LIFETIME STUDIES FOR POLARIZED AND UNPOLARIZED PROTONS IN COSY

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Abstract

Spin Filtering is the only experimentally demonstrated method which could lead to an intense beam of polarized antiprotons. The physics of spin filtering defines certain requirements to the storage ring, which have to be taken into account in the design of a dedicated spin filter ring. Spin filtering makes use of the repetitive interaction of circulating unpolarized particles with a polarized target in a storage cell. The polarization build up process for an antiproton beam is expected to be most effective around energies of 50 up to a few hundred MeV. The process makes use of the different scattering cross sections of particles with different polarization states, leading to different loss probabilities in the storage ring. In order to achieve a significantly high degree of polarization of the circulating ion beam with a reasonable intensity, the storage ring has to provide a long beam lifetime at a target thickness of a polarized target as high as possible. Depolarizing resonances have to be avoided to reach a long polarization lifetime.

INTRODUCTION

The PAX collaboration [1] has adopted Spin filtering of antiprotons[2] in a dedicated ring (APR) [3] as a method for the study of spin-dependent quantities in pbar-p interactions [4]. The Spin Filtering mechanism for ions was proved in 1992 at the TSR (MPI Heidelberg) with protons [5]. At COSY (FZ Juelich) we want additional measurements to fully understand the build-up process.

The spin filtering experiment requires a new low beta insertion in the COSY ring which is presently set up. The equipment will be commissioned and used at COSY to proof the ability to build up polarization in an initially unpolarized proton beam. After successful completion of this task, the future plan foresees to move the polarized target and detector to the CERN AD ring, to repeat the polarization build up with antiprotons and explore the predicted energy dependence of the polarization build up cross sections.

BEAM LIFETIME

Two kinds of particle loss mechanisms dominate the lifetime in a storage ring:

- Immediate loss of particles in a single collision
- slow blow-up of the beam emittance and subsequent loss of particles e.g. by hitting the vacuum chamber or due to resonances

The slow blow-up of beam emittance can be compensated by suitable cooling systems whereas the immediate loss of particles can not. The processes which cause immediate loss of particles are:

- Hadronic Interaction
- Single Coulomb Scattering
- Multiple Scattering
- Recombination
- Energy Loss

The optimum energy for the spin filtering process is expected to be at low beam momenta between 45 and 300 MeV/c.

Recombination losses on the residual gas discussed by Schlachter [6] can be neglected.

Multiple scattering can also be neglected, as scattered particles will be cooled back to the core of the beam.

Single Coulomb Scattering remains as the dominant loss process.

Single Coulomb Scattering Beam Lifetime

The Coulomb loss cross section $\Delta\sigma_C$ for protons is given by

$$\Delta\sigma_C = 2\pi \int_{\theta_{acc}}^{\pi} \frac{d\sigma}{d\Omega(\theta)} \sin\theta d\theta = 4\pi \frac{Z^2 r_p^2}{\beta^4 \gamma^2 \theta_{acc}^2} \tag{1}$$

with β=v/c and $\gamma=(1-\beta^2)^{-1/2}$, Z the atomic number of the target particles, r_p the classical electron radius, and θ_{acc} the acceptance angle at the target.

The local acceptance angle at any position s along the ring is given by

$$\theta_{acc} = \sqrt{\varepsilon\gamma(s)} \quad \text{with} \quad \gamma(s) = \frac{1+\alpha^2(s)}{\beta(s)} \tag{2}$$

with Twiss parameters $\alpha(s)$ and $\beta(s)$ obtained e.g. from MAD. Under the assumption that the lifetime of a stored beam is caused solely by the single Coulomb scattering losses, the lifetime τ is given by

$$\tau = \frac{1}{\Delta\sigma_C d_t f_c} \tag{3}$$

with the areal target density d_t and the revolution frequency of the beam f_C.

Beam Lifetime Measurements at COSY

During one week of beam time in November 2007 a careful study to understand the beam life time of the proton beam at COSY injection energy of 45 MeV was undertaken.

In each of the 8 COSY sections one quadrupole mass spectrometer measurement was taken to determine the partial pressure distribution of the rest gas. The contribution of the 9 most abundant gases was used together with the Twiss parameters from a MAD model of the ring to calculate the contributions to the beam life time according to eqns. (1)-(3).

Measurements of the beam life time where carried out with and without a D_2 target of density 2 10^{14} atoms/cm^2. The time behaviour of the stored beam current measured by a beam current transformer (BCT) was fit with an exponential decay function to yield the beam lifetime. The measured beam lifetimes are τ(with target) = (321.3 ± 0.4)s and τ(without target) = (4639 ± 69)s, which is about a factor 13-15 smaller than the calculated beam lifetime. More details can be found in [7,8].

Two possible explanations of the discrepancy of measurement and prediction based on single Coulomb scattering losses that where studied in a second one week beam time in September 2008 are:

- Overestimation of the local acceptance
- Insufficient beam cooling

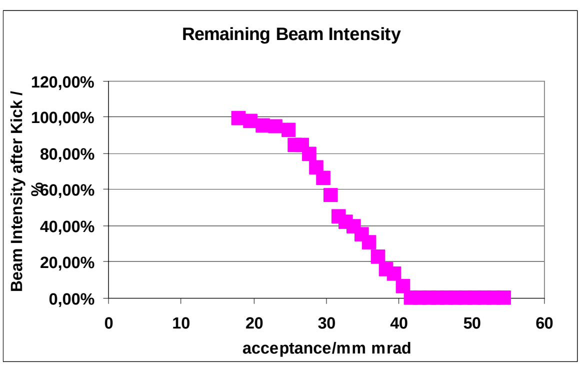

Figure 1: Acceptance measurement with fast kicker magnet. Fractional Beam Intensity versus acceptance, the acceptance is calculated from the used kick angle and the Twiss functions at the location of the kicker.

The acceptance of the COSY ring has been measured byods with and without electron cooling.

1. The measurements using a single turn angle kick of the beam using a fast kicker magnet yields approximately< 40 µm (Fig. 1).
2. Measurement of beam life time versus position of scrapers (Fig. 2) agree well with the kicker measurements in the case without electron cooling.

However, for electron cooled beam, the measured acceptance is with 14 µm much smaller. We conclude from this, that the machine acceptance was overestimated in the beam lifetime calculation, and the actual machine acceptance for a cooled beam is significantly lower.

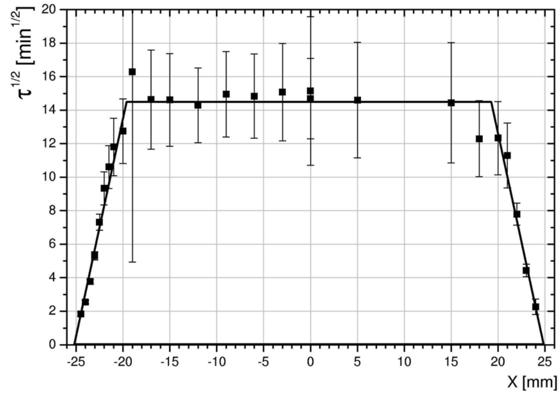

Figure 2: Acceptance measurement with Scrapers. Plotted is the inverse of the beam lifetime $\tau^{-1/2}$ versus Scraper position. The Scraper consisted of a rectangular aperture; the beam passes through its center. When the aperture is moved from the center, no change in beam lifetime is observed until the edge of the aperture reaches the beam. When the scraper is moved more, the beam lifetime gradually goes to zero; the distance determines the acceptance of the ring. To calculate the acceptance the Twiss functions at the scraper position are taken from a model (see [9]).

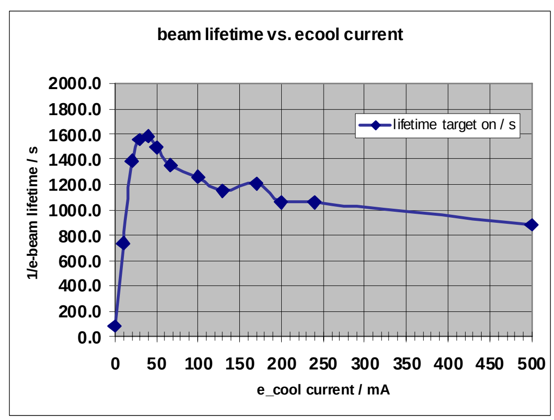

Figure 3: Beam lifetime as function of electron beam current. At low current the beam is not sufficiently cooled, therefore the beam lifetime is short. At large electron beam current the proton beam lifetime is reduced as well.

To gather more information, the dependence of the measured beam lifetime on the electron beam current was determined. For small currents, the cooling is not strong enough to compensate the energy loss and emittance growth. Therefore the beam lifetimes are short. However, for large electron currents the beam lifetime decreases, such that there is an optimum at beam currents around 40 mA (see Fig. 3).

An additional piece of information was the observation of so-called initial losses, when the electron beam was turned on to full current at the beginning of the cooling process. These initial losses can be avoided, when the electron current is slowly increased from zero to the desired maximum current as shown in Fig. 4.

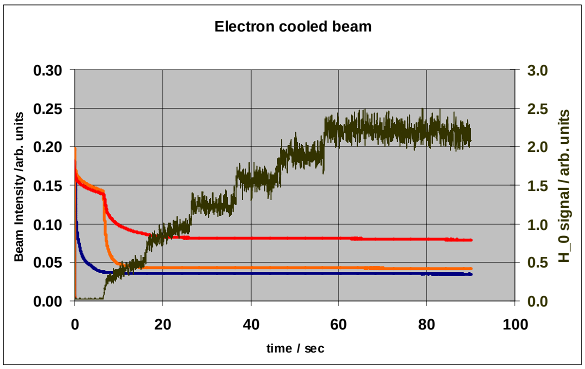

Figure 4: Investigation of initial losses. The blue trace shows the proton beam current measured by the BCT when the electron beam is at full intensity from the beginning, the orange trace when the electron beam is switched to full intensity after 10 sec, and the red trace when the electron current is gradually increased from zero to full intensity. The black trace shows the rate of H^0 from recombination in the electron cooler when the current is gradually increased (corresponding to the red trace BCT).

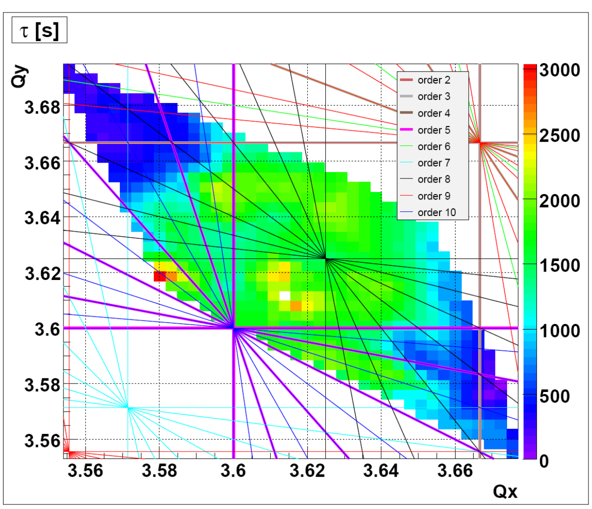

Figure 5: Beam lifetime as function of horizontal and vertical tunes Q_x and Q_y, respectively. The lines are the betatron resonances up to order 10. Longest beam lifetime is achieved at around $Q_x = Q_y = 3.61$.

The explanation for the three above observations could be the fact that the electron beam of the COSY electron cooler is with 2.5 cm diameter smaller than the uncooled proton beam (i.e. the acceptance of the ring). Therefore, for large electron beam current, beam particles circulating in the ring outside the electron beam acceptance may be lost because they encounter the non linear fields generated by the electron beam. This could cause the initial losses, as well as explain the reduction of the acceptance during electron cooling.

Betatron Resonances

During one of the discussed beam times, a scan of beam lifetime versus horizontal and vertical betatron tunes was carried out. As shown in fig. 5, the beam lifetime near betatron resonances will be reduced and a careful choice of the working point of the accelerator is of great importance. The typical working point for COSY are in the vicinity of $Q_x = Q_y = 3.62$.

CONCLUSION

Significant progress has been made by experimental investigation of the dependence of the beam life time at low energy in the COSY ring on many different parameters, such that an experiment to study the polarization build up of an initially unpolarized beam by interaction with a polarized internal target can be studied in the near future. It seems to be of great importance that the electron beam covers the full ring acceptance, to avoid a reduction of acceptance caused by circulating ions encountering the non linear fields outside the electron beam.

The working point of the accelerator has to be carefully chosen such that any depolarizing resonances are avoided, as for long storage times even higher order resonances can cause significant depolarization and reduced polarization lifetime.

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