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Beam performance and luminosity limitations in the high-energy storage ring (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 synchrotron storage ring in the momentum range 1.5–15 GeV/c. An important feature of this new facility is the combination of phase space cooled beams and dense internal targets (e.g. pellet targets), which results in demanding beam parameter requirements for two operation modes: high luminosity mode with peak luminosities to $2\times10^{32}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$, and high-resolution mode with a momentum spread down to 10^{-5}. To reach these beam parameters one needs a very powerful phase space cooling, utilizing high-energy electron cooling and high-bandwidth stochastic cooling. The effects of beam-target scattering and intra-beam interaction are investigated in order to study beam equilibria and beam losses for the two different operation modes.

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Keywords: Storage ring; Beam-target interaction; Intra-beam scattering; Phase space cooling

1. Introduction

The high-energy storage ring (HESR) 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 [1,2]. According to the conceptual design report (CDR) [1] the HESR was planned with only one internal interaction point, equipped with the PANDA detector [3]. Two other experimental groups (ASSIA [4] and PAX [5,6]) also expressed interest in spin physics experiments at the HESR. This requires a synchrotron mode to accelerate polarized beams in the HESR.

2. Design issues and experimental requirements

The HESR lattice is designed as a racetrack-shaped storage ring, consisting of two 180° arc sections connected by two long straight sections (see Fig. 1). One straight section will mainly be occupied by the electron cooler. In a later stage a Siberian snake can be installed to preserve polarization during acceleration [7]. The other straight section will host the experimental installation with internal frozen H_2 pellet jet target, injection kickers/septa and RF cavities. Two pickup tanks for stochastic cooling are located close to the ends of one straight section while the stochastic kicker tanks are placed opposite in the other straight section, diagonally connected with signal lines. Special requirements for the lattice are dispersion-free straight sections and small betatron amplitude of about 1 m at the internal interaction point, imaginary transition energy, and optimized ion optical conditions for beam cooling (e.g. matched betatron amplitudes at the pickups and kickers of the stochastic cooling system and in the electron cooler section). Details of the ion optical layout and features of the lattice design are discussed in Ref. [8]. The antiproton beam is accumulated in the CR/RESR complex at 3.8 GeV/c [9]. Beam parameters depend on the number of accumulated particles.

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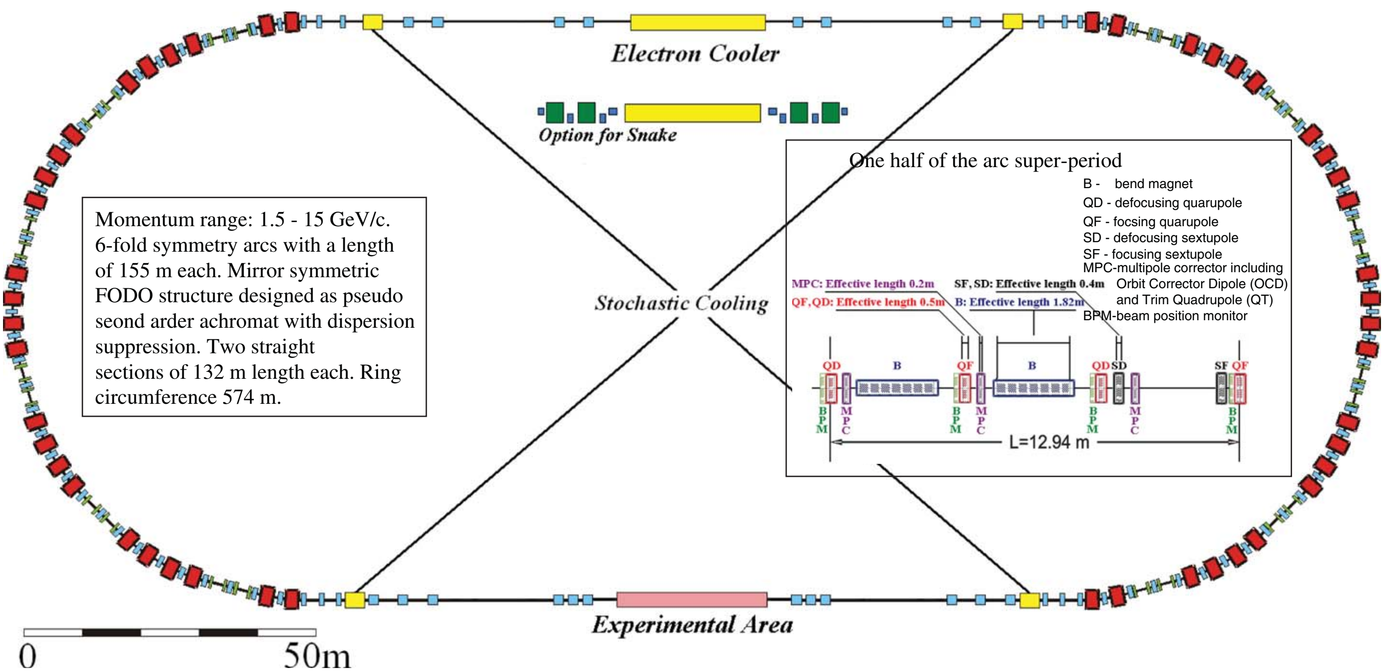

Fig. 1. Schematic view of the HESR with 6-fold symmetry lattice. Tentative positions for injection, cooling devices and experimental installations are indicated. Also shown is the arrangement of elements in the superperiod.

Table 1 summarizes the specified injection parameters, experimental requirements and operation modes. Demanding requirements for high intensity and high-quality beams are combined in two operation modes: high luminosity (HL) and high resolution (HR), respectively. The high-resolution mode is defined in the momentum range from 1.5 to 9 GeV/c. To reach a momentum resolution down to $\sigma_p/p\sim 10^{-5}$, only 10^{10} circulating particles in the ring are anticipated. The high-luminosity mode requires an order of magnitude higher beam intensity with reduced momentum resolution to reach a peak luminosity of $2\times 10^{32}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ in the full momentum range.

3. Beam cooling systems and targets

A feasibility study for magnetized high-energy electron cooling was presented by the Budker Institute for Nuclear Physics (BINP) [10]. An electron beam up to 1 A, accelerated in special accelerator columns to energies in the range of 0.45–8 MeV, is proposed for the HESR. The 30 m long solenoidal field in the cooler section ranges from 0.2 to 0.5 T with a magnetic field straightness on the order of 10^{-5}. Recently it was decided, that electron cooling should only cover the momentum range of the high-resolution mode, leading to maximum beam energy of 4.5 MeV. Further design work on the electron cooler is lead by The Svedberg Laboratory (TSL) in Uppsala in cooperation with other institutes including the Budker Institute, Fermi National Accelerator Laboratory (FNAL) and industry [11]. The main stochastic cooling parameters were determined for a system utilizing quarter-wave loop pickups and kickers [2]. Stochastic cooling is presently specified above 3.8 GeV/c. This beam cooling method has the advantage of being capable to separately cool the transverse and longitudinal phase space.

Frozen H_2 pellets are required to reach the specified target thickness of 4×10^{15} atoms cm^{-2}. The pellet size is 20–40 μm in diameter. The pellets velocity is 60 m s^{-1} with a flow rate of 60000 pellet/s, leading to an average longitudinal distance between pellets of roughly 1 mm. The pellet stream moves with an angular divergence of $\pm 0.04^\circ$ (FWHM) corresponding to a transverse position uncertainty of ± 1 mm (FWHM) at the interaction point [12]. For a betatron amplitude of 1 m, a beam emittance on the order of 1 mm mrad is required to ensure sufficient beam-target overlap.

4. Cooled beam equilibria

Beam equilibrium is of a major concern for the high-resolution mode. Calculations of beam equilibrium between electron cooling, intra-beam scattering and beam-target interaction are being performed utilizing different simulation codes like BETACOOL by Meshkov et al. (JINR, Dubna), MOCAC by Bolshakov et al. (ITEP, Moscow), and PTARGET by Franzke et al. (GSI, Darmstadt). Results from different codes for HESR conditions are compared in Ref. [13]. Studies of beam equilibria for the HESR are also carried out by Reistad for electron cooled beams [2] and by Stockhorst for stochastically cooled beams [14] utilizing the BETACOOL code.

To simulate the dynamics of the core particles, an analytic rms model was applied for the calculation