COOLING RATES AT ULTRA-LOW ENERGY STORAGE RINGS

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Abstract

Electrostatic low-energy storage rings have proven to be a highly flexible tool, able to cover experiments from a variety of different fields ranging from atomic, nuclear and molecular physics to biology and chemistry. Future machines will decisively rely on efficient electron cooling down to electron energies as low as some eV, posing new challenges to the cooler layout and operation. The BETACOOL code has already been successfully applied for the layout and optimization of a number of different electron coolers around the world. In this contribution, the results from calculations of the cooling rates at future low-energy machines equipped with an internal target like the Ultra-low energy Storage Ring (USR) at the Facility for Low-energy Antiproton and Ion Research (FLAIR) are presented.

INTRODUCTION

At lowest beam energies of only some tens of keV electrostatic storage rings [1-3] offer clear advantages as compared to their magnetic counterparts due to the lack of remanence of the fields and hysteresis effects. While existing machines are operated with local ion sources and are mainly used for the storage of singly charge molecular ions, future machines will possibly play an important role within large accelerator facilities to provide cooled beams of various ion ranging from antiprotons to exotic highly charged ions down to lowest energies as low as 20 keV [4].

A clear advantage of the such an **u**ltra-low energy **s**torage **r**ing (USR) in comparison with alternative structures like decelerating RFQs [5] will be 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.

However, it has to be pointed out that electron cooling at such low-energy is a completely new challenge, requiring novel design concepts for the cooler. In order to get an idea about the cooler parameters, its performance and resulting cooling times, simulation with the BETACOOL code [6] were done. The program has been actively used in the community for the design and optimization of electron cooling systems at a variety of different research centres, e.g. RIKEN, JINR and FZ Jülich [7-9].

The general goal of BETACOOL is the simulation of processes that lead to a variation of the ion distribution in six dimensional phase space. A basic assumption is that these processes can be considered slow processes as compared to the beam revolution time. The code provides different algorithms for an in-detail study of the ion beam dynamics:

- RMS dynamics simulation – used in this paper,
- Simulation of distribution function evolution using a Monte-Carlo based method,
- Multi-particle tracking based on a molecular dynamics technique.

Details about the models can be found in [10].

RING LATTICE

Within the Facility for Low-energy Antiproton and Ion Research (FLAIR) [11] the electrostatic USR will be used to decelerate antiprotons and exotic, possibly highly charged ions in a final step from 300 keV down to 20 keV. This will give access to both in-ring experiments with the stored ions as well as to external trap experiments with particles extracted via slow or fast extraction. The lattice of the storage ring is shown in Fig. 1.

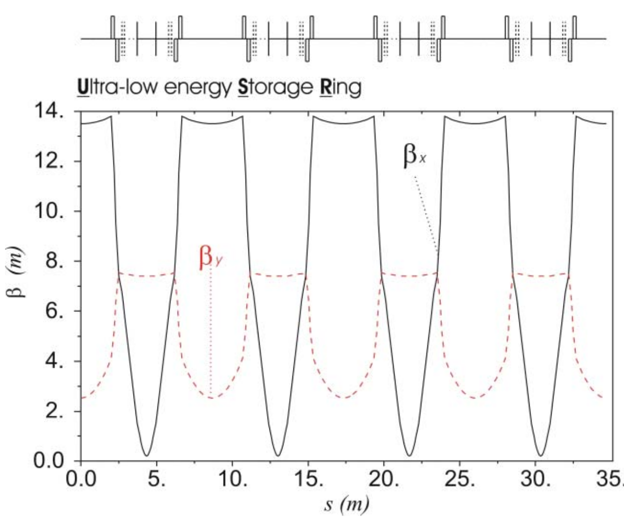

Figure 1: Betafunctions of the USR as calculated with the MAD code. Q_x=2.38 , Q_y=1.14.

The electron cooler and the compensation solenoids are housed in one of the four meter long straight sections. Initially, the ring will be filled with a cooled ion beam where $\varepsilon_x = \varepsilon_y = 5$ *mm mrad* at an energy of $E_{ion} = 300$ *keV*. All the following calculations are done with antiprotons.

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RESULTS

As pointed out before, 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. The general design parameters used in the calculations are shown in the following table 1.

Table 1: Overview of the electron cooler parameters

Design parameter	
Length [m]	0.8
Magnetic field [kG]	0.1
Beta function [m], horizontal / vertical	13.5 / 2.5
Horizontal dispersion [m]	0.77
Electron beam radius [cm]	0.5
Electron beam current [mA]	0.05
Electron temperature [meV], tr. /long.	4 / 0.5
Field homogeneity in cooler	$1\text{x}10^{-3}$

If one neglects the effect of the internal target, the overall cooling time is defined by the equilibrium between the intra beam scattering (IBS) heating rates, the effect of the rest gas 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 the following Fig. 2 and Fig. 3.

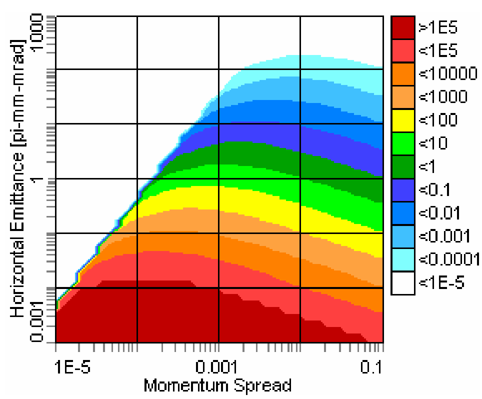

Figure 2: Transverse IBS heating rates (positive).

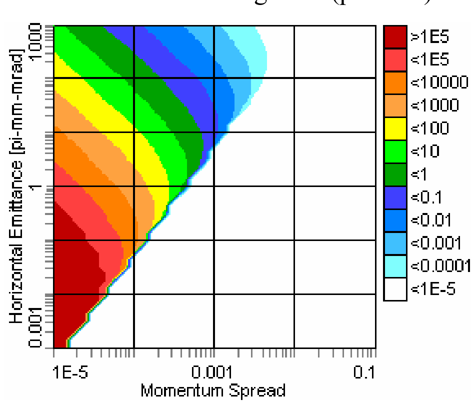

Figure 3: Longitudinal IBS heating rates (positive).

In a second step, these IBS rates need to be compared with the achievable electron cooling rates under the given specifications. Plots of the calculated transverse and longitudinal cooling rates are shown in Figs. 4 and 5.

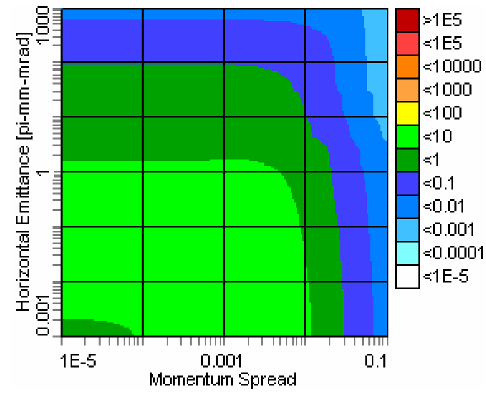

Figure 4: Electron cooling rates (negative) of the transverse component.

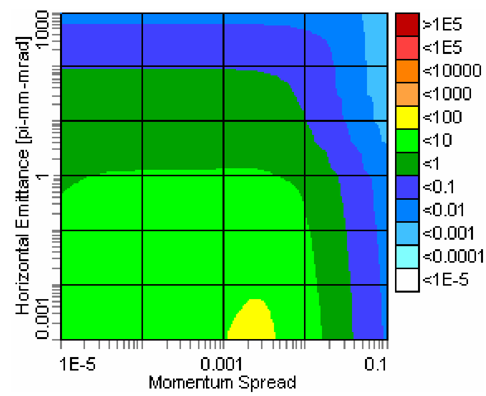

Figure 5: Electron cooling rates (negative) of the longitudinal component.

By overlapping these results together with the effect of the residual gas, one gets a direct picture of the beam dynamics during the cooling process as indicated by the black points in the following Fig. 6.

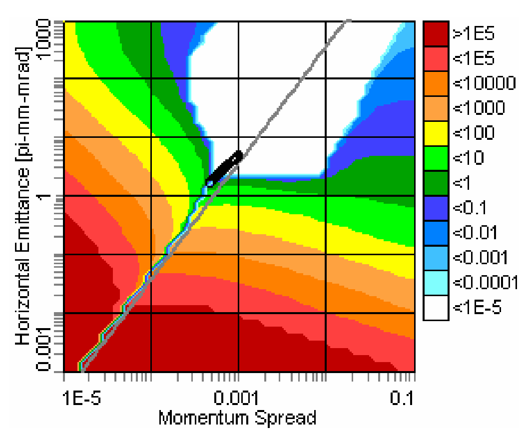

Figure 6: Result from overlapping the before-mentioned rates and the effects of the rest gas. Dynamics during the cooling process is given by the black points in the figure.

From these results, one can directly calculate the evolution of horizontal and vertical emittance as well as the momentum spread of the stored beam as a function of time. It can clearly be seen in Figs. 7 and 8 that even at lowest energies the cooling times are in the order of only a few seconds. The exact deceleration cycle within FLAIR has not been finalized yet, but the given cooling times will not be the limiting factor. A possible scenario could be an injection into the USR every 5 seconds, thus giving enough time for deceleration and cooling of the ions before extraction.

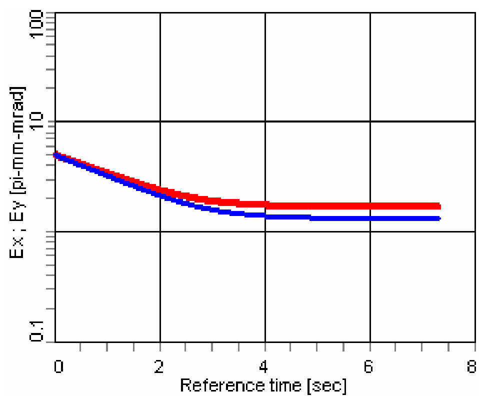

Figure 7: Evolution of the horizontal and vertical emittance during the cooling process.

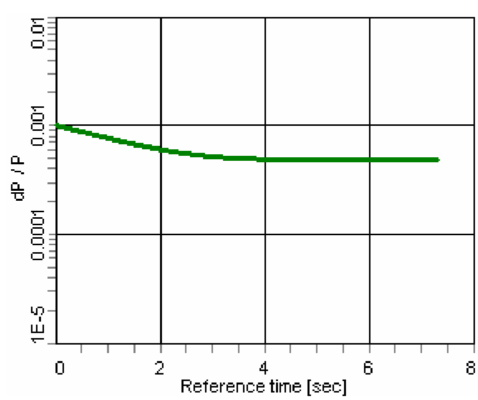

Figure 8: Momentum spread of the stored beam as a function of time during the cooling process.

A summary of the results is given in the following table.

Table 2: Summary of the BETACOOL results.

Parameters of the BETACOOL results	
Equ. emittance [mm mrad] (h / v)	1.66 / 1.32
Equilibrium momentum spread	4.88×10^{-4}
IBS heating rates at equ. [s^{-1}] (h / v)	0,77 / 0,82
Rest gas heating rates at equ. [s^{-1}] (h / v)	0,26 / 0,01
Electron cooling rates at equ. [s^{-1}] (h / v)	-1,03 / -0,83
Beam lifetime on rest gas [s]	1000

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