Preliminary design studies of an extraction of the USR

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Abstract The next-generation Facility for Low energy Antiproton and Ion Research (FLAIR) at GSI is going to be a dedicated research facility for ion research in the keV range. These ion beams will allow to explore fundamental properties in matter-antimatter research at ultra-low energies of only 20 keV/q in hitherto impossible experiments. To provide these very low energy beams, the Ultra-low energy Storage Ring (USR), an electrostatic synchrotron, will play a major role within the FLAIR complex. It combines the electrostatic storage mode with deceleration from an initial energy of 300 keV/q down to 20 keV/q—as well as an efficient beam cooling. To fulfill its role as a multi-purpose experimental facility, the design of the USR has not only to cover in-ring experiments, but needs to include a highly flexible beam extraction for serving different external experiments as well.

Keywords Electrostatic · Storage ring · Extraction

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1 Introduction

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 will include a dedicated research program with low energy antiprotons in the keV regime, realized with the FLAIR project [1]. Within this planned accelerator complex the deceleration of antiprotons, arriving from the NESR storage ring housed in the FAIR facility with an initial energy of 30 MeV down to ultralow energies of 20 keV will be realized in two steps. First, the beam is decelerated to an energy of 300 keV in a conventional magnetic ring, the Low energy Storage Ring (LSR), and cooled, before being transferred to the USR, an electrostatic synchrotron [2]. In this circular machine the deceleration to a final energy of 20 keV will be realized.

As the ring aims to be a multi-user facility by itself, a high luminosity, low emittance and low momentum spread of the beam together with variable beam shapes are required [3]. External experiments for precision studies, like e.g. trap experiments, will form an integral part of FLAIR and the USR needs to provide fast as well as slow extraction, for the first time in an electrostatic storage ring [4]. A more detailed description of the ring is given in [5].

2 Preliminary design of a highly flexible extraction scheme

2.1 The fast extraction scheme of the USR

In the fast extraction process, all stored particles are moved in a single turn over the septum wall into the extraction channel. To initiate such a process in the USR, the beam will be moved by a local orbit bump slowly towards the extraction septum, located in one of the straight sections. To allow for the highest flexibility during this process, this bump will be created by four dedicated electrostatic deflectors. This controls not only the bump height, but at the same time, in contrast to a three-kicker bump, creates a parallel beam in the center between the electrodes. Due to the closed orbit bump, the necessary “kick-out” field strengths—used for the actual extraction process—can be reduced.

As soon as the beam moves along the bump, an additional kicking voltage is applied to one of the bump electrodes. This effectively pushes the beam over the septum wall into the extraction channel. A simulation of such a fast extraction process was performed, using the tracking code SIMION [6]. For a 20 keV (anti)proton beam the required electrode potentials are below ± 800 V, which can be easily realized.

2.2 Operation scheme for slow extraction

In case an external experiment requires a continuous beam of antiprotons, e.g. for measurements of $\frac{dE}{dx}$ and ionization measurements with slow antiprotons or x-ray spectroscopy of $\bar{p}$ —light nuclei, as measured at LEAR or the AD [7, 8], the only option is the use of slow extraction from the storage ring.

The principle behind slow resonant extraction is the use of controlled transverse resonances in the synchrotron for beam extraction [9, 10]. One additional advantage

Fig. 1 Phase-space distribution at the position of the electrostatic septum (*top*) and a schematic depiction of the RF-knock-out extraction method (*bottom*)

of such a stochastic feeding is that the extracted momentum bite is not only stable but also narrower than in the internal circulating beam. This particular extraction mode is normally realized by the application of a so-called third-order resonance. Thereby the betatron tune in the extraction plane has to be close to the resonance condition, for the case of the said resonance: $3 \cdot Q = \text{integer}$.

Before starting the extraction process, the circulating beam inside the USR has to be set-up with respect to the resonance. The horizontal tune is moved close to the $3 \cdot Q = 8$ resonance by varying the strength of all quadrupoles around the machine. At the same time the field of the dedicated electrostatic sextupole is raised to its nominal strength S in a quasi-adiabatic way. This leads to a distortion of the elliptical trajectories (in un-normalized phase-space) and the available phase-space is split into stable and unstable regions by the separatrices that define the stable triangle.

In this process a particle will move on a stable orbit, if its emittance is smaller than or equal to the area of the stability triangle. Otherwise the particle is forced onto one of the separatrix arms (see Fig. 1 as an example), where it spirals outwards, returning to the initial arm at a position further away from the beam center every three turns. The step-size increases non-linearly and is dependent on the sextupole strength S .

It can be assumed that the particles move on a stable orbit after the machine has been set to extraction conditions. Therefore the particles have to be moved from the inner, stable area of the triangle onto the separatrix arms during the course of the extraction. For this step several different mechanisms are currently operational in different synchrotrons worldwide. For the slow extraction from the USR, a stochastic

extraction scheme, using some transversal RF noise will be applied. In this scheme, the oscillation amplitudes of the particles are increased, moving the individual tune of the particles into the unstable resonance [11]. The advantage of this method is not only the possibility to exactly control the spill period, but more importantly, the overall setting of the lattice can be kept constant during the whole spill time, as shown schematically in the Steinbach diagram for this process, depicted in Fig. 1.

Tracking simulations of such a $3\text{-}Q = 8$ resonant extraction in the USR using the thin-lens tracking option in the numerical simulation code MAD-X [12] were performed, leading to the geometry and the settings of the extraction process. The phase space plot of the beam resulting from these investigations is depicted in Fig. 1.

2.2.1 Electrostatic sextupole design

The slow extraction process requires a dedicated electrostatic sextupole to cause the phase-space distortion. Thus, first real-field simulations for a possible sextupole design were performed. A model of a sextupole, including the hyperbolic electrode shape necessary for a homogeneous field distribution, was implemented into TOSCA-3D [13]. This model is presently used to optimize the overall geometry for an effective minimization of the fringe fields. We are aiming at finalizing the design of the whole extraction region until the end of 2009 and to have a prototype installation setup until mid 2010.

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