THE HIGH-ENERGY STORAGE RING (HESR)

R. Maier# for the HESR Consortium, Forschungszentrum Jülich, Germany

Abstract

The High-Energy Storage Ring (HESR) is part of the upcoming International Facility for Antiproton and Ion Research (FAIR) at GSI in Darmstadt. An important feature of this new facility is the combination of powerful phase-space cooled beams and thick internal targets (e.g., pellet targets) to reach the demanding requirements of the internal target experiment PANDA in terms of beam quality and luminosity. In this paper the status of the preparatory work for the HESR at the FZ Jülich is summarized. The main activities are beam dynamics simulations and hardware developments for HESR in combination with accelerator component tests and beam dynamics experiments at the Cooler Synchrotron COSY.

INTRODUCTION

The HESR is an essential part of the physics program at FAIR [1]. It is dedicated to the field of high-energy antiproton physics to explore the research areas of charmonium spectroscopy, hadronic structure, and quark-gluon dynamics with high-quality beams over a broad momentum range from 1.5 to 15 GeV/c. A consortium consisting of FZ Jülich (as leading institution), GSI Darmstadt, Helmholtz-Institute Mainz, University of Bonn and ICPE-CA Bucharest is in charge of HESR design and construction. In storage rings the complex interplay of different processes like beam cooling, beam-target interaction and intra-beam scattering determines the final equilibrium distribution of the beam particles. Electron and stochastic cooling systems are required to ensure the specified beam quality and luminosity for experiments at HESR, which initially will be performed with the PANDA detector [2].

The modularized start version is a stepwise approach to the realization of FAIR [3]. The accumulator ring RESR is part of an upgrade program and only the collector ring CR is going to be available for antiproton collection and beam cooling from the beginning. Therefore, a modification of the HESR injection and accumulation scheme is required. The most cost-efficient accumulation method is to use the already designed stochastic cooling system together with the barrier bucket cavities [4]. Also the planned 4.5 MV electron cooling system is postponed to a later stage. To enhance the performance of the stochastic cooling system the coupling structures of the 2-4 GHz system have been optimized and successfully tested at COSY [5]. First prototype structures operating in the 4-6 GHz range have been built to improve the performance of stochastic cooling.

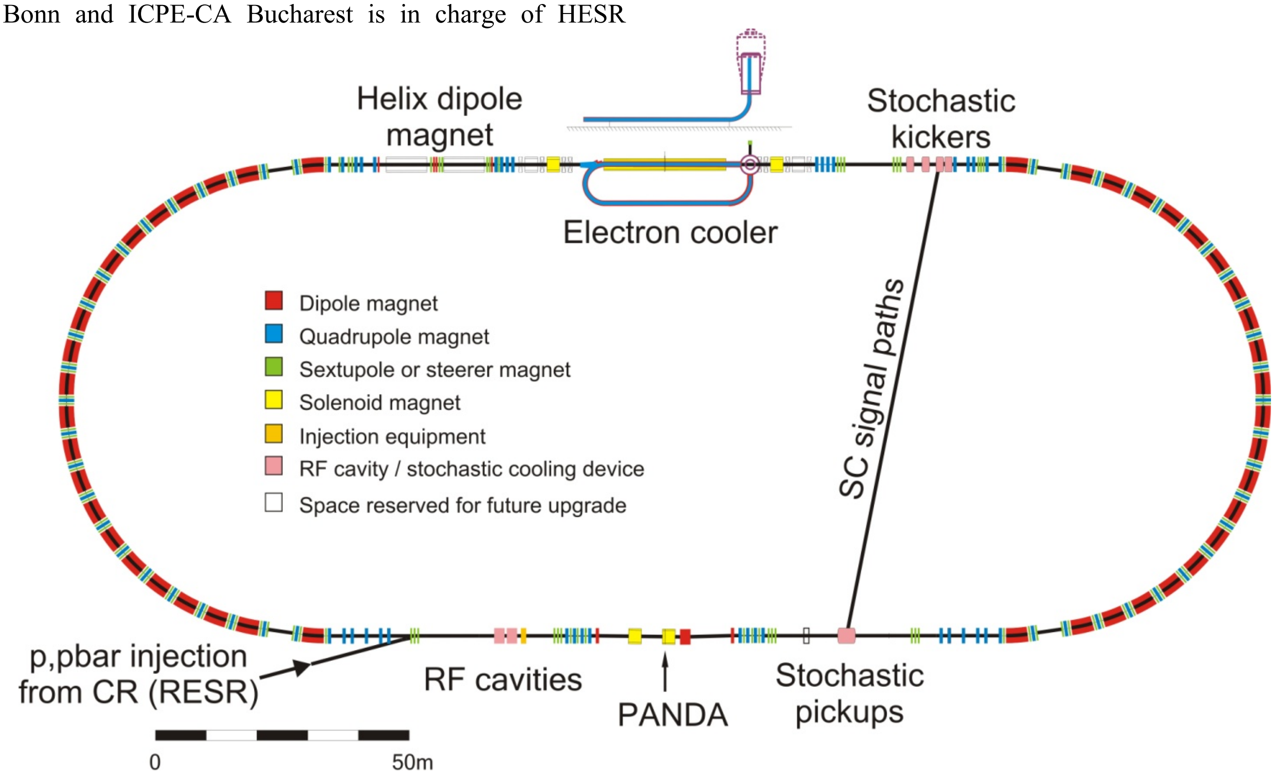

Figure 1: Schematic view of the HESR. Positions for injection, cooling devices and experimental installations are indicated. The upper straight is housing electron cooler, stochastic kickers, and space for a future upgrade. The lower straight contains injection, RF cavities, PANDA with target, and stochastic pickups.

#r.maier@fz-juelich.de

LATTICE DESIGN AND EXPERIMENTAL REQUIREMENTS

The HESR lattice is designed as a racetrack shaped ring with a maximum beam rigidity of 50 Tm (see Fig. 1). The basic design consists of FODO cell structures in the arcs together with a missing dipole concept. The arc quadrupole magnets are grouped into four families, to allow a flexible adjustment of transition energy, horizontal and vertical betatron tune, and horizontal dispersion in the straights sections.

General Layout

One straight section will mainly be occupied by the proposed electron cooler. Same space is also reserved for a future upgrade with polarized beams [6]. The other straight section will host the experimental installation of PANDA with internal H_2 pellet target, RF cavities, injection kickers and septa. For stochastic cooling pickup and kicker tanks are also located in the straight sections, opposite to each other.

Special requirements for the lattice are low dispersion in straight sections and adjustable betatron amplitudes in the range between 1 and 15 m at the internal interaction point of the PANDA detector. In addition, the betatron amplitude at the electron cooler can be varied within a large range between 25 and 200 m. In order to optimize the stochastic cooling, the transition energy (γ_{tr}) can be changed between 6.2 and 15. There are several optical settings defined where the γ_{tr} = 6.2 optics (see Fig. 2) is most important due to the PANDA flagship experiment at 8.9 GeV/c. Both betatron tunes are roughly 7.62 for different optical settings and natural chromaticities are ranging in X from -12 to -17 and in Y from -10 to -13.

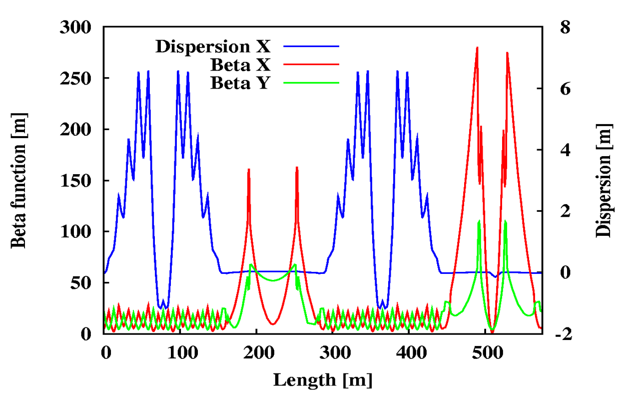

Figure 2: Optical functions of γ_{tr} = 6.2 lattice: horizontal and vertical betatron functions and horizontal dispersion function versus location in the ring. The electron cooler and the target are located at s=222 m and s=509 m, respectively. The kink in the horizontal dispersion is caused by the PANDA dipole chicane.

R&D Work

Magnet design of dipole, quadrupole, sextupole and correction dipole magnets has been finalized. Three-dimensional field calculations have been performed to minimize the multipole components of the various magnet types [7]. After negotiations with tenders the magnet production is going to be started with a pre-series.

A detailed concept for the vacuum system of the HESR has been worked out [8]. Two test devices are manufactured. The first device to test the mechanical stability of the favored clamping flanges under ultra high vacuum conditions is already operated. The second test facility will be a genuine cut-out of the arc from one center of a dipole to the next neighboring one.

Special equipment like multi-harmonic RF cavities, stochastic and electron cooler enable high performance of this antiproton storage ring, which will make high precision experiments of PANDA feasible. Key tasks for the HESR design work to fulfill these requirements are:

- Design and testing of multi-harmonic RF cavities. Two identical cavities will be installed in the HESR. Both cavities will not only be used to accelerate/decelerate antiprotons in the HESR but also to build a barrier bucket during the experiment, and a moving barrier bucket during the accumulation.
- Development and testing of high-sensitivity stochastic cooling pickups for the frequency range 2–4 GHz. The main stochastic cooling parameters have been determined for a cooling system utilizing pickups and kickers with a band-width of 2-4 GHz and the option for an extension to 4-6 GHz. Since stochastic filter-cooling is specified above and stochastic time-of-flight cooling below 3.8 GeV/c, the whole HESR momentum range is covered by the stochastic cooling system. New high-sensitivity pickups for stochastic beam cooling have been designed and built for the HESR. They have been successfully tested with COSY beam and have proven their predicted performance.
- A new 2 MV electron cooler is built in close collaboration with the Budker Institute for Nuclear Physics and will be installed at COSY in 2011 [9]. Technical developments for this electron cooler are important steps towards the 4.5 MV electron cooler. The HESR electron cooler layout will strongly benefit from the experiences of the electron cooler operation at COSY. The measurement of beam cooling forces and other features of magnetized electron cooling at high energies are essential for the planned HESR electron cooler. For the start-up phase of the HESR this 2 MV electron cooler is also well suited for beam cooling and accumulation at injection energy.

BEAM DYNAMICS

Various beam dynamics simulations have been performed to guarantee the required equilibrium beam parameters, beam lifetime and beam stability in HESR [10,11].

A chromaticity correction scheme has been developed for the HESR and optimized by dynamic aperture calculations. The estimated field errors of the HESR dipole and quadrupole magnets have been included in nonlinear beam dynamics studies. The ion optical settings of the HESR have been improved using dynamic aperture calculations and the technique of frequency map analysis [12]. The related diffusion coefficient was also used to predict long-term stability based on short-term particle tracking.

The accumulation and clearing of ion trapping in HESR has also been studied in detail. Positively charged ions are caused by the interaction of the antiproton beam with residual gas and are continuously trapped in the negative potential well of the circulating antiproton beam [13]. The negative potential well and the corresponding electric fields of the antiproton beam are calculated in order to study the motion of the ions and the accumulation in trapping pockets. The removal of ions can be achieved using clearing electrodes and resonant beam shaking together with a broadband barrier bucket cavity. Due to a huge pressure bump cause by the PANDA pellet target, special measures in the interaction region like the installation of continuous clearing electrodes are necessary.

Comprehensive beam dynamics experiments have been carried out to test the developed momentum cooling models. The interaction of the antiproton beam with an internal target and the fields of a barrier bucket cavity are included [14].

CONCLUSION

A new HESR beam accumulation scheme has been developed taking the modifications of the modularized start version of FAIR into account. In addition the performance of stochastic cooling has been improved to allow for beam accumulation at injection and efficient beam cooling in the whole HESR momentum range.

Beam dynamics simulations are well advanced and benchmarked with COSY beam experiments.

The design work of the HESR is in the final stage and the construction phase can start together with FAIR construction.

ACKNOWLEDGEMENT

The author is grateful to all members of the HESR Consortium for contributing to this project.

REFERENCES

[1] An International Accelerator Facility for Beams of Ions and Antiprotons, FAIR Baseline Technical Report, GSI Darmstadt, ISBN 3-9811298-0-6 (2006).

[2] PANDA Collaboration, Physics Performance Report for PANDA, Strong Interaction Studies with Antiprotons,

[3] FAIR - Facility for Antiproton and Ion Research, Green Paper - The Modularized Start Version, October 2009.

[4] T. Katayama et al., Beam Accumulation with Barrier Voltage and Stochastic Cooling, Proc. of IPAC'10, Kyoto, Japan, MOPD065, 837 (2010).

[5] R. Stassen et al., COSY as Ideal Test Facility for HESR RF and Stochastic Cooling Hardware, Proc. of PAC09, Vancouver, BC, Canada, TU5PFP022, 861 (2009).

[6] A. Lehrach et al., Polarized Beams in the High-Energy Storage Ring of the future GSI Project, Proc. of the 16th International Spin Physics Symposium SPIN 2004, Trieste, World Scientific, 742 (2005), ISBN 9812563156.

[7] H. Soltner et al., Magnetic-Field Calculations for the Magnets of the High-Energy Storage Ring (HESR) at FAIR, Proc. of PAC09, Vancouver, BC, Canada, MO6PFP016, 166 (2009).

[8] U. Bechstedt (FZ Jülich), private communication.

[9] J. Dietrich et al., Status of the 2 MeV Electron Cooler for COSY/ HESR, Proc. of IPAC'10, Kyoto, Japan, MOPD067, 843 (2010).

[10] O. Boine-Frankenheim et al., Nucl. Instr. Meth. A 560, 245 (2006); A. Lehrach et al., Nucl. Instr. Meth. A 561, 289 (2006); F. Hinterberger, Beam-Target Interaction and Intrabeam Scattering in the HESR Ring, Report of the Forschungszentrum Jülich, Jül-4206, ISSN 0944-2952 (2006).

[11] A. Lehrach et al., Beam Dynamics of the High-Energy Storage Ring (HESR) for FAIR, International Journal of Modern Phys. E (IJMPE) Vol. 18 Issue: 2, 420 (2009).

[12] D.M. Welsch et al., Investigation and Optimization of Transverse Non-linear Beam Dynamics in the High-Energy Storage, Proc. of IPAC'10, Kyoto, Japan, THPE063, 4659 (2010).

[13] F. Hinterberger, report in preparation.

[14] H. Stockhorst et al., Stochastic Momentum Cooling Experiments with a Barrier Bucket Cavity and Internal Targets at FAIR, Proc. of IPAC'10, Kyoto, Japan, MOPD068, 846 (2010).