DESIGN WORK FOR THE HIGH-ENERGY STORAGE RING OF THE FUTURE GSI PROJECT*

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Abstract

The High-Energy Storage Ring (HESR) of the future international Facility for Antiproton and Ion Research (FAIR) [1] at GSI in Darmstadt is dedicated to Strong Interaction studies with antiprotons in the momentum range from 1.5 to 15 GeV/c. Powerful phase-space cooling is needed to reach demanding experimental requirements in terms of luminosity and beam quality.

An overview of the design work for the HESR is given, focusing on recent developments and planned R&D work. Further details can be found in [2].

EXPERIMENTAL REQUIREMENTS AND DESIGN ISSUES

The HESR is being built to exploit the research areas of charmonium spectroscopy, hadronic structure, and quark-gluon dynamics. An important feature of this new facility is the combination of phase-space cooled beams, comprising demanding beam parameter in two operation modes: high-luminosity mode with beam intensities up to 10^{11}, and high-resolution mode with a momentum spread down to 10^{-5}, respectively (see Table 1). Powerful electron and stochastic cooling systems are needed to meet the experimental requirements.

According to the Conceptual Design Report and Technical Report [1,2] the HESR is a storage ring for one internal interaction point only, equipped with the PANDA detector [3]. The antiproton beam is accelerated in SIS100 to the desired energy before being injected and stored in the HESR. Recently, a second scenario was discussed, adding a synchrotron mode to the HESR [4]. This would allow transferring 3.8 GeV/c antiprotons directly from the accumulator rings to the HESR, saving costs for the 50 Tm high-energy beamline, and additional provisions for extraction of antiprotons from SIS100. Beam injection and accumulation in the HESR could be designed for one particular, relatively low injection energy only. In a later stage, it would also be possible to accelerate polarized beams in the HESR [5,6,7] with a ramping rate of about 25 mT/s.

Table 1: Experimental requirements and operation modes.

Ion species	Antiprotons
Antiproton production rate	$2 \cdot 10^{7}$ /s ($1.2 \cdot 10^{10}$ per 10 min)
Momentum / Kinetic energy range	1.5 to 15 GeV/c / 0.83 to 14.1 GeV
Number of stored particles	10^{10} up to 10^{11}
Target thickness	$4 \cdot 10^{15}$ cm^{-2}
Optical functions at IP	$\beta_{x,y}$=1 m, D_x=0 m
Beam radius at IP	1mm (rms) for pellet target
High luminosity (full momentum range)	Average luminosity $2 \cdot 10^{32}$ cm^{-2}sec^{-1}, rms momentum spread of σ_p /p ~ 10^{-4}
High resolution (up to 8.9 GeV/c)	Average luminosity $2 \cdot 10^{31}$ cm^{-2}sec^{-1}, rms momentum spread of σ_p /p ~ 10^{-5}

The HESR lattice is designed as a racetrack shaped ring, consisting of two 180° arc sections connected by two long straight sections (see Fig. 1). It contains two six-fold symmetry arcs with a length of 155 m each, using a mirror symmetric FODO structure. They are designed as pseudo second-order achromat with dispersion suppression [8]. One straight section will mainly be occupied by the electron cooler, injection kicker and septa and RF cavities. The other section will host the experimental installation with internal supersonic H_2 cluster jet and/or frozen H_2 pellet target. For stochastic cooling two pickup tanks are located at the entrance and exit of one straight section diagonal to the location of the two kicker tanks in the opposite straight section, connected with two signal lines.

Special requirements for the lattice are dispersion free straight sections and small betatron amplitude in the range of 1m at the internal interaction point. The design of the straight sections has to allow for adjustment of betatron amplitudes at pick-ups and kickers of the stochastic cooling system and in the electron cooler section.

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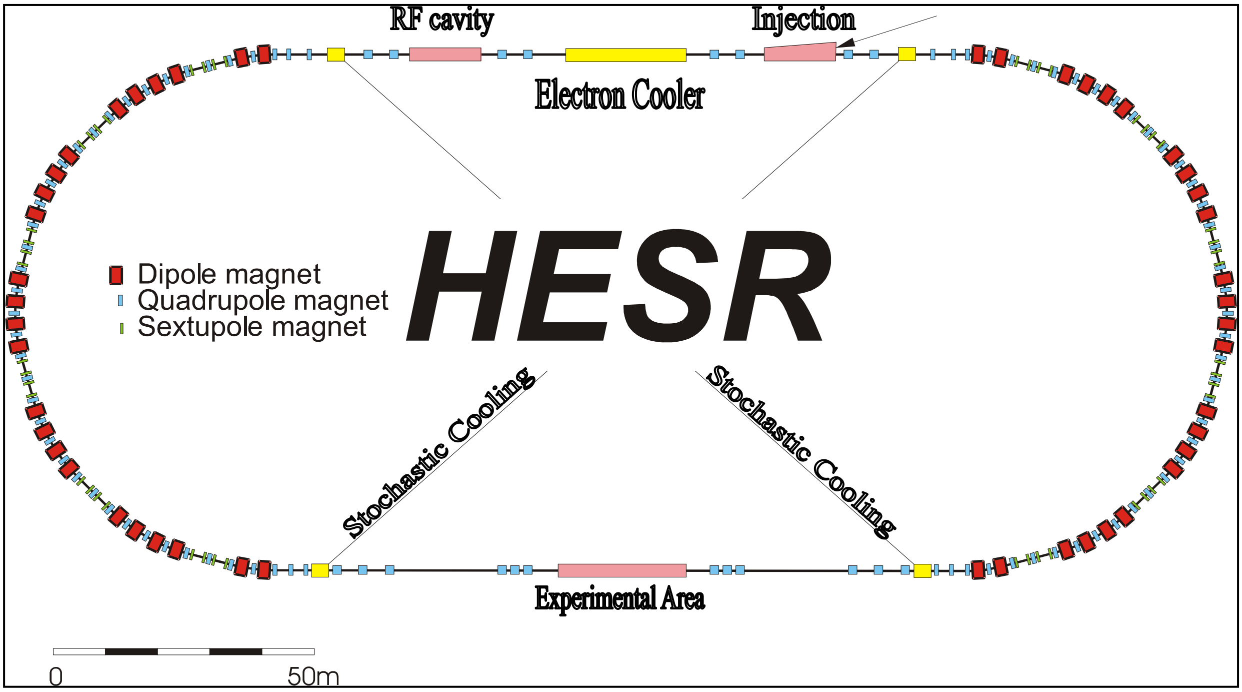

Figure 1: Schematic view of the HESR with a six-fold symmetry lattice and a ring circumference of about 574 m. Tentative positions for injection, cooling devices and experimental installations are indicated.

The proposed lattice also provides an adjustable momentum compaction factor in order to reduce the effect of beam instabilities due to longitudinal impedances, and to optimize ion optical conditions for stochastic cooling. Technical and ion optical integration of experimental installations like PANDA including detector magnet and dipole chicane is done in close cooperation with the corresponding experimental collaboration.

The following design issues have to be taken into account to ensure beam quality and luminosity in the HESR cooler ring to be well suited for the experimental demands:

- Powerful phase space cooling counteracting beam heating due to beam-target interaction and intrabeam scattering.
- Low impedance design of kicker, beam diagnostics, and vacuum chamber (especially with respect to modifications required for beam cooling and experimental devices).
- Efficient low-loss antiproton injection and accumulation.
- High accuracy and stability of beam parameters.

COOLED BEAM EQUILIBRIA

In the HESR, beam cooling is needed for beam accumulation after injection, compensation of beam heating due to beam interaction with internal targets, and finally to compensate for other beam heating processes like intrabeam scattering. Beam cooling scenarios are discussed utilizing the combination of electron and stochastic cooling, since these two cooling techniques to some extent are complementary concerning operation modes and beam energies.

Calculations of beam equilibrium including electron cooling, intrabeam scattering and beam-target interaction are performed utilizing different codes like BETACOOL by I.N. Meshkov et al. (JINR, Dubna), MOCAC by A.E. Bolshakov et al. (ITEP, Moscow), and PTARGET by A. Dolinskii at al. (GSI, Darmstadt). Results from different codes for the previous HESR lattice [2] are compared in [9]. Equilibrium beam parameters for electron-cooled beams differ by a factor 3 to 5 for the different simulation codes.

Similar studies are also carried out for stochastically cooled beams in the HESR operated in high-resolution mode in the energy range from 8.9 to 15 GeV/c. Recently stochastic cooling was also implemented in the BETACOOL in collaboration of JINR Dubna and FZ Jülich.

Independent of the applied beam-cooling technique, simulations based on rms dynamics assuming Gaussian beam distribution show, that the requirements for the high-resolution mode are most challenging. Especially momentum spreads on the 10^{-5} level in combination with moderate transverse emittances in the range of 1 mm mrad, needed for the required beam size on the pellet target, are difficult to reach simultaneously. Intrabeam scattering turns out to be limiting the beam-heating process.

Presently more sophisticated models for arbitrary phase-space distributions are being implemented in existing simulation codes. The study of equilibrium, cooled beam distributions in presence of intrabeam scattering, internal target scattering, non-linear space charge, simulation and control of collective effects in cooled beams induced by ring impedances and trapped ions are important tasks covered by an INTAS research project 'Advanced Beam Dynamics for Storage Rings'. A beam dynamics software library will be set up containing more sophisticated modules and simulation tools, benchmarked with existing cooler storage rings like CELSIUS, COSY, ESR, etc.

R&D WORK

Highest priority is assigned to R&D work related to the high-energy electron cooler. The main issue is the reliable operation of high-brilliance electron beams in high-voltage environment. The Budker Institute for Nuclear Physics (BINP) presented a feasibility study for magnetized high-energy electron cooling up to 8 MV [10]. Further design work is lead by TSL in cooperation with the Budker Institute, the Fermi National Accelerator Laboratory (FNAL), and industry.

With regard to maximum field strength, magnet aperture and ramping rate RHIC-type super-conducting "cosθ"-magnets [11] installed in the interaction regions fit the HESR requirements except for the magnet length. Short straight super-conducting magnets need careful R&D work [12]. Prototypes have to be built to ensure the design choice. In addition R&D work with high priority is allotted to curved super-conducting magnets for improved sagitta in the HESR energy range.

High-priority R&D is also required to prototype critical components of the stochastic cooling system. Sophisticated pick-up structures for broad bandwidth with enhanced sensitivity and low noise suitable for operation in low impedance environment will be developed.

The development of low impedance kicker and septa is of great importance for the design choice of injection. Furthermore broad-band amplifiers for beam feedback, alignment and assembly issues for bent cryostats and super-conducting multilayer magnets combining several multipoles will be investigated before start of production. Finally the optimum number of magnets per cryostat segment has to be found before the final design is completed.

Prototype development (except for super-conducting dipole magnets) is already partially funded by the European Community's FP6 program. This design study work will cover the years 2005 to 2007.

CONCLUSION

In the next step a correction scheme for the lattice has to be developed to correct for field errors, misalignments and chromatic effects of magnets. Major R&D issue is feasibility demonstration for magnetized high-energy electron cooling. High-priority R&D for curved super-conducting magnets and high-bandwidth stochastic cooling is planned. In parallel simulation codes for cooled beams interacting with internal targets have to be improved. Requirements for broadband feedback systems have to be specified after intense study of collective effects.

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