Cooling Rates of the USR as Calculated with BETACOOL

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Abstract. The ultra-low energy storage ring (USR) will be a multi-purpose facility providing electron-cooled antiprotons in the energy range between 20 keV and 300 keV for both in-ring experiments and effective injection into traps. The low beam energies and high beam quality to be provided by this accelerator will enable new studies of antimatter/matter interactions using in-ring experiments with an internal gas jet target as well as particle traps, which can be efficiently filled using the decelerated and cooled antiproton beam. High luminosity, low emittance and low momentum spread are some of the main characteristics of the electron-cooled antiproton beam that shall be achieved and that the various experiments may take advantage of. The layout of an electron cooler at such low energies is a great challenge and questions like the competition between multiple scattering and electron cooling, the needed cooling power with an installed internal target or the influence of the electron temperature on the cooling time have to be addressed for the first time. In this contribution, the layout of the USR is summarized and results from simulations with the BETACOOL code are presented.

Keywords: Electrostatic storage ring, electron cooling, antiproton physics, USR.
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INTRODUCTION

Within the Facility for Low-energy Antiproton and Ion Research (FLAIR) [1, 2] the ultra-low energy storage ring will be used to decelerated antiprotons and ions in a final step from 300 keV down to 20 keV, giving access to both in-ring experiments with the stored ions as well as external trap experiments with particles extracted via slow or fast extraction.

Using only electrostatic elements for the beam optics, i.e. electrostatic quadrupoles and cylinder deflectors, one avoids problems with remanence and hysteresis effects that would occur in a “standard” magnetic storage ring. In addition, costs of the ion optical elements can be reduced and experience gained from other low-energy electrostatic rings be used [3-5].

A clear advantage of the USR in comparison to alternative structures like decelerating RFQs is the availability of a cooled ion beam at all intermediate energies and the possibility to guide low-emittance extracted beams directly to external experimental installations. The basic design parameters of the USR are summarized in table 1 with the corresponding lattice functions at the mentioned working point shown in Fig. 1.

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TABLE 1. Summary of the USR design parameters.

Machine Parameter	
Circumference	22.28 m
Gamma transition	3.43
Base pressure	< 5.10^{-11} mbar
Betatron tunes (h/v)	2.29 / 1.08
Chromaticity	-2 / -1.5
# of pbars at 20 keV	10^7
Initial momentum spread	10^{-3}
Antiproton beam	
Base Energy	20 keV
# pbars @ 20 keV	10^7
$\varepsilon_{initial}$ (h/v) [mm mrad]	5 / 5
$\Delta p/p$	10^{-3}

The machine is given access to an extremely wide physics program, ranging from the study of antimatter–matter interactions at lowest energies in in-ring experiments at an internal gas jet target, as well as to a all the experiments employing traps as they can be efficiently filled using the decelerated and cooled antiproton beam. High luminosity, low emittance and low momentum spread are some of the main characteristics of the electron-cooled antiproton beam that shall be achieved and that the various experiments may take advantage of.

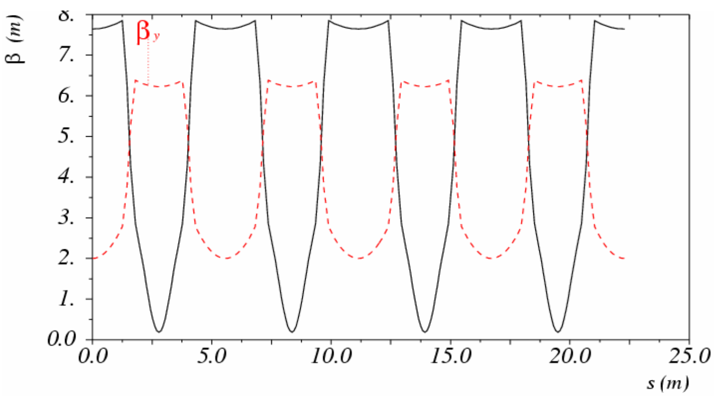

FIGURE 1. USR lattice functions at the working point Q_x=*2.29*, Q_y=*1.08* as calculated with MAD.

Including beam growth during transport within FLAIR, the USR will be filled with cooled antiprotons from the LSR at 300 keV and an emittance of $\varepsilon_x = \varepsilon_y =$ *1.5 mm mrad*. The beam will then be decelerated in one step to the final energy of 20 keV and then cooled again.

RESULTS FROM THE SIMULATIONS

The following calculations were done using the *rms dynamics* function of the BETACOOL code. The goal of the algorithm is to calculate the growth rates of the beam's rms parameters. More detailed studies with the code are feasible and will be done in the future to help optimizing the design of the cooler. The general design parameters used in the calculations are shown in the following table 2.

TABLE 2. Overview of the electron cooler parameters.

Design parameter	
Length [m]	0.8
Magnetic field [kG]	0.1
Beta function [m], horizontal / vertical	7.5 / 2
Horizontal dispersion [m]	0.77
Electron beam radius [cm]	0.5
Electron beam current [mA]	0.05
Electron temperature [meV], transverse/longitudinal	4 / 0.5
Field homogeneity in cooler	$1x10^{-3}$

Neglecting the influence of the internal target, the overall cooling time is defined by the equilibrium between the intra beam scattering (IBS) heating rates and the cooling rates achieved by the electron cooler. BETACOOL allows a momentum spread dependent analysis of the IBS rates for both the horizontal and longitudinal component, the results are shown in Fig. 2.

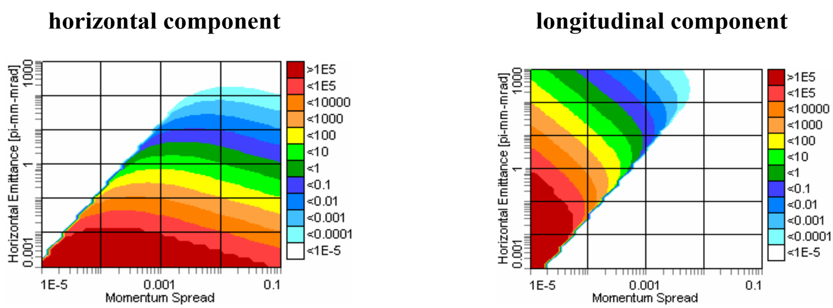

FIGURE 2. Intrabeam scattering heating rates (positive).

These results of IBS beam growth need to be compared with the achievable electron cooling rates under the given specifications. Again, a component split representation can be done and is shown in Fig. 3.

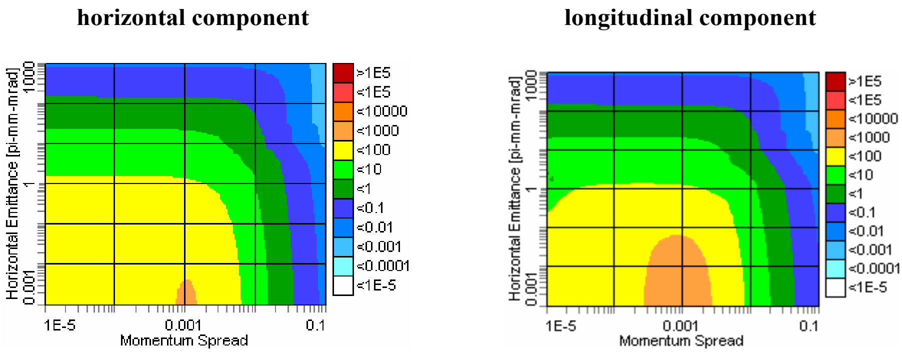

FIGURE 3. Electron cooling rates (negative).

By overlapping the results from the figures 1 and 2 with each of the two components, one gets a direct picture of the beam dynamics during the cooling process as indicated by the black points in Fig. 4.

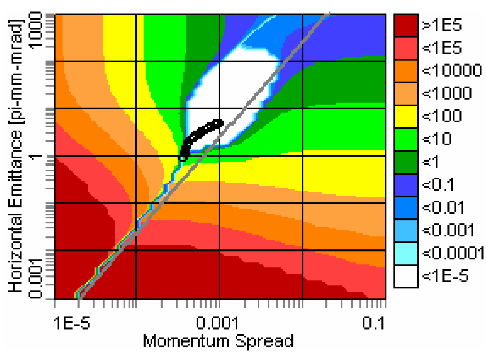

FIGURE 4. Overlapping components of figures 2 and 3. Beam dynamics shown by the black points.

Using these results, one can calculate the horizontal/vertical emittance and the momentum spread of the antiproton beam as a function of time. It can clearly be seen in Fig. 5 that even at lowest energies the cooling times are below one second.

A possible operating scheme for FLAIR could thus foresee the rf bunching in the LSR at e.g. the higher harmonics $h=4$ allowing to fill the USR up to its space charge limit with each of the bunches. Due to the short cooling times, each shot can be decelerated, cooled at 20 keV and be used either for the in-ring experiments or extracted from the machine. With a space charge limit of ~ 2.5×10^7 pbars and a cycle time of 5 s, this gives an ideal number of 5×10^6 pbars/s or – assuming (conservative) 90% losses – 5×10^5 pbars/s.

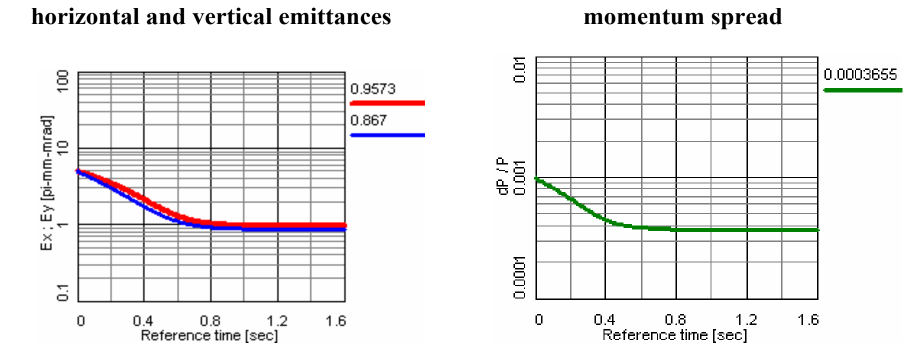

FIGURE 5. Beam dynamics in the USR during the cooling process.

A summary of the results obtained with BETACOOL is shown in the following table 3.

TABLE 3. Summary of the different results obtained with BETACOOL.

Parameters after the cooling process	
Equilibrium emittance [mm mrad] (h / v)	0.96 / 0.87
Equilibrium momentum spread	3.65×10^{-4}
IBS heating rates at equilibrium [s^{-1}] (h / v)	1.7 / 12.2
RestGas heating rates at equilibrium [s^{-1}] (h / v)	12.2 / 1.3
Electron cooling rates at equilibrium [s^{-1}] (h / v)	-13.9 / -13.5
Beam lifetime on RestGas [s]	100

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