HESR LINEAR LATTICE DESIGN

B. Lorentz[#], A. Lehrach, R. Maier, D. Prasuhn, H. Stockhorst, and R. Tölle, Forschungszentrum Jülich GmbH, D-52425 Jülich, Germany

Abstract

The High Energy Storage Ring (HESR) [1] is part of the future Facility for Antiproton and Ion Research (FAIR) [2] at GSI in Darmstadt. The ring is used for hadron physics experiments with a pellet target and the PANDA [3] detector. It will supply antiprotons of momenta from 1.5 GeV/c to 15 GeV/c. The ring will consist of two 180 degree bending sections (arcs) of 157 m length, each, and two 132 m long straight sections. In one of the straight sections the PANDA experiment will be installed, the other straight section will be equipped with a High Energy Electron Cooler [1]. A longitudinal and transverse stochastic cooling system will be used in the momentum range from 3.8 GeV/c to 15 GeV/c [4]. Adjustment of beta functions at target and electron cooler, to achieve highest beam lifetimes, most efficient cooling and highest luminosities are the main design requirements. The basic design consists of FODO cell structures in the arcs. The arc quadrupole magnets are grouped into four families, to allow a flexible adjustment of transition energy, horizontal and vertical tune, and dispersion. The details of the linear lattice and operation modes will be discussed in this presentation.

INTRODUCTION

The High Energy Storage Ring HESR is dedicated to the field of high energy antiproton physics with high quality beams over the broad momentum range from 1.5 to 15 GeV/c to explore the research areas of hadron structure and quark-gluon dynamics, e.g. non-perturbative QCD, confinement, and chiral symmetry. An important feature of the new facility is the combination of phase space cooled beams with internal targets which opens new capabilities for high precision experiments.

Wide international collaborations (e.g. PANDA [3]) with a rich scientific program are working on new experiments with antiprotons in the energy range between the CERN Antiproton Decelerator AD and the Tevatron energies.

The following requirements have to be taken into account to make the HESR design well suited for the experimental demands:

- large dynamic aperture [5],
- highly efficient antiproton injection and accumulation,
- high accuracy and stability of beam parameters for high precision experiments,
- appropriately small beam size at the interaction point with the internal target,
- powerful beam cooling systems to counteract beam heating (from beam-target interaction and intra-beam scattering) to achieve high luminosity and high beam quality [6],[7].

Special equipment like multi-harmonic RF cavity, electron cooling and stochastic cooling enable the high performance of this antiproton machine, which will make high precision experiments feasible that are not possible up to now. Key tasks for the design work to fulfil these requirements are:

- multi harmonic RF cavity [8],
- technical design study and prototyping of critical elements for high voltage electron cooling system,
- high sensitivity stochastic cooling pickups for the frequency range 4-6 GHz,
- powerful beam cooling systems to counteract beam heating (from beam-target interaction and intra-beam scattering) to achieve high luminosity and high beam quality.

The combination of electron and stochastic cooling is necessary to fulfil all user demands. Electron cooling is favoured for high resolution (HR) experiments with very small momentum spread of σ_p/p of about 4×10^{-5} at momenta up to 8.9 GeV/c. Stochastic cooling will be used in the momentum range from 3.9 GeV/c up to the maximum momentum of 15 GeV/c for high luminosity experiments with luminosities of $2\ 10^{32}\ \mathrm{cm}^{-2}\ \mathrm{sec}^{-1}$ and momentum spread of 10^{-4}.

HESR LATTICE DESIGN

The HESR is designed as a racetrack-shaped storage ring with a magnetic bending power of 50 Tm. The storage ring will cover an area of about 120 m by 250 m with a circumference of 575 m including 132 m long straight sections. One of these sections will be used for the experimental installation with an internal target (either a supersonic H_2 gas jet or frozen H_2 pellets of 30-50 μm diameter) and a large detector complex for secondary hadron and lepton detection. The detector concept requires a large aperture dipole magnet for the separation of secondary particles at small laboratory angles. This straight section will also accommodate the RF cavities as well as the equipment for two injection systems. The first one is needed for injection of protons and antiprotons from RESR, the second one for protons circulating in opposite direction without changing the polarity of the magnet system of HESR. These protons will be injected via SIS18. The second straight section is used for the electron cooler. At both ends of the electron cooler compensation solenoids are foreseen. In addition a stochastic cooling system for transverse and longitudinal cooling is planned.

Two other experimental groups (ASSIA and PAX [1],[9]) also expressed interest in spin physics experiments at the HESR. In the HESR design sufficient

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[#] b.lorentz@fz-juelich.de

space is reserved to allow an upgrade for polarized beams.

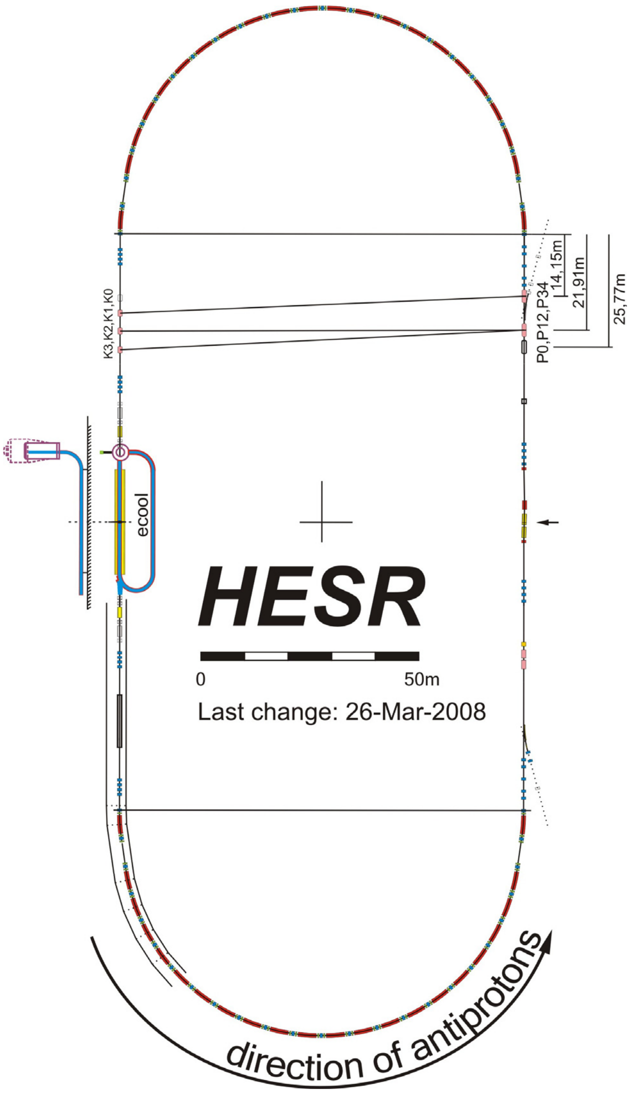

Figure 1: Schematic view of the HESR ring, electron cooler is located in the middle of the left straight section, the target position for PANDA is indicated by the arrow in the middle of the right straight section. Injection is placed on the bottom right, positions of stochastic cooling pickups (P0-4) and kickers (K0-4) are also indicated.

The magnet structure of the HESR needs to fulfil several different requirements. The straight section of the ring should be dispersion free. The betatron amplitude functions (beta functions) at the interaction point with the target as well as at the electron cooler need to be adjustable over a large range, to allow best overlap with target and electron beam, respectively. At the target the beta functions range from 1 – 10 m, at the electron cooler from 25 to 100 m. The HESR will be operated as synchrotron ring with a fixed injection momentum of 3.8 GeV/c and acceleration as well as deceleration to momenta between 1.5 and 15 GeV/c. Therefore the transition energy in the ring should be adjusted to values outside that range, to avoid crossing of transition energy, that would lead to unwanted beam losses and emittance growth. In addition, beta functions and phase advance between pickups and kickers of the stochastic cooling system have to be adjusted for optimum operation. Several different lattice options have been investigated that would satisfy these requirements.

Table 1: Lattice Properties

lattice type	FODO with dispersion suppression
magnet type	normal conducting
number of dipoles	44
length of dipole	4.2 m
dipole field	0.17-1.7 T
deflection angle	8.2 deg.
number of quadrupoles	50 (arcs) + 34 (straights)
quadrupole length	0.5 m
max. gradient	25 T/m
working point	7.61
arc $\beta_{xy}^{max.}$	24-80 m
$D_x^{max.}$	2-8.5 m
straight $\beta_{xy}^{max.}$	490 m -110 m
target β_{xy}	1-10 m
cooler β_{xy}	25-200 m
chromaticity ξ_{xy}	-20 to -10
transition γ_{tr}	6.2 – 25
arc length	157 m
ring length	576 m
injection	150 m long bunches from RESR at 3.8 GeV/c
horizontal/ vertical geometrical acceptance	3.8 / 4.4 mm mrad for $\beta_{target} = 1$m 13 / 10 mm mrad for $\beta_{target} = 3$m
relative momentum acceptance	$\pm 2.5\times10^{-3}$
dipole ramp rate, energy change / turn	25 mT/sec, 400 eV
high resolution mode (HR): 10^{10} particles	below 8.9 GeV/c peak luminosity $2\cdot10^{31}$ cm^{-2}sec^{-1} rms momentum spread about 4×10^{-5}
high luminosity mode (HL): $<10^{11}$ particles	whole energy range peak luminosity $< 2\times10^{32}$ cm^{-2}sec^{-1} rms momentum spread about 10^{-4}
rms beam size (radius) at target	~1 mm

The lattice type chosen for the HESR consists of normal conduction dipole and quadrupole magnets. The arcs consist of a FODO type lattice structure. To achieve dispersion free straight sections, an option with dispersion suppression at the exit of each arc is foreseen.

Lattice Structure in the Arc Sections

For a regular FODO lattice in the arcs, the value of transition energy would be located inside the energy range of the ring. However, this can be overcome by dividing the focussing and defocusing quadrupole families in the arcs into several sections with different focussing. The transition energy can then be moved outside the HESR energy range. To still be able to reach zero dispersion in the straights a well known dispersion suppression scheme can be applied. In the last FODO cell of each arc, one dipole is removed, and the missing bending power is distributed equally to the rest of the dipole magnets in the arc.

Lattice Structure in the Straight Sections

In each straight section the focussing structure consists of four quadrupole triplets. This allows telescopic operation of the straight sections with a betatron phase advance of 2π in the horizontal and vertical plane on either side of the HESR ring. For higher flexibility in adjustment of beta functions at target and electron cooler, the triplets can be operated away from the telescopic setting.

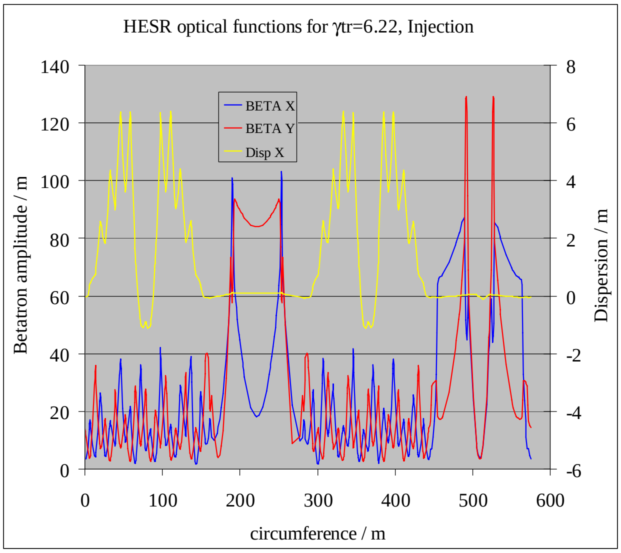

Figure 2: Optical functions for the HESR normal conducting magnet lattice with dispersion suppression for transition energy of γ_{tr}=6.22. Shown are the horizontal betatron amplitude β_x (blue), the vertical betatron amplitude β_y (red), and the horizontal dispersion D_x (yellow) along the ring.

In Figures 2 and 3 two examples of the optical functions for the whole HESR ring are shown for transition energy of γ_{tr} of 6.22 and 13.44, respectively.

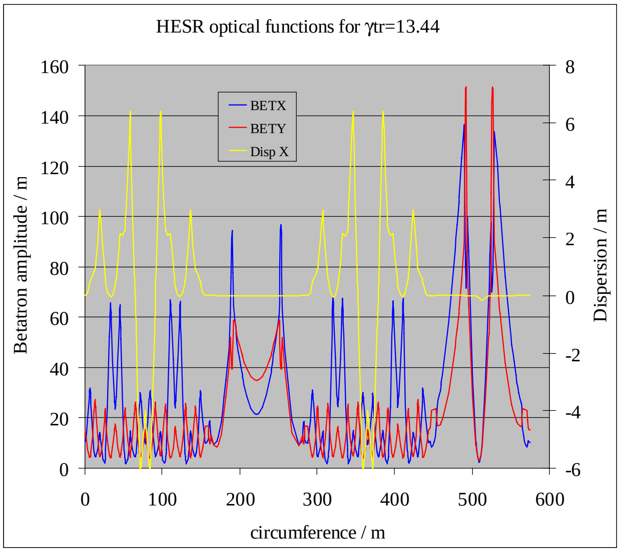

Figure 3: Optical functions for the HESR normal conducting magnet lattice with dispersion suppression for transition energy of γ_{tr}=13.4. Shown are the horizontal betatron amplitude β_x (blue), the vertical betatron amplitude β_y (red), and the horizontal dispersion D_x (yellow) along the ring.

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