THE S317 EXPERIMENT ON HIGH INTENSITY BEAM LOSS AND EMITTANCE GROWTH

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Abstract

We describe the first results of an extensive experimental campaign, called S317, performed at GSI in the SIS18 synchrotron. High intensity effects on the beam during one second storage after injection are examined using the available transverse and longitudinal beam profile diagnostics. A first discussion of the results in comparison with the CERN-PS experiment is outlined.

INTRODUCTION

The theoretical possibility of trapping phenomena in high intensity beams has recently been considered in detail for two types of scenario:

- when the machine tune dynamically changes during storage and the tune-spread acts against a machine resonance or a structure resonance (space charge induced). This scenario may happen in FFAG's [1] and Linacs [2];
- when the machine tune is kept static, and the beam is confined by an RF force which longitudinally moves the beam particles so that a periodic crossing of the machine resonance (or a structure resonance) may, via transverse space charge detuning, take place [3, 4].

The experimental verification for the long term storage of a high intensity bunched beam in the presence of a controlled octupole was carried out at the CERN-PS in the years 2002-2003 taking advantage of the well controlled beam available in the PS synchrotron as obtained directly from the bunch to bucket transfer from the PS booster to the PS. The beam profile measurements were performed by using a flying wire and time evolution has been assessed by repeating the measurements while changing the trigger time. The resulting measurements use therefore several beams, which are affected by some unavoidable fluctuations from shot to shot. In the S317 experiment we study the long term space charge effect in the presence of controlled sextupoles (octupoles are not available). The interest in these studies is mainly to benchmark the understanding and the code capability of predicting beam loss and emittance increase in long term storage as is foreseen in the main scenario for the SIS100 synchrotron part of the FAIR project [5].

EXPERIMENTAL BACKGROUND

The study of these high intensity effects on a resonance requires the excitation of a controlled resonance and the preparation of a high quality beam, together with the analysis of the transverse and longitudinal profile with time. In our case the transverse profiles are measured with a restgas ionization profile monitor (RGM). The longitudinal profile is measured with a Beam Position Monitor.

Identification of the relevant resonance

An experimental campaign on SIS18 performed in 2004 (see Ref. [6, 7]) resulted in the resonance diagram shown in Fig. 1 by scanning tunes across the tune plane and measuring beam loss (see scale for relative loss, no loss blue). Several 2nd and 3rd order resonances are excited by machine errors. The synchrotron is equipped with only sextupoles

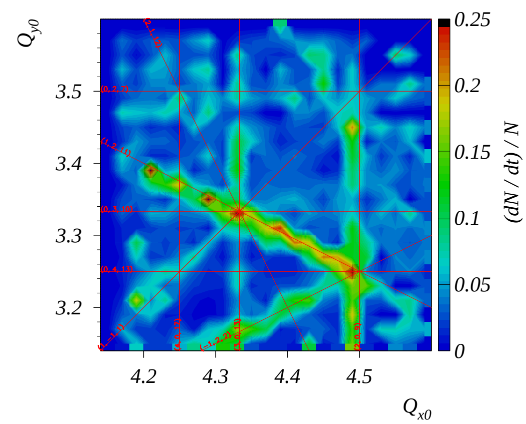

Figure 1: SIS18 measured beam loss as function of tunes.

for chromatic corrections and in order to perform a study of the interplay of space charge with lattice resonances, we select a natural resonance which is not too strong and allows sufficient free space for space charge tuneshift. The resonance for the slow extraction is a good candidate. In fact, in the SIS18 a system of 12 sextupoles is used to control the chromaticity and simultaneously the strength of the 3rd order resonance $3Q_{x0} = 13$, which is routinely used for slow extraction. As the position of the sextupoles for chromatic correction is the same in each SIS18 lattice period (where the beta functions are assumed to be identical) the control of the 3rd order resonance is reached by changing the sextupoles in pairs; One sextupole is added a certain strength, which is then subtracted from the another sextupole changing thus the resonance strength, but keeping unchanged the level of chromatic correction.

Beam condition

In the experimental campaign an ion beam of $^{40}A^{18+}$ was used. The beam emittances measured at the exit of the

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UNILAC are $\epsilon_x = 6.58$ mm-mrad, $\epsilon_y = 3.49$ mm-mrad. The beam intensity in the UNILAC was set to $I_U = 0.8$ mA (Fig. 2). The injection energy in the SIS18 is 11.35 MeV/u.

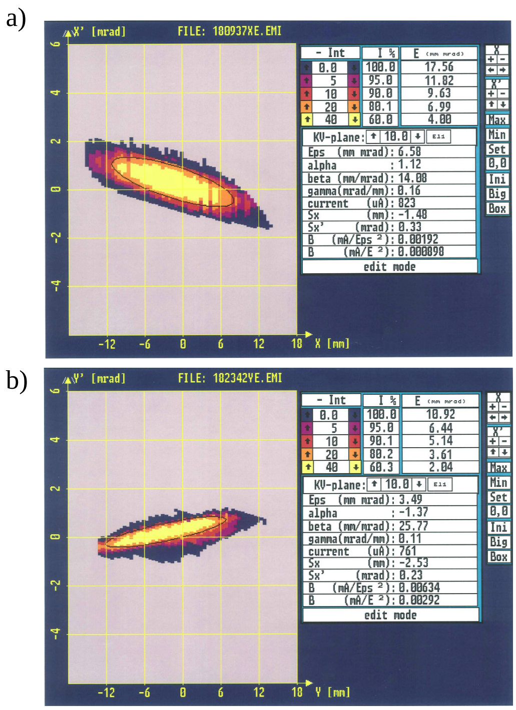


Figure 2: Measurement of August 2007: a) Horizontal beam emittance measured in the transfer channel between UNILAC and SIS18; b) Vertical beam emittance.

For the purpose of observing a high intensity driven beam blow-up, a beam smaller than the SIS18 acceptances ($A_x \simeq$ 200 mm-mrad, $A_y \simeq 50$ mm-mrad) has been created by setting the injection chopper window to 10 μs only (Bump. Flank = 150 μs; Chop. delay = 50 μs). After injection the beam is stored for $\simeq 1$ second at injection energy and then accelerated for extraction. The radial position of the closed orbit at injection is set at 6 mm.

At injection energy the revolution time is 4.6μs and an injection with a chopper window of 10 μs corresponds to 2.13 turns equivalent to a number of 2.1×10^9 ions in SIS18. However, because of the efficiency of the multi-turn injection, the number of particles stored in the SIS18 did not exceed 1.5×10^9.

The beam emittances are retrieved from the beam profiles measured with the rest gas monitor (RGM) [8]. In Fig. 3 we plot the beam profiles right after multiturn injection and after storage of 1 second for the SIS18 tunes of $Q_x = 4.33, Q_y = 3.245$. By using the beta functions at the position of the RGM, $\beta_x = 6.28$ m, $\beta_y = 7.8$ m, and the measured beam distribution, the transverse rms emittances can be calculated. Note that the measurements from the RGM have to be interpreted carefully: in fact, the acceptance $A_x \simeq 200$ mm-mrad, $A_y \simeq 50$ mm-mrad is translated at the position of the RGM into an area accessible to the beam within ± 35 mm horizontally and ± 20 mm vertically. Consequently an apparent ion detection measured at $y = 50$ mm in Fig. 3b cannot be attributed to the ion beam. The reason for this is that the RGM spatial area of detection is larger than the accelerator acceptances. We avoid this artifact by cutting the data measured by the RGM below 10% of its maximum value (blue line in Figs. 3a,b). For Fig. 3 we obtain then the rms beam emittances $\epsilon_{x,rms} = 6.5$ mm-mrad, $\epsilon_{y,rms} = 3.5$ mm-mrad, with edges (at 3σ) corresponding to the emittances: $\epsilon_{x,edge} = 56.5$ mm-mrad, $\epsilon_{y,edge} = 31.5$ mm-mrad. Therefore the tail of this beam is not at the edge of the SIS18 vertical acceptance and possible beam blow-up can be measured more accurately.

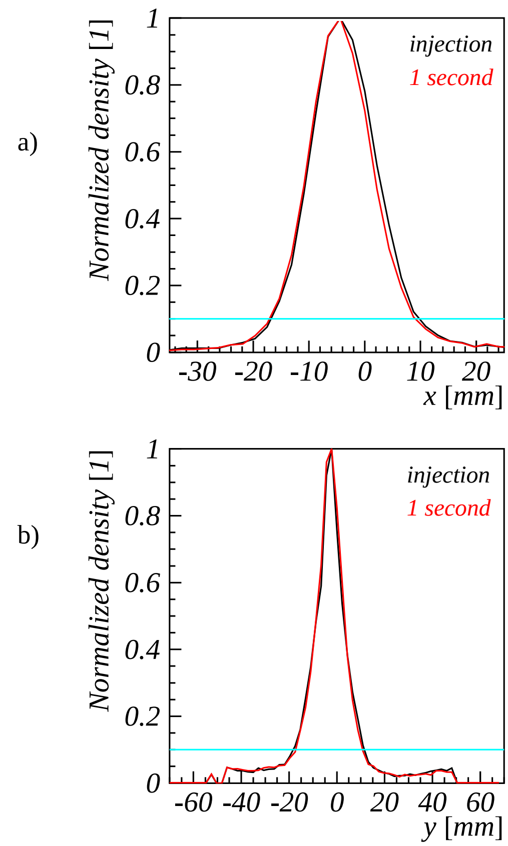


Figure 3: Measurement of August 2007 for $Q_x = 4.33, Q_y = 3.245$: a) Horizontal beam profile; b) vertical beam profile.

Intensity control

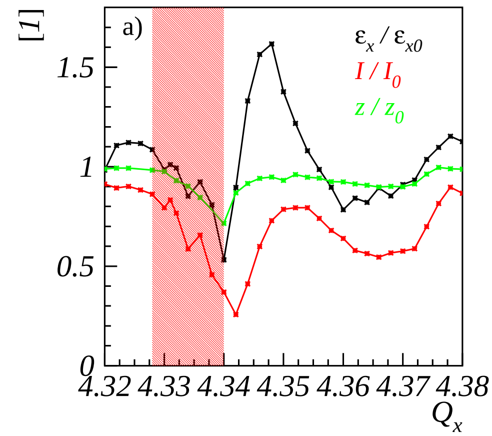
The possibility of creating beams of equal size at several intensities is important for proof of principle measurements. In order to keep the same initial profile at injection in SIS18, the intensity was changed directly via the UNILAC. However, the Linac-Synchrotron injection scheme based on the 'multi-turn injection' is affected by the change of the horizontal tune Q_x. This drawback cannot be avoided, and makes a difference with respect to the CERN-PS experiment, were the bunch to bucket transfer kept the intensity virtually independent from the machine tunes.

THE MEASUREMENT CAMPAIGN

As the resonances measured in Fig. 1 were obtained without including the sextupoles for chromatic correction, the effective stop-band in this experiment resulted from the combined effect of natural errors and sextupoles. In order to assess the strength of this resonance, a tune scan has been performed by using a coasting beam at low intensity. By monitoring the beam loss a stop-band of $\Delta Q_x \simeq 0.12$ due to the 3rd order resonance $3Q_{x0} = 13$ has been found. After injection the beam is left to coast for 100 ms as prior to being bunched in 10 ms with a final RF voltage of 4KV. This bunch, characterized by a bunching factor $B_F = 0.37$ and $(\delta p/p)_{rms} = 1.3\times10^{-3}$, is stored for 0.9 seconds then adiabatically de-bunched in 100 ms (before a final bunching with acceleration and extraction). Under this operational scheme we explored the beam response as a function of Q_x. The average peak space charge tuneshift directly measured from the RGM data yields $\Delta Q_x \simeq -0.04$, and $\Delta Q_y \simeq -0.06$. In Fig. 4a we show the experimental finding. We find as in the CERN-PS experiment that a region of beam loss (red curve) is located on the right side of the resonance. In absence of beam loss ($Q_x \sim 4.35$) an emittance growth is observed (Fig. 4a black curve): this result is consistent with trapping/scattering regimes discussed in [4]. The red stripe marks the position of the beam loss stop-band measured with the low intensity coasting beam. The green curve shows the relative bunch length measured with a Gaussian fit, which becomes shorter in correspondence with the maximum beam loss at $Q_x = 4.34$. In Fig. 4b is shown the time evolution, for $Q_x = 4.34$, of one bunch intensity I/I_0, horizontal emittance ϵ_x/ϵ_{x0}, and bunch length z/z_0. This picture refers to the evolution of one bunch and is not the result of repetitions of measurements. Note the strong correlation between beam loss (red curve) and bunch length (green curve) which is kept during all the storage time. Note that on the other side of the single particle stop-band at $Q_x = 4.375$ no bunch shortening or beam loss is observed. The correlation beam loss / bunch shrinkage shown in Fig. 4b was already observed in the CERN-PS experiment [9] but only for a few bunch profiles. Here it is confirmed for the full storage time and it is consistent with the interpretation that particles with large synchrotron amplitude are lost because they are trapped/scattered into the stable islands [4]. In absence of beam loss ($Q_x \sim 4.35$) an emittance growth without bunch shrinking is observed (Fig. 4a black and green curves).

OUTLOOK

In this experiment we have studied the interplay between the high intensity of a bunched beam and the presence of the 3rd order resonance. The nonlinear dynamics is in this case different from that one of the CERN-PS experiment. The octupole induced 4th order resonance is always stable, even for very weak space charge, which is not the case for a sextupole resonance for which at low intensity the three stable fixed points can be found at very large amplitudes. Nonetheless we retrieve similar features of emittance growth and beam loss in both cases. The further discussion and numerical benchmarking of this experiment is left to a dedicated future paper.



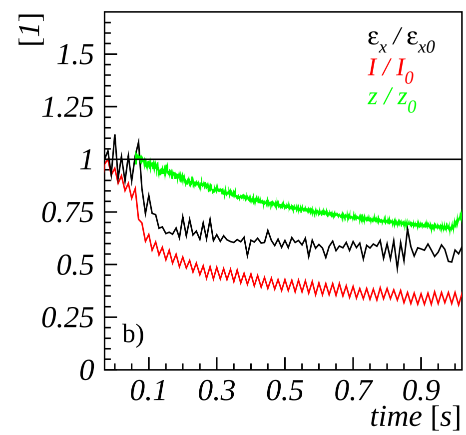


Figure 4: a) Transverse-longitudinal beam response to the long term storage as function of working points around the third order resonance; b) Time evolution of horizontal emittance, intensity, and bunch length at $Q_x = 4.34$.

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