PRELIMINARY DESIGN OF A HIGHLY-FLEXIBLE EXTRACTION SCHEME FOR THE USR

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Abstract

In the future Facility for Low-energy Antiproton and Ion Research (FLAIR) at GSI, the Ultra-low energy electrostatic Storage Ring (USR) will provide cooled beams of antiprotons and possibly also highly charged ions down to energies of only 20 keV/q. Beams with small momentum spread and low emittance will enable a wide range of hitherto impossible experiments. The large variety of planned experiments requires a highly flexible longitudinal time structure of the extracted bunches, ranging from ultra-short pulses in the nanosecond regime to quasi DC beams. In this contribution, a preliminary design of the extraction scheme is presented, including results from beam transport calculations.

MOTIVATION

The next-generation antiproton facility at GSI, the Facility for Antiproton and Ion Research (FAIR), will not only provide future users with high fluxes of antiprotons in the high energy range, but it is also intended to include a dedicated program for low energy antiproton research in the keV regime, realised with the FLAIR project [1]. Within the planned accelerator complex the deceleration of antiprotons with an initial energy of 30 MeV down to ultra low energies of 20 keV will be realised in two steps. First, the beam is cooled and slowed down to an energy of 300 keV in a conventional magnetic ring, the Low energy Storage Ring (LSR) before being transferred into the USR. In this synchrotron the deceleration to a final energy of 20 keV will be realised. In the energy range of a few tens of keV the use of electrostatic elements has the significant advantage that, as compared to their magnetic counterparts, a high field homogeneity in combination with a fast ramping of the fields over a wide range is possible. In addition, remanence and hysteresis effects do not occour in electrostatic elements.
As the ring aims to be a multi-user facility, a high luminosity, low emittance and low momentum spread of the beam together with various beam shapes are required. External experiments for precision studies, like e.g. trap experiments, will form an integral part of FLAIR and the USR will provide fast as well as slow extraction, for the first time in an electrostatic storage ring.

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USR LATTICE

The USR shall provide an efficient cooling, storage and deceleration of high intensity antiproton beams, while keeping the (basic) lattice as simple as possible. At the same time the lattice should allow a flexible operation which includes the following different operation modes:
While internal experiments ask for short bunches down to the ns-range [2], external setups have to be served with extracted beams of variable pulse structure. Furthermore, basic ring operation schemes for efficient electron cooling and beam deceleration have to be provided for.
The basic outline of the USR allowing for the above mentioned options, is shown schematically in figure 1. Similar to the initial layout of the USR [3], the lattice is designed as a square with four straight sections, each 4 m long, which are reserved for extraction, beam cooling and the experiments, as well as four bending sections, each deflecting the beam a total of 90^o.
The ring has a super periodicity of four, resulting in identical lattice functions for each quarter of the ring. Each cell itself is formed by two half straight sections with a bending section centred in between.
To keep an ion beam on a circular orbit, the lattice of each cell is formed by electrostatic cylinder deflectors, ar-

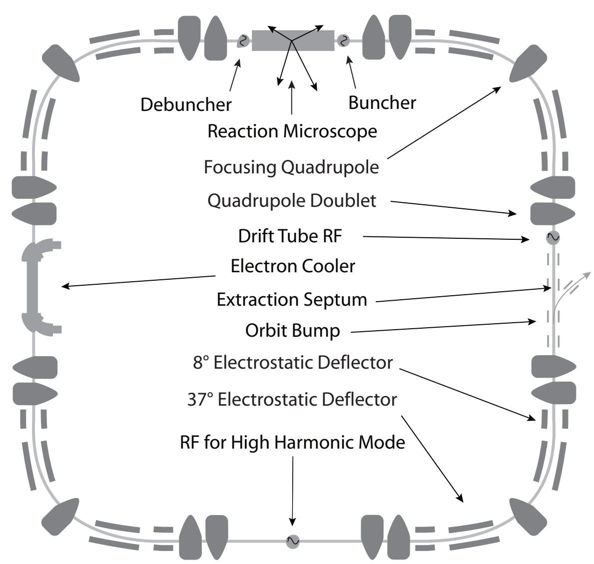

Figure 1: Preliminary layout of the ultra-low energy storage ring.

ranged in an achromat-type lattice. To control the transverse dimensions of the beam, a quadrupole doublet is implemented in front of and after each bending section. The central focusing quadrupole is used for reducing the dispersion in the insertions, which is necessary for specific operations (e.g. short pulse operation).

As can be seen in the above figure, the cylinder deflectors are split further into an 8^o and a 37^o bend. The reason for this step is twofold:

- Splitting of the deflector allows the injection of the beam along one of the 8^o elements, avoiding the installation of a further dedicated injection section.
- Neutral particles emerging from experiments in the straight section (e.g. neutral antihydrogen formed by an overlaid positron beam) will leave the central orbit in the bend, allowing their detection outside of the ring.

Two of the four straight sections are reserved for internal experiments like a reaction microscope or a positron ring, while in the third section an electron cooler for reduction of the momentum spread of the beam will be placed. The last straight section will house the extraction elements as well as the RF for beam deceleration. The linear lattice func-

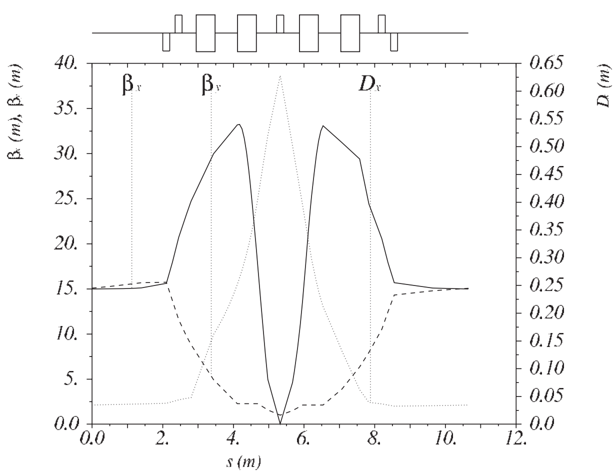

Figure 2: Linear lattice functions for one possible operation mode of the ultra-low energy storage ring. All functions are shown for a quarter section of the ring.

tions for one possible operation mode, providing a round beam for experiments, are shown in figure 2.

Due to the achromat-type lattice a dispersion close to zero can be obtained in the straight sections and a maximum value of $D_x \leq 0.7$ m is reached in the central focusing quadrupole. In this operation mode a circular shaped beam is achieved in the insertions, favourable for beam experiments and electron cooling. Apart from the example shown above, an operational mode with zero dispersion in the straight sections, as required for the "short-bunch" mode, was analysed. In the following table 1, the basic parameters of the USR for "round-beam" operation are listed.

Table 1: Basic machine parameters of the USR, if used for antiproton storage.

General parameters	
Energy range	(300 - 20) keV
Circumference	42.6 m
Base pressure	$\leq 10^{-11}$ mbar
8^o Deflector	
Height	240 mm
Radii	1940 mm and 2060 mm
Voltage |U|	≤20 kV
37^o Deflector	
Height	120 mm
Radii	970 mm and 1030 mm
Voltage |U|	≤20 kV
Quadrupoles	
Length	200 mm
Aperture radius	50 mm
Voltage	±10 kV
Machine parameters	
Q_x	2.609
Q_y	0.934
ξ_x	-7
ξ_y	-1.5

PRELIMINARY DESIGN OF THE BEAM EXTRACTION

To fulfil its role as a multi-purpose experimental facility, the design of the USR has not only to cover in-ring experiments, but also needs to include a highly flexible beam extraction. To provide experiments requiring single short pulses of antiprotons per deceleration cycle (e.g. for filling a trap), fast extraction will be available. To provide beam for nuclear/particle physics type of experiments, a slow extraction scheme will be used. The USR is the first electrostatic storage ring that will feature slow extraction.

For the simplification of the design and the future operation of the synchrotron, the same extraction septa and therefore same extraction channel will be used for both extraction modes. The extraction is installed in one of the straight sections, next to the RF for beam deceleration (see figure 1). An overview of the extraction region is shown in figure 3.

A local orbit bump will be created in the extraction region by four kicker electrodes with the extraction septum centred in the middle of the bump. Thereby the beam will be moved closer towards the septum, reducing the necessary voltages on the extraction elements. Particles diverted into the extraction septum will experience a deflection by 6^o towards the outside of the ring, followed shortly afterwards by a 30^o kick in the first deflecting element of the extraction

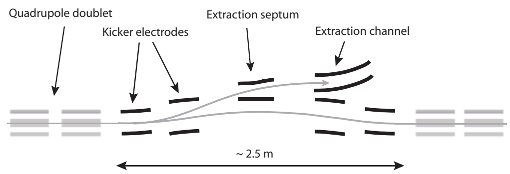

Figure 3: Schematic drawing of the USR extraction section.

channel. The extraction septum itself is bend to reduce the effect of field gradients (e.g. fringe fields) on the extracted beam motion.

Fast extraction

In the beginning of the fast extraction, the beam will be moved slowly towards the extraction septum by the local orbit bump. Then an additional ”kicking voltage”, provided on the second kicker of the orbit bump, moves the whole beam in one turn over the septum wall into the extraction septum.

A simulation of such a fast extraction process, using the tracking code SIMION [4], is shown in figure 4.

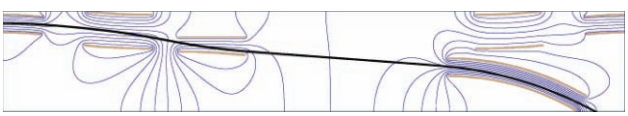

Figure 4: Simulation of the fast extraction process of a proton beam from the USR. For details see text.

For this simulation a proton beam with an energy of 20 keV and with 6 mm diameter was assumed. The electrodes and the potential distribution are drawn shaded, while the proton beam is shown as a solid black line.

All particles are guided into the extraction septum by the first two kicking electrodes of the orbit bump, where a further diversion takes place towards the 30^o deflector. All necessary field strengths are below 1 kV, allowing the use of standard power supplies, as could be shown in this simulation.

Slow extraction

For the slow extraction of particles from the USR, a resonant extraction scheme using a third order resonance was designed. Compared to the resonant extraction scheme using the half-integer resonance, the third-integer resonance allows more controllable spills.

To drive the third order resonance two appropriately placed sextupoles, e.g. with the adequate phase advance but with different polarity, will be installed. This not only allows to control the area but also the phase space orientation of the separatrix, providing a greater degree of freedom during the extraction process. The positioning of the sextupoles inside the lattice must be carefully chosen in a dispersion free section, to avoid an influence on the natural chromaticity of the lattice.

Similar to the fast extraction, the beam can be moved closer to the extraction septum by the local orbit bump, which ensures that the septum is the horizontal aperture limitation in the machine during the extraction process and that the minimum necessary sextupole strengths can be used. As soon as the resonance-driving sextupoles are powered, the stable phase-space area is distorted, creating the separatrix arms on which the particles will eventually move towards the vacuum chamber.

For the start of the actual extraction process, RF-noise will be applied onto the beam, amplifying the betatron amplitudes [5] and moving the particles from the stable phase-space area onto the separatrix arms, allowing them to jump into the extraction septum. The advantage of this method is the precise control of the spill structure as well as the possibility to keep the lattice elements at their initial settings.

CONCLUSION

In this contribution the new lattice configuration of the USR was presented, as well as a preliminary design of the extraction region. The layout of the extraction scheme and the corresponding parameters of the extraction elements seem promising, but further simulations as well as tracking of particles through this lattice are required and will be performed in near future.

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