LAYOUT OF AN ACCUMULATOR AND DECELERATOR RING FOR FAIR

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Abstract

The main task of the RESR storage ring of the FAIR project is the accumulation of high intensity antiproton stacks. They are injected at 3 GeV after pre-cooling in the CR storage ring. The accumulation scheme is longitudinal momentum stacking with a stochastic cooling system. The requirements of the stochastic cooling system entered into the ion optical properties of the RESR lattice. The RESR can also be used for fast deceleration of rare isotope beams, which are produced with an energy of 740 MeV/u. This allows transfer of the rare isotopes at the energy required for experiments.

OVERVIEW

A new storage ring has been added to the FAIR project [1]. Its name RESR refers to the recycling of many components of the existing storage ring ESR at GSI [2]. The main task of the RESR in the complex operation of the FAIR facility is the accumulation of high intensity beams of antiprotons. An additional mode of operation is the fast deceleration of rare isotope beams.

The antiprotons with an energy of 3 GeV will be continuously accumulated by injection of a pre-cooled bunch of up to 1×10^8 antiprotons from the CR every 10 s. A dedicated stochastic cooling system cools the incoming beam and transfers it to the stack position at a higher momentum. A high intensity stack of up to 1×10^{11} antiprotons is built up. Depending on requirements this stack will be transfered to the HESR storage ring [3], which is the main user of antiprotons. For transfer the beam must be returned to the injection orbit. It is also foreseen to separate a fraction of the entire stack for transfer. This fraction can be used as a pilot pulse for the preparation of the transfer of the intense stack or it can be provided to the NESR storage ring [5], where the antiprotons are decelerated and delivered to a low energy experimental area. The two extraction points, towards the HESR and towards the NESR, are located in two opposite straight sections.

For rare isotope beams, the RESR will be operated as a decelerator if the ions are needed at energies lower than the standard injection energy of 740 MeV/u after pre-cooling in the CR. The main application is operation of the NESR in the collider mode with electrons [6], which requires very stable conditions for the ion beam stored in the NESR. The RESR can be ramped with a maximum ramp rate of 1 T/s from the injection energy 740 MeV/u to a minimum energy of 100 MeV/u.

An additional future option is the deceleration of antiprotons for an experiment requiring NESR operation as a collider for rare isotopes and antiprotons. The antiprotons can be stored at a maximum energy of 125 MeV in the electron ring. Therefore the RESR has to decelerate the antiprotons below 125 MeV. This deceleration mode should be supported by intermediate electron cooling. The existing ESR electron cooler could, after installation in the RESR, provide electrons of up to about 250 keV for cooling of decelerated antiprotons. The injection energy of the antiprotons should be lowered below the transition energy $\gamma_t = 3.62$ of the RESR in order to avoid crossing of the transition energy during deceleration.

GENERAL LAYOUT

The RESR is a racetrack-shaped storage ring with a circumference of 245.5 m and a magnetic bending power of 13 Tm. It shares a common building with the CR (Fig. 1).

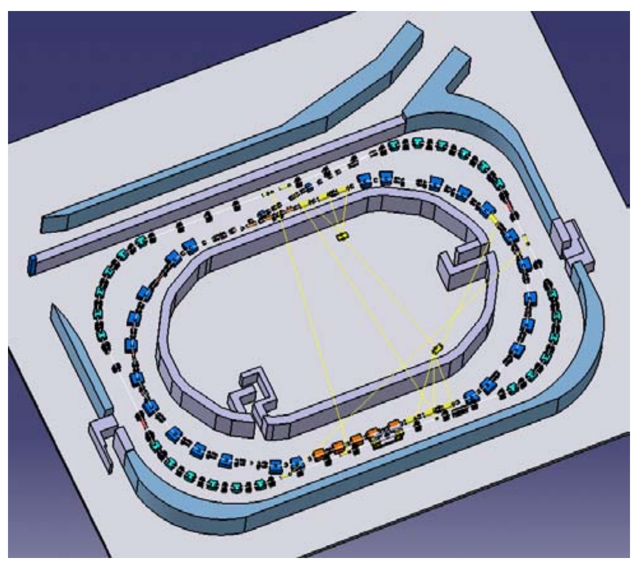

Figure 1: Location of the RESR surrounding the CR storage ring in a common hall. The RESR beam axis is 1.2 m above the CR beam axis.

The lattice and the beam optics are mirror-symmetric (Fig.2). The lattice consists of 24 dipole magnets and 44 quadrupole magnets. In order to minimize the design effort, the same dipoles as in the NESR are used. A further cost reduction is achieved by reusing some components of the ESR storage ring, amongst them quadrupole magnets and some beam diagnostic elements.

The RESR lattice design is mainly determined by the requirements of the stochastic cooling system. A momentum stacking scheme is foreseen for accumulation of antiprotons.

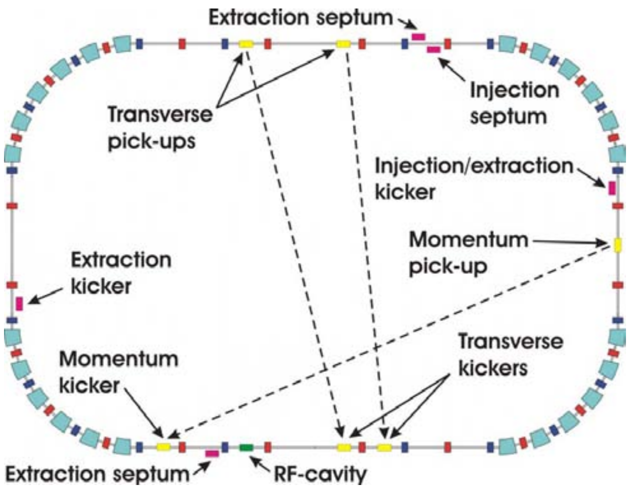

Figure 2: Sketch of the RESR lattice layout.

BEAM OPTICS CONSIDERATIONS

The lattice has to fulfill the requirements of the stochastic cooling system with respect to the choice of (i) the transition energy γ_t in order to achieve a sufficient amount of desired mixing between kicker and pick-up without having too much undesired mixing between pick-up and kicker (ii) the betatron phase advance between pick-up and kicker of the transverse cooling system and (iii) in particular, a sufficiently large dispersion and small vertical beta function at the momentum pick-up of the longitudinal accumulation system (see below). The momentum kickers are placed at locations of zero dispersion. With $\gamma_t = 3.62$, the ring is operated above transition in case of the 3 GeV antiproton beam ($\gamma = 4.20$), yielding a frequency slip factor $\eta = \gamma^{-2} - \gamma_t^{-2} = -0.020$.

The deceleration of RI beams makes use of the same optical layout. For RI beams the ring is operated well below transition.

Chromaticity correction is achieved by two groups of four sextupole magnets installed in the dispersive arcs of the RESR. Calculations using the MAD8 and SIXTRACK codes under reasonable assumptions about field errors indicate that the dynamic aperture of the RESR beam optics is larger than the geometric acceptance for all momenta needed.

16 horizontal correctors and 8 vertical correctors are used for beam orbit correction.

Figure 3 shows the beam envelopes inside the RESR.

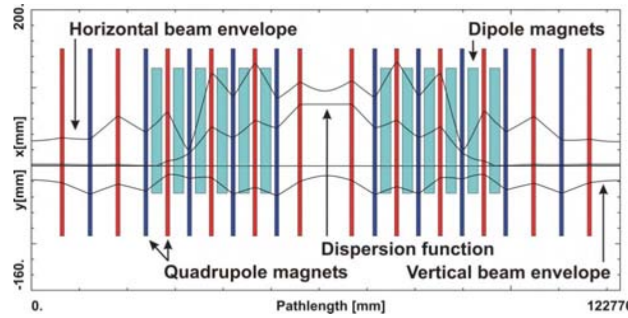

Figure 3: Beam envelopes in the RESR calculated with the MIRKO code.

INJECTION AND EXTRACTION SCHEME

Since all beams come from the CR, the injection septum is placed on the inner side of the RESR ring. The injection and extraction of beams at the RESR is considerably relieved by the availability of cooling. The transverse emittance of the injected pre-cooled beams is below 5 mm mrad. Therefore half aperture kickers with a gap of 60×50 mm^2 are sufficient.

Antiprotons are injected to an inner orbit with a momentum deviation of $\Delta p/p = -0.8$ % with respect to the central orbit in order to facilitate longitudinal stacking. The momentum stacking scheme requires a kicker at a dispersive location. Before extraction the beam is decelerated from the stack back to the extraction orbit where the kickers can deflect it into the extraction channel.

The requirements on the rise and fall times of the kickers of 150 ns are moderate as the full circumference is available for injection. The use of a barrier bucket system for antiproton accumulation has been investigated [7]. Although the creation of a gap in the stacked beam and the injection of new beam into it seems feasible, this scheme is even more demanding for the stochastic cooling system. The separation of stack and new beam has to be large enough to suppress coupling of the stack to the new beam which causes a reduction of cooling efficiency.

Two extraction systems are needed to deliver beams to the HESR and the NESR. Extraction towards the HESR uses the same kicker as the injection system. The extraction kicker for the NESR is located on the opposite side with respect to the injection kicker.

STOCHASTIC ACCUMULATION

A preliminary layout of the stochastic cooling system has been worked out assuming an incoming batch of 10^8 antiprotons and an accumulation of up to $2 \cdot 10^{11}$ particles. It works with a 1-2 GHz system bandwidth.

The stochastic accumulation process takes place essentially in longitudinal phase space. Its most demanding component is the pick-up at a location with a dispersion function of 8 m (Fig. 4). The process works essentially as follows: The pre-cooled antiprotons from the CR are injected to an inner orbit where they are captured in a matched rf bucket. Then the rf system shifts them to a handover orbit and debunches them adiabatically. The beam produces a signal in a so-called tail pick-up which is strongly amplified. The stochastic system moves the fresh particles as fast as possible to a tail orbit. After that, the handover orbit is free from particles and can be used for the next injection. Then, the stochastic cooling system cools the beam and shifts it from the tail orbit to the final stack core orbit at higher momentum. In order to achieve that efficiently, the gain curve from the tail orbit to the final stack core orbit should be exponentially *decreasing*, such that gradually an exponentially *increasing* distribution function builds up with its maximum at the core [8]. The requirement for a decreasing gain characteristics of the tail cooling subsystem is demanding and is not fulfilled until several different measures cooperate:

- large dispersion at the pick-up.
- small height of the vacuum chamber compared to the distance between tail and core in the pick-up.
- additional cascaded notch filters in the tail cooling signal path.

At the core orbit, a core cooling system with much lower gain than the tail system takes over, keeping the core together.

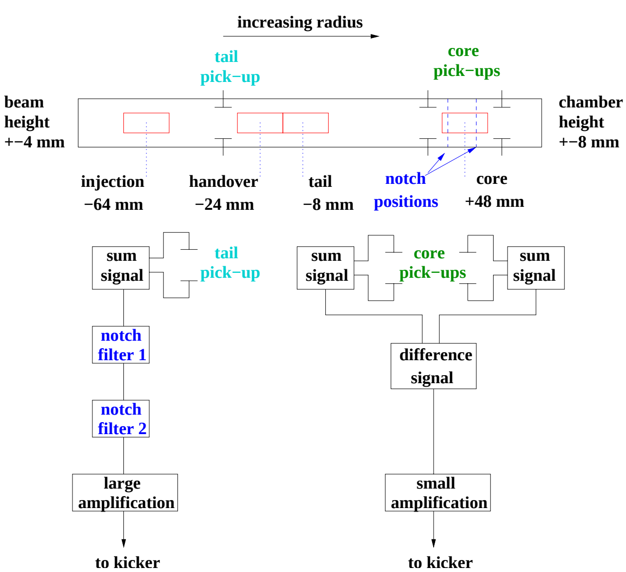

Figure 4: Sketch of pick-up chamber and signal processing. The dispersion at the pick-up is 8 m.

A similar system was applied in the former AA ring at CERN. The details of the system parameters (geometry of pick-ups, ratio of tail and core amplification, position of notches etc.) are determined by a sophisticated optimization process using cooling simulation programs. One has to guarantee that the handover orbit gets free for the next shot without disturbing the core. A dedicated simulation program for the RESR is in preparation.

In addition to the momentum cooling system, there are two transverse core cooling systems. A transverse cooling system for the injected particles is left as an optional future extension.

OTHER SUBSYSTEMS

For the debunching of injected beams and for the deceleration of rare isotope beams an rf system operating at the first harmonic will be used. The necessary frequency range from 0.51 to 1.19 MHz can be covered by a slightly modified SIS rf system. In the course of modifications for FAIR this system will be available for the RESR. The voltage of 16 kV which is needed during deceleration can be generated with this system.

For cooling of antiprotons at an intermediate energy of about 400 MeV, the electron cooling system of the existing ESR storage ring could be integrated. The long straight sections of the RESR offer sufficient space for the electron cooling device and additional magnetic correction elements. The ESR electron cooling system is able to accelerate electrons up to a maximum energy of 250 keV and can be reliably operated with an electron current of 1 A. These parameters should be adequate for intermediate antiproton cooling.

To reach the required beam lifetimes in the RESR, the vacuum pressure must stay below $1 \cdot 10^{-10}$ mbar. A moderate bakeout with temperatures up to 200^0 C is foreseen.

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