STATUS OF STOCHASTIC COOLING PREDICTIONS AT THE HESR

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Abstract

The High-Energy Storage Ring (HESR) of the future International Facility for Antiproton and Ion Research (FAIR) at GSI in Darmstadt is planned as an antiproton cooler ring in the momentum range from 1.5 to 15 GeV/c. An important and challenging feature of the new facility is the combination of phase space cooled beams with internal targets. In the modularized start version of FAIR the accumulator ring RESR is part of an upgrade program and only the collector ring CR is available from the beginning for antiproton beam cooling. Antiproton accumulation will then be accomplished in the HESR by utilizing the already designed stochastic cooling system with moving barrier buckets. The status of momentum cooling simulation results is presented taking into account the new pickup and kicker structures.

INTRODUCTION

The High-Energy Storage Ring (HESR) [1] of the future International Facility for Antiproton and Ion Research (FAIR) at GSI in Darmstadt is planned as an antiproton cooler ring in the momentum range from 1.5 to 15 GeV/c. The circumference of the ring is 575 m with two arcs of length 155.5 m each. The long straight sections each of length 132 m contain the future 4.5 MV electron cooler and on the opposite side the Panda experiment [1]. The pre-cooled antiproton beam bunch with 500 ns length delivered from the CR every 10 s with 10^8 antiprotons and an rms relative momentum spread of $5 \cdot 10^{-4}$ is injected at 3 GeV kinetic energy. The horizontal and vertical beam emittances are 5 mm mrad. Stochastic cooling will be available in the whole momentum range. The major tasks are antiproton beam accumulation and to provide beams with 10^{10} antiprotons above 3 GeV at a momentum resolution down to 10^{-5} during the PANDA internal experiment. A (2 – 4) GHz cooling system has been chosen to accomplish these goals. The development of new ring slot-couplers [2] for the pickups and kickers in the frequency range 2 – 4 GHz will enhance the cooling performance. This has been confirmed experimentally at COSY [3]. Momentum cooling in the energy range above 3 GeV is provided using the Filter cooling technique while the time of flight (TOF) cooling method yielding a larger momentum acceptance is envisaged below 3 GeV [4]. For momentum cooling two pickup tanks each equipped with 64 ring slot coupler cells yielding a total shunt impedance of 1152 Ohms are installed. As indicated in figure 1 they are located in the PANDA section. The momentum kicker tank equipped with 64 cells yields a total shunt impedance of 2304 Ohms. It is mounted in the cooler section. The distance between pickup and kicker is about 200 m. The length of 64 cells amounts only 800 mm. The pickups can be operated simultaneously in both sum and difference mode. To avoid signal coupling of the structures when they are driven as kicker two additional kicker tanks for horizontal and vertical emittance cooling will be installed in the cooler section. The pickup will be cooled to 20 K. Low noise amplifier with an equivalent noise temperature of 40 K will be used. First prototype structures operating in the 4 - 6 GHz range have been already built to further improve the performance of stochastic cooling [5].

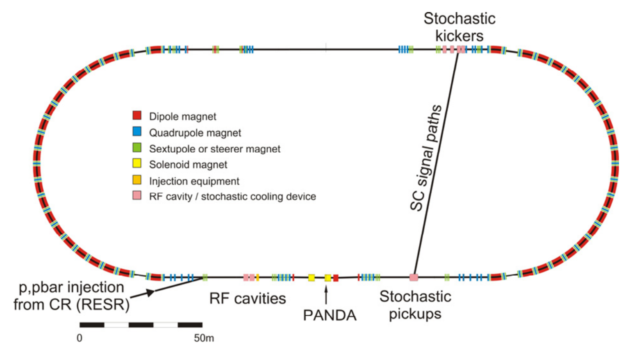

Figure 1: Schematic view of the HESR. The upper straight will accommodate the future electron cooler.

This contribution reports on antiproton accumulation and Filter momentum cooling with internal target using the new pickup and kicker structures in the frequency range 2 to 4 GHz. The performance of TOF and transverse cooling is treated in a separate paper. The latter is mainly necessary to keep a good beam-target overlap.

ANTIPROTON ACCUMULATION

In view of the budget limitation the construction of the RESR is postponed in the modularized start version of FAIR and instead it is proposed to include the antiproton accumulation function in the HESR downstream of the Collector Ring (CR), the pre-cooling ring of the antiproton beam. The accumulation of antiprotons can be accomplished with the stochastic stacking method developed and well established at CERN and FNAL [6]. This method requires pickups positioned in a region with large dispersion where the orbits of the injected and already stacked beam can be separated. A large horizontal acceptance is thus required. A sophisticated stochastic cooling system with a cooling force decaying radially with an exponential gain profile from the injection position to the stack top is necessary. Applying this accumulation scheme would result in a completely new and additional cooling system in the HESR. Instead a different way of beam accumulation has been selected that uses the already designed stochastic cooling system and the barrier bucket (BB) cavity [3] of the HESR. The BB cavity is used to separate the circumference of the

HESR ring into two regions, one reserved for the injected beam and the other one for the accumulated beam.

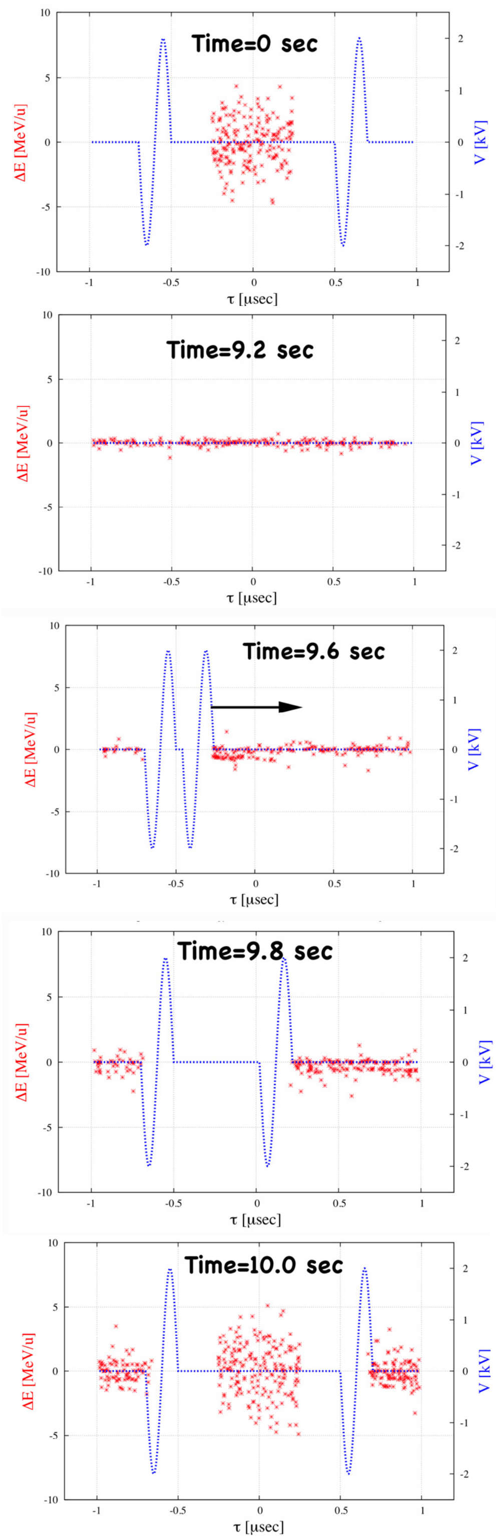

Figure 2: First cycle of antiproton accumulation with a moving barrier. At t = 9.5 s the initially overlapping two barrier pulses are created. One barrier is then moved in the direction as indicated by the arrow. During the barrier motion the beam is compressed to provide new space for injection. The second batch is injected at t = 10 s.

The fixed and moving barrier cases have been studied in detail with a particle tracking code [7]. Considerably better results of antiproton beam accumulation were achieved when the moving barrier method is applied. The results are illustrated in figure 2 for the first injection cycle. Every 10 s a bunch with 500 ns length and 10^8 antiprotons with an rms relative momentum spread of $5 \cdot 10^{-4}$ is kicked-injected into the HESR. The injection kicker pulse rise and fall time is 250 ns each. The pulse flat top length is 500 ns.

Two one-wave length pulses (5 MHz) with 2 kV peak voltage are prepared within one revolution period (2 µs) and the beam is injected between the two barrier pulses (Figure 2, t = 0 s). The barrier voltages are switched off adiabatically within 200 ms and the beam begins to debunch. At t = 9.2 s the beam is already completely coasting and stochastic momentum cooling which is permanently in operation has reduced the momentum spread as is clearly visible. Before the next injection the barrier pulses are switched on at t = 9.3 s adiabatically within 200 ms. The adiabatic compression (t = 9.6 s and t = 9.8 s) of the cooled coasting beam to the bunched beam (the bunching factor is around 1/2) is performed with the moving barrier voltage within 500 ms to prepare the gap for the next beam injection at t = 10 s. The figure clearly shows that the injected particles are completely moved into the accumulation area so that no particles losses occur at the second injection at t = 10 s. Strong momentum cooling power is necessary to prevent a too large momentum spread increase during the compression phase. The number of accumulated antiprotons for the moving barrier scheme is depicted in figure 3. After 100 injections (1000 s) 10^{10} antiprotons are accumulated. The accumulation efficiency reaches 97 %. The accumulation efficiency is defined as the ratio of the number of accumulated particles to the number of particles totally injected. The relative momentum spread is reduced to $5 \cdot 10^{-5}$ at the end of accumulation.

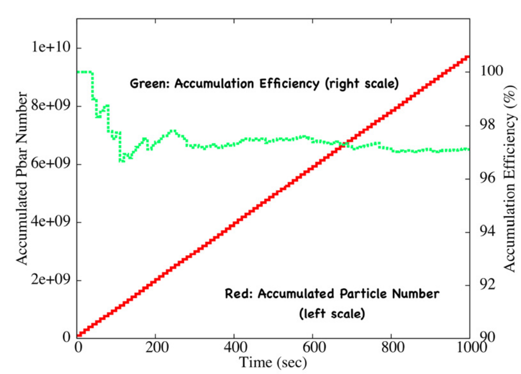

Figure 3: Number of antiprotons during accumulation (red) and accumulation efficiency (green) for the moving barrier scheme.

To ensure an efficient accumulation it is essential to reduce the electronic gain of the cooling system from initially 130 dB to 115 dB during accumulation. This is due to the fact that Schottky noise heating being proportional to the amplifier voltage gain squared increases with an increasing antiproton density in the HESR. The microwave particle power is less than 70 W.

To gain confidence in the accumulation simulation results and to prove the reliability of the method a Proof-Of-Principle (POP) experiment is indispensable. Recently, an international collaboration consisting of members from GSI, Japan, Russia, CERN and FZJ Juelich could successfully demonstrate at the GSI the possibility of beam stacking with a BB system assisted by electron and stochastic cooling [8]. The results are in close agreement with accumulation simulations [9].

MOMENTUM COOLING WITH INTERNAL TARGET

Detailed simulations of momentum cooling with an internal target have been already carried out [4]. The cooling performance has been now determined taking into account the new pickup and kicker ring slot-couplers and the new positioning in the ring.

Figure 4 shows the result of filter momentum cooling for 10^{10} antiprotons at T = 3 GeV with an internal Hydrogen target with thickness $N_T = 4 \cdot 10^{15}\, cm^{-2}$. A Fokker-Planck equation [4] has been solved to determine cooling of the momentum spread for two initial conditions. The mean energy loss induced by the target-beam interaction has been compensated with a BB cavity. The blue curve shows the reduction of the rms relative momentum spread for the initial value $5 \cdot 10^{-4}$ while the green curve starts with the initial value $5 \cdot 10^{-5}$ resulting at the end of the accumulation process. In both cases the equilibrium value attained approximately after 200 s is $(\Delta p / p)_{rms} = 8 \cdot 10^{-5}$. The red curve shows the increase in momentum spread when cooling is switched off.

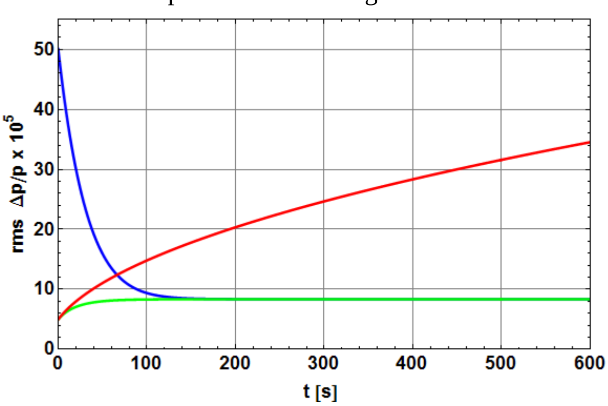

Figure 4: Time development of the relative momentum spread of a beam with 10^{10} antiprotons at 3 GeV interacting with an internal target. The red curve shows the beam heating when cooling is off.

The momentum cooling performance at three energies is summarized in table 1. In all cases an equilibrium value is attained at $(\Delta p / p)_{rms} \approx 8 \cdot 10^{-5}$. The time (cooling down time) needed to approach this value depends on the initial value. The simulation results are found for an optics lattice with γ_{tr} = 6.2. The frequency slip factor for the ring η_{Ring} and from pickup to kicker η_{PuKi} is listed. Both quantities determine the cooling acceptance [4] of filter cooling. The Schottky particle power is below 25 W. The thermal noise power is negligible.

Table 1: Stochastic Filter Momentum Cooling

T [GeV]:	**3**	**8**	**15**
Initial rms rel. momentum spread δ_{rms}:	$5 \cdot 10^{-4}$	$5 \cdot 10^{-4}$	$5 \cdot 10^{-4}$
Final rms rel. momentum spread δ_{rms}:	$8 \cdot 10^{-5}$	$8 \cdot 10^{-5}$	$6 \cdot 10^{-5}$
cooling down time [s]:	≈ 200	≈ 300	≈ 300
γ_{tr}:	6.2	6.2	6.2
η_{ring}:	0.031	-0.015	-0.022
η_{PuKi}:	0.02	-0.026	-0.033
Time of flight Pu to Ki [ns]:	687	671	668
Voltage gain [dB]:	110	118	120
Schottky power [W]:	5	7	24
Thermal Noise [W]:	0.06	0.4	0.6
Cooling acceptance x 10^3:	± 1.8	± 2.6	± 1.9

SUMMARY

From the detailed simulation studies of the moving barrier scheme with application of the envisaged (2 - 4) GHz momentum cooling system it can be concluded that an efficient accumulation of 10^{10} antiprotons in the HESR within 1000 s should be possible at 3 GeV. Albeit not very practicable for a regular operation, a collection of up to 10^{11} antiprotons is possible in the simulation within 10000 s. The great advantage of the proposed accumulation scheme is that a significant cost increase can be avoided. The momentum cooling performance at three energies has been examined. In all cases an equilibrium value is attained at $(\Delta p / p)_{rms} \approx 8 \cdot 10^{-5}$.

REFERENCES

[1] R. Maier et al., proc. of PAC11, New York, USA, March 28-April 1, 2011
[2] L. Thorndahl, internal report FZ-Juelich 2009
[3] R. Stassen et al., proc. of PAC09, Vancouver, Canada, May 4-8, 2009
[4] H. Stockhorst, et al., ibid.
[5] R. Stassen et al., to be published at COOL11
[6] F. Caspers and D. Möhl, Stacking with Stochastic Cooling, CERN-AB-2004-028 RF
[7] T. Katayama et al., proc. of IPAC10, Kyoto, Japan, May 23-28, 2010
[8] M. Steck et al., to be published at COOL11
[9] T. Katayama et al., to be published at COOL11