THE CONCEPT OF ANTIPROTON ACCUMULATION IN THE RESR STORAGE RING OF THE FAIR PROJECT

M. Steck, C. Dimopoulou, O. Dolinskyy, B. Franzke, T. Katayama,
S. Litvinov, F. Nolden, C. Peschke, GSI Darmstadt, Germany,
D. Möhl, L. Thorndahl, CERN, Geneva, Switzerland

Abstract

The RESR storage ring of the FAIR project was designed for use as an accumulator ring for antiprotons. Therefore its optical design offers a large momentum acceptance and large flexibility in the choice of the working point. This is crucial, if longitudinal stacking with a stochastic cooling system is planned. The accumulation system has been studied in simulations which include both the properties of the optical design and details of the stochastic cooling system. The simulations confirm that the stochastic cooling system can support the accumulation with a repetition rate of 10 s for the injection of pre-cooled batches of 10^8 antiprotons from the collector ring CR. A maximum of intensity of 10^{11} accumulated antiprotons can be achieved as required for high luminosity experiments.

INTRODUCTION

One of the major tasks of the Facility for Antiproton and Ion Research (FAIR) [1] will be the preparation of high intensity stacks of antiprotons. The RESR storage ring of the FAIR project is mainly designed as an accumulator ring for antiprotons. In the sequence of accelerators it follows the antiproton target, the antiproton separator and the collector ring CR. The CR is a large acceptance storage ring which allows injection of the large emittance bunch of secondary particles after the production target [2]. The primary 29 GeV proton beam is compressed into a single short bunch of up to 2×10^{13} particles before it impinges on a nickel target. The magnetic separator selects negatively charged particles with a momentum corresponding to 3 GeV antiprotons and transports them to the CR. In the CR fast bunch rotation and stochastic cooling are applied. The cycle of antiproton production takes 10 s, which is determined by the time needed for pre-cooling of the antiprotons in the CR. At the end of this cycle 10^8 antiprotons with an emittance of 5 mm mrad, both horizontally and vertically, and a momentum spread of 1×10^{-3} (2σ-values) are ready for transfer from the CR to the RESR. This production cycle is repeated continuously. Thus for antiproton accumulation the RESR storage ring should be able to manipulate the incoming beam such that a large stack of up to 10^{11} antiprotons can be built up efficiently.

From the RESR the antiprotons can be transferred to two different users. The High Energy Storage Ring (HESR) allows the acceleration or deceleration of the antiprotons to energies in the range 0.8 to 14.1 GeV for experiments with an internal target [3]. The second branch after the RESR uses the New Experimental Storage Ring (NESR) as a decelerator to reduce the antiproton energy from 3 GeV to a variable end energy with a minimum energy of 30 MeV [4].

After first considerations to use a barrier bucket system for the accumulation of antiprotons, it was decided to base the accumulation on a longitudinal accumulation system similar to the ones which were used at the CERN AA [5] and the FNAL Accumulator Ring [6]. The main reason was the sensitivity of the method to imperfections, e.g. wrong kicker timing, and expected problems with the stochastic cooling system at higher antiproton intensities due to insufficient separation of injected beam and stack and feedback from the intense stack to the injected beam.

RESR OPTICAL LATTICE

For the proposed accumulation system in the RESR various requirements are imposed on the optical lattice of the storage ring. The accumulation in longitudinal phase space requires a momentum acceptance of $\Delta p/p = \pm 1$ % and a special focussing structure [7]. Injection from the CR is performed from the inside of the ring at an orbit with about $\Delta p/p = -0.8$ % offset with respect to the central orbit. The dense core of the stack is accumulated at an offset $\Delta p/p = +0.8$ %. The accumulation is based on the acceleration of the antiprotons from the injection to the core orbit. Part of the acceleration is performed with an ordinary rf system, whereas the final part and the formation of a dense core is based on stochastic cooling.

The injection of the antiprotons requires a partial aperture kicker located in a dispersive section of the storage ring which allows transfer of the particles from the injection to the core orbit. The vertical beta function at the location of the stochastic cooling pick-ups and kickers should be small in order to have a good localization of the electric field and a small extension of the fringe fields in radial direction. The selectivity of the electrodes to the different components of the accumulated beam increases with the value of the dispersion at the location of the electrodes. Consequently a dispersion as large as possible at the stochastic cooling electrodes is favorable. The stochastic cooling performance is very sensitive to the momentum slip factor $\eta = 1/\gamma^2 - 1/\gamma_t^2$ which is determined by the transition energy γ_t of the storage ring.

The lattice design of the RESR was guided by these requirements and provides a large flexibility in the tuning of the focusing structure. The transition energy can be adjusted in the range $3.0 \leq \gamma_t \leq 6.4$ without significantly affecting the beta function along the circumference (Fig. 1). Thus the momentum slip factor can be optimized according to the requirements of the stochastic cooling system.

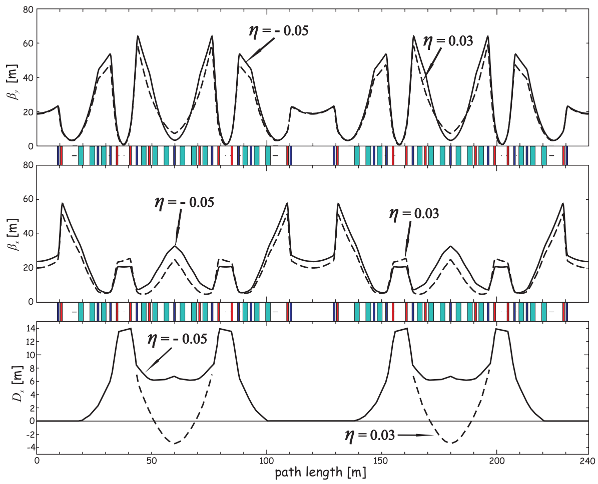

Figure 1: Optical beta functions and dispersion along the ring circumference for two values of the momentum slip factor $\eta = 0.03$, -0.05 corresponding to $\gamma_t = 3.0$, 6.4. The longitudinal stochastic cooling pick-up will be installed in the arc at the position of maximum dispersion, all other stochastic cooling electrodes in the long straight sections.

ACCUMULATION SYSTEM DESIGN

The flexibility of the optical lattice is crucial for the optimization of the stochastic accumulation system. For beam dynamics simulations two codes were employed in this optimization process, the code developed at CERN for antiproton accumulation with some modifications for the application to the RESR and a newly developed Fokker-Planck code. The goal was to establish a basic set of parameters of the stochastic accumulation system. The use of two independent simulation tools allows a cross-check of the results.

The structure of the electrode system which was the result of the optimization procedure is shown in Fig. 2. The various electrodes are positioned at different radial positions. They are not necessarily located at the same azimuthal position along the ring, but can occupy different positions, if the beta functions and dispersion have appropriate values at the location of the electrodes. The purpose of the various electrodes is the following. The antiprotons injected at an inner orbit ($\Delta p/p = -0.8$ %) and then adiabatically captured by the rf system will be accelerated to the deposit orbit ($\Delta p/p = 0.0$ %). Two sets of so-called tail electrodes push the particles to an outer orbit. The purpose of the two tail electrodes, which for simplicity are of identical geometry, is the shaping of an exponential gain profile decreasing towards the core orbit where the particles are collected in the stack. Two core electrodes which are at the inner and outer side of the stack continuously stabilize the dense high intensity core. The size of the core electrodes which is half the size of deposit and tail electrodes reflects the fact that the core system operates in the band 2-4 GHz, whereas the tail cooling systems are designed for the frequency band 1-2 GHz. The vertical gap of the electrodes of 20 mm is matched to the emittance of the incoming beam and the vertical beta function at the electrode location which is smaller than 4 m.

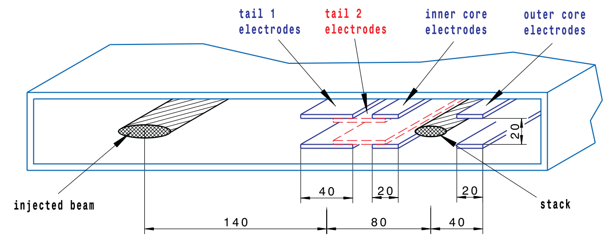

Figure 2: The radial positions of the electrodes (dimensions are in mm) of the stochastic accumulation system are matched to the local dispersion D=13 m. The tail 2 electrodes can be installed at an azimuthal location which is different from the tail 1 electrodes.

For the parameters given in Table 1, loop couplers were assumed, although it seems more favorable to use Faltin type structures. It is straightforward to take different electrode types into account by calculating the equivalent impedance of the structure. The Faltin structure turned out to be about 1.25 times shorter than the equivalent array of loops. Further details which enter into the simulations are the thermal noise of the pick-up and pre-amplifier system and special rf signal processing. Other features of the cooling circuit are a variable signal delay after the pick-up and the use of special filters to shape the input signal of the power amplifiers. Different filters were tried in the simulations, the most promising is a double notch filter system with two notch filters in series. The central frequencies of the two filters can be designed with a small offset, resulting in a broader notch. Finally the power of the main amplifier was considered and optimized. The amplification was adjusted in each of the different cooling circuits (tail 1, tail 2, core) individually.

RESULTS OF SIMULATIONS

The simulations of the accumulation process by the stochastic cooling system take many details of the ring and the cooling system into account. The basic parameters of the cooling system are listed in Table 1.

The required microwave power depends on many details of the cooling system, therefore the value can vary. The main power goes into the tail 1 cooling system which has to force the particles rapidly to an outer orbit to provide empty space before the next batch arrives on the inner orbit and is accelerated to the deposit orbit. The power for the tail 2 cooling system is at least two orders of magnitude smaller, therefore this power is not a major issue in the system cost. The same is true for the core cooling sys-

Table 1: Parameters of the different subsystems of the RESR accumulation system

cooling circuit	tail 1	tail 2	core
frequency band (GHz)	1-2	1-2	2-4
number of pick-ups	64	25(64)	64
active pick-up length (m)	1.45	0.58	0.73
pick-up impedance (Ω)	25	25	25
number of kickers	16	16	16
kicker impedance (Ω)	100	100	100
active kicker length (m)	1.16	1.16	0.58
gain (dB)	130-140	84-106	90
total power (W)	100-1000	0.06-1.2	0.2

tem which also requires only moderate power in the band 2-4 GHz. Some flexibility in the power will be needed for experimental adjustments of the parameters for accumulation. Usually the installed microwave power is a factor of 3-5 higher than the power required for operation. This power reserve guarantees linear behavior of the amplifiers. During accumulation an increasing number of particles is cooled to the core region which has a momentum spread of $\delta p/p = \pm 2.5 \times 10^{-4}$. After one hour of accumulation (corresponding to 360 injections) more than 80 % of the accumulated antiprotons are cooled into this momentum window. The result of the simulation for the set of standard parameters is shown in Fig. 3, which represents the calculated distribution of antiprotons after different number of injection cycles.

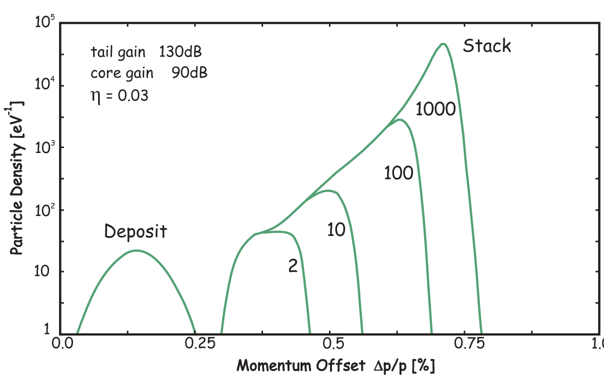

Figure 3: Longitudinal distribution after various numbers of injections of pre-cooled antiprotons at 3 GeV from the CR with a repetition period of 10 s.

Beyond the standard case, variations of the parameters were studied in order to investigate the sensitivity of the accumulation process to various parameters, such as beam parameters, cycle time, optical setting of the ring, cooling system parameters, maximum particle number in the RESR. The flexibility in the choice of the transition energy is expected to be a valuable tool for the final optimization of the accumulation process. The accumulation system should be able to cope with an increase of the repetition rate of injections by a factor of two (reduced cycle time of 5 s). The cooling system will be adjusted to the faster cycle by increase of the gain (amplifier power) and re-tuning of the filters. If pulses with higher antiproton numbers are injected from the collector ring CR, the accumulation system will be able to accumulate the higher intensity with a correspondingly higher rate. The simulations showed that this can be achieved by higher amplifier power in the tail cooling circuits which is needed due to the increased Schottky noise power of the beam. According to the simulations, the RESR accumulation system will be able to accumulate up to 3×10^{11} antiprotons, if higher amplifier power is installed. The higher stack intensity, however, brings the beam closer to the stability threshold and beam feedback will be of increasing importance.

The accumulation process turned out to be insensitive to the variations, smaller readjustments of the cooling system should allow the achievement of comparable performance for deviations from the standard parameters. As an option, it was studied to increase the vertical gap between the electrodes from 20 to 30 mm. In case of an acceptance limitation in the electrodes the gap increase is feasible, although the efficiency of accumulation is slightly deteriorated.

Intrabeam scattering effects were included in the simulations, but with the present beam parameters from the CR intrabeam scattering is almost negligible, its effect on the stack can be compensated by the core cooling system. Even if the intrabeam scattering rate is higher than presently calculated, a core cooling power of 1 W should be sufficient to compensate intrabeam scattering.

The design beam quality after pre-cooling in the CR seems sufficient for accumulation in the RESR. Smaller momentum spread will be advantageous, either to speed up accumulation or to reduce the required power for the tail cooling systems. Smaller emittances will help to inject without losses and allow electrodes which can be located closer to the beam, which again will speed up accumulation and/or save microwave power. Therefore potential improvements of the pre-cooled antiproton beam quality from CR will be investigated.

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