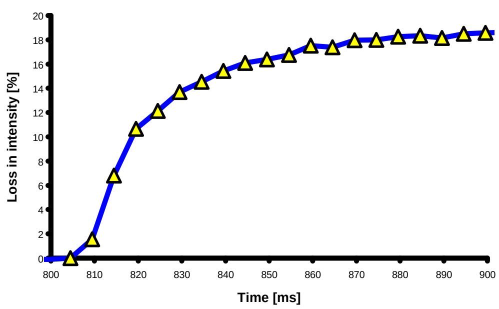

FIGURE 2. Beam loss profile of $^{40}Ar^{10+}$ beam from an ESME simulation.

A rough estimate for the maximum allowable beam emittance which causes the particles with the most shifted vertical tune may be obtained from [3]:

$$\Delta Q_y^{inc,\max} = -\frac{Z}{A}\frac{r_0 IR}{ec\beta^3\gamma^3}\frac{g}{B_f}\frac{2}{\varepsilon_y+\sqrt{\varepsilon_x\varepsilon_y}} \qquad (1)$$

using an estimated bunching factor of B_f=0.3 at t=100ms from an ESME simulation, which is the maximum value reached for the Ar^{10+} beam. The SIS parameters were: R=34.492m β=0.155, I=17mA, and g=2. It was found that the emittances required to reach a measured resonance, nearest to the working point at (4.29, 3.29) believed to correspond to the 3rd order difference resonance $-q_x+2q_y=2$, yielded the conservate estimate $\varepsilon_x \leq$ 130mm.mrad, and $\varepsilon_y \leq$ 30mm.mrad. These values are plausible since they compare closely to the transverse acceptance of SIS limited by the injection septum ε_x =150mm.mrad, and ε_y =50mm.mrad. Although this resonance produces merely an emittance exchange between the horizontal and vertial, upon exchange, the vertical emittance becomes 130 mm.mrad (worst case) leading to loss since the vertical acceptance becomes exceeded.

Emittance Growth During The Bunch-Accelerate-Debunch Process

The current procedure to optimize the injection conditions in order to eliminate known causes of phasespace dilution; the reduction of the coasting beam's relative momentum spread dp/p and reduction of the mean ion-energy offset relative to the synchronous energy. The dp/p of the debunched beam was minimized by changing the so called radial position at injection denoted RPOSI (proportional to the RF cavity frequency). The minimum value of dp/p thus corresponded to no injected energy-offset and hence the least emittance growth. Other schemes may also be applied [4]. The dp/p at injection must also be set such that the full width in dp/p (e.g. 4σ) of the bunches remain well within the acceptance of the accelerating RF bucket, otherwise beam loss would occur. Tomography was applied to calculate the phasespace distribution of the beam from the point in the machine cycle at which losses have stopped and the bunch is within the RF bucket. By this means the emittance was calculated and its development is in figure 3. Since the injected beam's Schottky spectrum varied significantly between consequtive injections and the measure longitudinal bunch profiles had a tail due to the pickup's finite bandwidth, the emittances could vary by about ±10%, hence the straight line fit. We thus estimate an average emittance growth of ~20% during acceleration for the Ar^{10+} beam over ~540ms, which is almost the complete bunch-accelerate-debunch process. The simulated case using an initial phasespace from a Montecarlo generation of the macroparticle coordinates using as the probability distribution the 2D-phasespace density of the tomography. We notice that under the ideal conditions of the simulation, that is, no RF noise and no beam loading voltages, the expected emittance growth is practically zero. A rough estimate of the growth from t=0-100ms was also made. Four Schottky spectra at injection were used to generate the DC beam's phasespace distribution at t=0ms using however this time a 1D-Montecarlo method. Using an isoadiabatic ramp with an adiabaticity $\alpha_c = \omega_s^{-2} \left| d\omega_s / dt \right| << 1$ where ω_s is the synchrotron angular frequency for small oscillations; an initial amplitude of 0.1kV; a final amplitude of 38kV; a capture time of 100ms; and no acceleration, the beam was bunched and the rms emittance was determined. Out of the four initial conditions the growth was less than ~40% assuming ideal RF ramps.

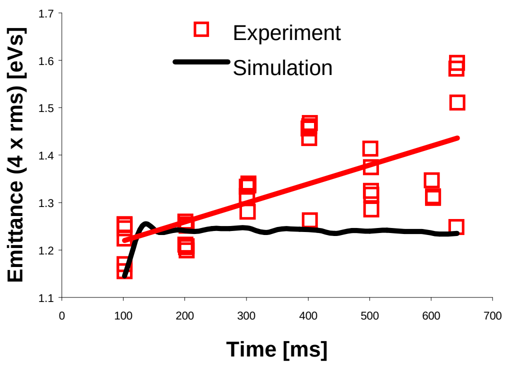

FIGURE 3. Longitudinal emittance growth profile of the fully bunched $^{40}Ar^{10+}$ beam during acceleration.

A later experiment on Ar^{18+}, sought to evaluate the total emittance growth over the complete machine cycle. The emittance growth was evaluated by comparing the normalized emittances of the DC beams[1] at injection and well after the beam was debunched to allow the Landau damping sufficient time (~200ms) to smear out any coherence. The commissioned ramps used are those in figure 4. These ramps have an adiabaticity α_c<<1 for all except near the beginning and end of the ramp where the gap-amplitude is just a few volts for ~2ms. The emittance grew from 1.7-6.3 eVs; an increase of ~270%. This increase lies within the factor range 3-5 from previous measurements [5]. Deriving the initial phasespace distribution for the ESME simulation from a measured Schottky band at injection, and running the simulation with the ramps from figure 4, we obtained an increase of ~50%. The simulated phasespace development of the beam is also shown. To allow maximum sensitivity of the beam to RF noise etc., the maximum attained bucket area along the ramp should be several percent larger than for example the 2σ-envelope emittance of the beam.

[1] The DC beam emittance was defined as FWHM [eV] x revolution period [s]. The FWHM comes from a fitted Gaussian.

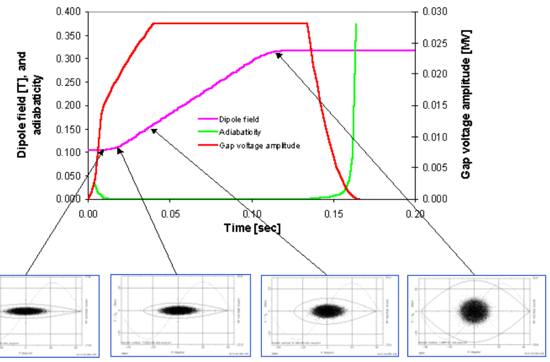

FIGURE 4. Simulated phasespace development of the beam distribution for $^{40}Ar^{18+}$. Injection offset was zero.

CONCLUSIONS

Losses during capture may stem from the particle tunes crossing resonance lines due to space-charge detuning. The emittance growth in longitudinal phasespace during acceleration was ~20% yet the debunched beam emittance showed a growth of ~270%. The debunched beam emittance from the ESME simulation was much smaller; only ~50% larger than at injection. A proper feeback control of the bunch-to-synchronous phase is still needed. This shall be part of the functionality of the dual-cavity digital RF control system, which at present minimizes just the phase lag of the slave with respect to the master cavity. It may be that the 270% blow-up in emittance arises from a microwave instability onset during debunching. Future experiments hope to check this hypothesis.

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