STATUS OF THE HESR ELECTRON COOLER DESIGN WORK*

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Abstract

The electron energy of the HESR electron cooler shall be variable from 450 keV to 4.5 MeV, and the design shall not exclude a further upgrade to 8 MeV. Operation of the HESR in collider mode, which requires electron cooling of both protons and antiprotons traveling in opposite directions, is an option for the future.

INTRODUCTION

The High Energy Storage Ring (HESR) [1] will be part of the FAIR facility [2]. HESR will be used with high-quality antiproton beams ranging from 1.5 to 15 GeV/*c*. Both electron cooling and stochastic cooling [3] schemes are foreseen. Electron cooling will be used in order to achieve the most demanding beam requirements for the high-resolution mode of PANDA [4]. This high-resolution mode is required from the lowest momentum of antiprotons in HESR, 1.5 GeV/*c*, up to 8.9 GeV/*c*. The electron energy in the electron cooling system shall therefore range from 400 keV to 4.5 MeV. The design shall however not exclude a further upgrade to the full momentum range of HESR, or up to 8 MeV electrons.

Earlier studies of the electron cooling system for HESR have been carried out by the Budker Institute of Nuclear Physics and GSI [5, 6]. The responsibility for the ongoing design work on the HESR now belongs to a consortium consisting of FZ Jülich, GSI, and Uppsala University.

Fermilab has demonstrated cooling of 8 GeV antiprotons with a recirculating electron beam at 4.3 MV [7].

The HESR electron cooler has to compensate the target effects of the internal target. This requires magnetised electron cooling. In this respect the HESR electron cooler will differ from the one at FNAL. However, the design of the high voltage part will be similar and based on a Pelletron [8]. Other alternatives that have been considered include basing the high-voltage on a Dynamitron [9, 10], or to create the high-voltage by charging the high-voltage platform with an H^- beam from a cyclotron [5, 6]. The possibility to take advantage of the experience gained at Fermilab with the Pelletron leads to our choice of this preferred alternative.

ELECTRON COOLER LAYOUT

The layout of the electron accelerator has to be vertical in order to support the weight of the solenoids generating the longitudinal magnetic field. Figure 1 shows an overall layout. This can be adapted to a possible future update of HESR to collider mode [11].

CHOICE OF PARAMETERS

Magnetic Field and Electron Beam Radius

Busch's theorem implies that the magnetic flux, which is contained in the electron beam, remains constant during the beam transport from the cathode to the collector. The magnetic field in the accelerating column is limited by the power that can be transmitted to the high voltage terminal using rotating shafts, and can be cooled away by the insulating SF_6 gas. The accelerating tubes from National Electrostatic Corporation have an aperture diameter of 1 inch, which cannot be increased while guaranteeing the high-voltage performance, and this aperture must have a sufficient safety margin over the electron beam diameter. Therefore, it is necessary to trade-off electron beam diameter against the magnetic field in the cooling section.

We have concluded that the electron beam diameter in the acceleration sections shall be 17 mm in order to have a sufficient margin to a 25.4 mm aperture, and that the magnetic field in the accelerating section can be up to 0.07 T. Thus, the magnetic flux, which is contained in the electron beam in the cooling section, is going to be $0.07\times\pi\times0.085^2$ Tm^2.

It has been shown [6] that magnetization of the electron beam at 15 GeV/*c* requires a magnetic field of about 0.2 T. In [5, 6] a magnetic field of 0.5 T was chosen.

On the other hand, a lower value of the magnetic field in the drift tube allows a larger diameter of the electron beam. This reduces the effect of resonances induced by the non-linear tune shift caused by the electron beam onto the antiproton beam. We therefore choose a magnetic field strength of 0.2 T in the cooling section. The electron beam radius in the cooling section then becomes 5 mm.

Beta Values at Cooling Straight Section

Large beta-values at the cooling section will speed up the cooling-down process and increase the longitudinal cooling force. On the other hand, if the beta values are too large, a significant fraction of the antiprotons will be outside of the electron beam in the beginning of the cooling process. We choose the horizontal and vertical beta values at the cooler to be $50\,\mathrm{m}\times\beta\gamma/\beta_0\gamma_0$ (where β and γ are the relativistic parameters, and β_0 and γ_0 are those parameters at 3 GeV) to have more than 90 % of the antiprotons inside of the electron beam (with radius 5 mm) in the beginning of the electron cooling process.

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Beam Spot on Internal Target

The anticipated internal target for PANDA is a hydrogen pellet target [12]. In order to keep the ratio between the maximum instantaneous count rate $\hat{L}$ and the average count rate $\langle L \rangle$ reasonable, the antiproton beam size must not be too small [13]. We have found that the beam spot on the target should not be smaller than 0.3 mm in order to maintain $\hat{L}/\langle L \rangle \leq 5$. This will be achieved by an appropriate choice of beta value at the target and especially by introducing a controlled misalignment between the electron and antiproton beams. Such a misalignment creates antidamping of antiprotons with small betatron amplitude, as has been observed at CELSIUS [14]. The appropriate tilt angle between the antiproton and electron beams has been found by BETACOOL [15] to range between 10^{-5} radians at 15 GeV/*c* and 10^{-4} radians at 1.5 GeV/*c* while the beta values in both planes are 8 m and 2 m at the highest and the lowest momenta respectively.

MAGNET SYSTEM

The electron beam is transported in a longitudinal magnetic field, which extends from the electron gun to the collector. As already mentioned above, the magnetic field strength is 0.07 T in the acceleration/deceleration columns and 0.2 T in the interaction region. The field is also 0.2 T in the electron gun, but decreases to about 0.01 T in the collector. The magnetic field in the columns and in the gun and collector must be created with solenoids placed on high voltage, and with power transmitted to high voltage by mechanical means (rotating shafts).

The requirement on straightness of the magnetic field lines in the interaction section is very high, indeed the rms. angle of the magnetic field lines must be as good as 10^{-5} radians. The ongoing design work is on a normal-conducting magnet system. Achieving such precision has been achieved in much smaller normal-conducting electron cooling systems [16].

The magnetic field in the interaction region will be created with “pancake” solenoids, which are mechanically adjustable, similar to what is described in [16], but with a longitudinal separation between 80 mm thick “pancakes” of 90 mm. This is to assure access to the vacuum chamber for instrumentation and pumping. The inner and outer diameter of the pancakes is 450 mm and 850 mm respectively. The pancakes are mounted in 2,970 mm long steel subunits with external cross section dimensions 1 m × 1 m. Each such subunit is also mechanically adjustable, and also contains windings, which can produce horizontal and vertical magnetic fields. These will be used for correcting for mechanical shifts of the subunits, which are likely to occur over time.

MAGNETIC FIELD MEASURING SYSTEM

As mentioned above, the magnetic field lines must have a straightness of 10^{-5} radians rms. We have identified two

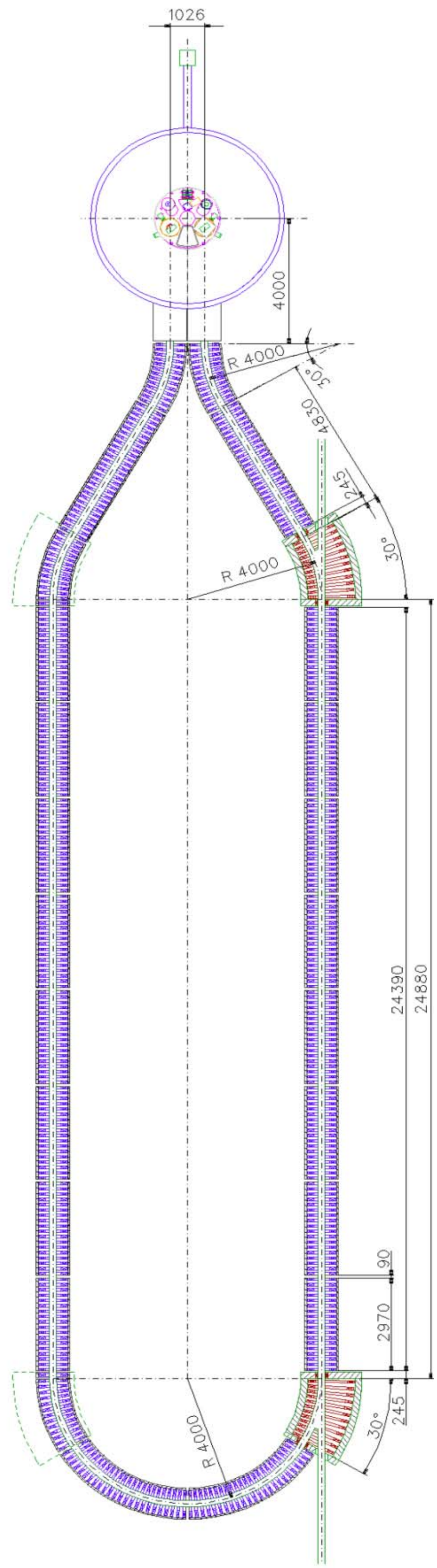

Figure 1: Top view of the HESR electron cooling system.

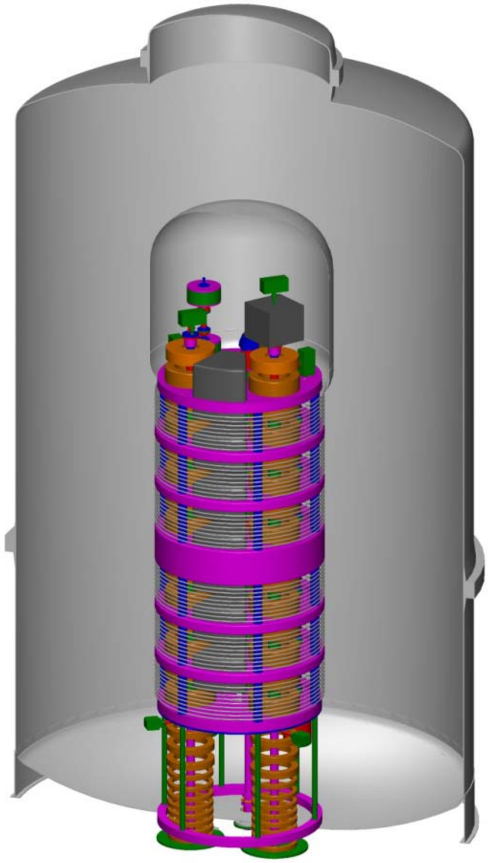

Figure 2: High voltage tank and column based on a 6 MV NEC MV Pelletron.

possible methods to measure the straightness of the magnetic field lines. One method is the compass-needle method, developed by the BINP and successfully used to measure the straightness of the magnetic field lines in many electron-cooling systems [16]. The other method is based on an NMR-probe with resolution 10^{-7} [17], and comparing the measured magnetic field strengths while applying horizontal and vertical magnetic fields with strength 10^{-2} of the longitudinal field of both polarities (four measurements). The horizontal and vertical magnetic fields must be precisely perpendicular to the wanted field direction, and can be created with windings, that travel on the same carriage as the NMR probe.

ELECTRON BEAM DIAGNOSTICS AND BEAM-BASED ALIGNMENT

The electron beam diagnostics will be based on that at the Fermilab high-energy electron cooling system [18]. It will include beam position monitors, beam loss monitors, beam profile monitors (multiwire chamber and optical transition radiation devices) and scrapers. Beam position monitors will be placed between each subunit on the interaction straight section, and will be used for beam-based alignment to maintain the electron beam on the same straight line as the antiproton beam. Scrapers will be used to measure electron-beam envelope oscillations.

ELECTRON GUN AND COLLECTOR

The design of the electron gun and collector are based on the design of the gun and collector in the Fermilab high-energy electron cooling system [19, 20]. Calculations have been performed with ULTRASAM [21]. Details are described in separate notes [22].

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