STATUS OF ELECTRON COOLER DESIGN FOR HESR*

B. Gålnander#, T. Bergmark, S. Johnson, T. Johnson, T. Lofnes, G. Norman, T. Peterson, K. Rathsman, D. Reistad
(The Svedberg Laboratory, Uppsala University, Sweden),
H. Danared
(Manne Siegbahn Laboratory, Stockholm University, Sweden).

Abstract

The HESR-ring of the future FAIR-facility at GSI will include both electron cooling and stochastic cooling in order to achieve the demanding beam parameters required by the PANDA experiment. The high-energy electron cooler will cool antiprotons in the energy range 0.8 GeV to 8 GeV. The design is based on an electrostatic accelerator and shall not exclude a further upgrade to the full energy of HESR, 14.1 GeV. The paper will discuss prototype tests of critical components such as the electron beam diagnostics and the magnetic field measuring system.

INTRODUCTION

The High Energy Storage Ring (HESR) is a part of the future FAIR facility [1] and will be dedicated to Strong interaction studies with antiprotons in the momentum range of 1.5 to 15 GeV/c. In order to meet the demanding requirements of the experiments both stochastic cooling [2] and electron cooling will be employed. Electron cooling is needed, in particular, to reach the low momentum spread requirements for the high-resolution mode of PANDA.

The design of the high-energy electron cooler is based on an electrostatic accelerator and will be used to cool antiprotons in the energy range 0.8 GeV to 8 GeV. However, the design should not exclude a future upgrade to the full energy of HESR, 14.1 GeV. This was one reason to base the design on a Pelletron which is modular and possible to extend in energy. [3]. A similar electron cooling system is in operation at Fermilab [4].

The PANDA experiment will use an internal target, most probably a hydrogen pellet target. The cooler will have to compensate for the effects of this target on the antiproton beam. For this to take place efficiently, magnetised cooling is required. Detailed calculations of the electron cooling force are discussed in Ref. [5].

Technical challenges

One challenge for the electron cooler design is beam alignment between electrons and anti-protons. The deviation of the electron beam relative to the anti- proton beam should be smaller than 10^{-5} radians rms to fulfil the beam quality and lifetime demands of the anti-protons. This requires very accurate procedures for beam diagnostics and alignment along the 24-meter interaction section.

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bjorn.galnander@tsl.uu.se

The field must also be continuous enough or shaped so than an electron beam with diameter 10 mm and energy anywhere in the range from 0.45 to 8 MeV must not be “heated” by any variation of the magnetic field. The dipole and envelope oscillations created by the total effect of all such transitions in the system should be smaller than a corresponding Larmor radius of 0.1 mm.

LAYOUT

The Layout of the HESR Electron Cooler is shown in Figure 1. The electrons are produced by the gun in the high voltage tank and circulate the beam transport system before being captured by the collector. The layout of the cooler has been described more in detail elsewhere [3].

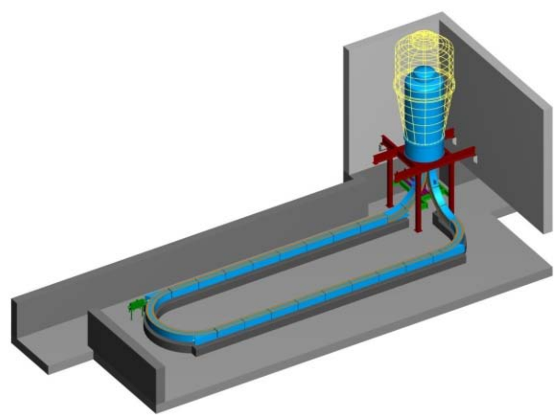

Figure 1: Layout of the HESR electron cooler showing the Pelletron tank and the beam line system of solenoid magnets. The length of the interaction section is 24 m. In the case of a future upgrade to 8 MeV a larger high voltage tank is needed, as indicated in the figure.

Magnet system

The electron beam transport system is divided into a number of manageable modules, see Figure 2. These modules are about three meters at the straight sections and two meters in the arcs. The modules consist of short pancake solenoids mounted in a rigid iron stand. The pancake solenoids can be adjusted individually to a high precision [6]. The modules are designed to be mechanically rigid so that floor instabilities or other mechanical shifts should not deform the modules. Corrector windings of the same length as the modules will be used to correct the direction of the magnetic field.

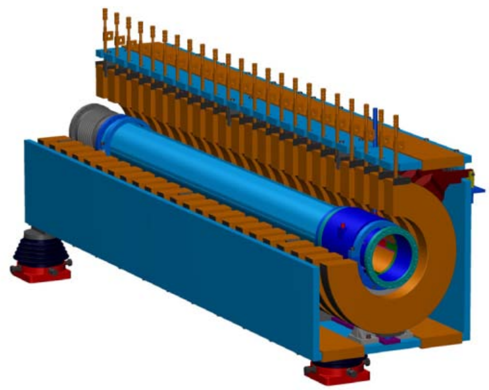

Figure 2: Each straight module on the interaction straight includes: 23 pancake solenoids, four corrector windings, a vacuum chamber with diagnostic unit and bellows.

STRAIGHTNESS OF THE LONGITUDINAL MAGNETIC FIELD

The straightness of the longitudinal magnetic field at the interaction straight section is an important parameter in order to reach the necessary cooling force. As already mentioned, the straightness has to be adjusted to 10^{-5} rad. rms. It should be possible to verify the magnetic field straightness without opening the vacuum system.

A prototype straightness measurement system, which is UHV-compatible, has been designed and manufactured. The system is based on a compass needle sensor and consists of a carriage with wheels that can be moved along the interaction straight under vacuum, see Fig. 3. The vacuum tube at the interaction section is made of aluminium and has integrated rails which the wheels rest on. The sensor has to be kept in a position closer than 5 mm from the symmetry axis.

The magnetic field sensor has been designed and manufactured by BINP [7]. The sensor mounted in its dedicated holder is shown in Figure 3. Similar devices have been used for verification of the straightness of the magnetic field lines in much shorter electron cooling systems [6]. Also, previous devices have not been designed to be ultra-high vacuum compatible.

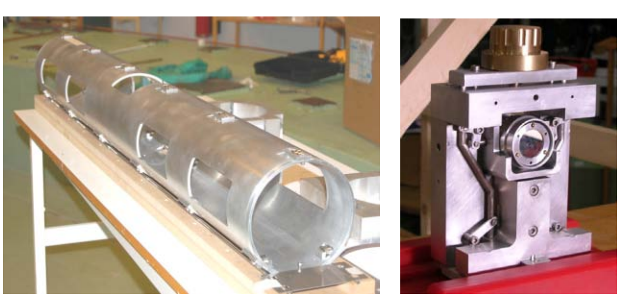

Figure 3: Carriage used for magnetic field measurements (left). Compass based sensor mounted in dedicated holder mechanism (right).

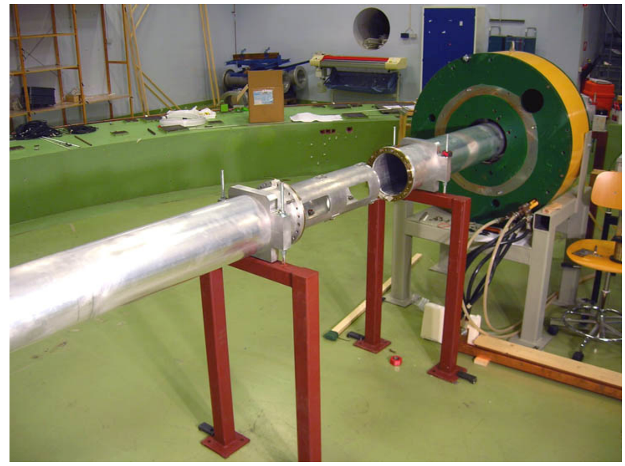

Figure 4: Test set-up with the carriage for the magnetic field probe.

Prototype tests

The prototype set-up of the straightness measurement system has been tested at TSL. The objectives of the tests were to establish that the system will give the expected sensitivity, to test the stability and to test ability to move the carriage inside the vacuum tube bridging the gaps where bellows and diagnostics units will be situated. The set-up including two prototype vacuum tubes and a test solenoid are shown in Figure 4.

The set-up also includes a laser system. The laser light is reflected by a mirror mounted on the compass needle and is detected by a position sensitive four-sector detector from Thorlabs, PDQ80A. The signal from the detector is digitized by an ADC.

The measurements have to be carried out all along the 24 m straight section. This means that it must be possible to move the carriage on the rails, bridging the gaps where the bellows and diagnostic units are situated. In order to test this two prototype vacuum tubes with rails inside were produced, and set up with a gap of about 0.7 m in-between, see Figure 4. The movement of the carriage was tested with respect to misalignment of the two tubes. From these tests it was concluded that the carriage design can tolerate a misalignment of ± 1 mm of the vacuum tubes in order to bridge the gap smoothly. A few modifications of the carriage design are suggested on the basis of the prototype tests which will improve the tolerance to misalignment errors.

The stability of the sensor was tested by applying a step in the current to the transverse magnetic field coils. The response by the sensor can be shown in Figure 5. It can be seen that the time constant for the damping of the oscillations in the sensor is about 0.5 s. From these tests it can be concluded that the measurement procedure of probing the field direction over the full length of the interaction section is not seriously impaired by the damping time for mechanical oscillations of the sensor.

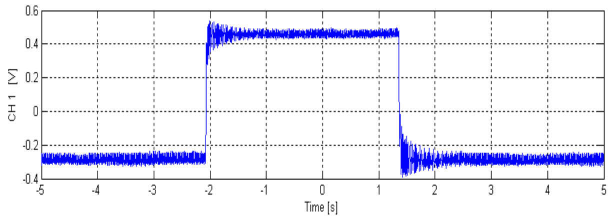

Figure 5: The response of the sensor of a step in the field direction.

The sensitivity of the measurement system was tested by adding a transverse field to the longitudinal field of 0.2 T to alter direction of the field. An added field of $1x10^{-5}$ (2 µT) gives a change of position of 40 pixels at the detector. The error was estimated to be less than 20 pixels rms. This gives an accuracy of the straightness measurements of better than of $1x10^{-5}$. This means that the prototype set-up fulfils its specifications.

ELECTRON BEAM DIAGNOSTICS

In the interaction straight section of the electron cooler there will be 9 pairs of beam position monitors, horizontal and vertical. Due to space limitations, the position monitors have to be integrated with scrapers. A prototype of such a device has been designed and manufactured and will be tested at TSL, see Figure 6. This unit has been named SPUC, Scraper and Pick-Up Combined.

When the scraper plates are folded into the beam centre the unit acts as a scraper, and when the scraper plates are in their parking position, the unit acts as a position monitor. The scraper will mainly be used to measure the envelope oscillation of the beam.

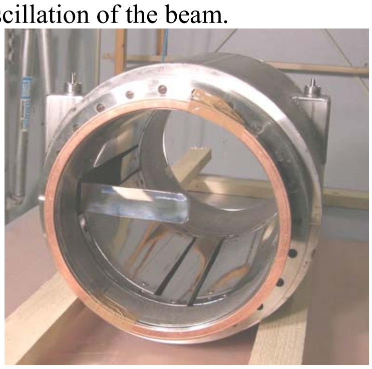

Figure 6: SPUC prototype. (Before the orifice is drilled in the scraper.)

Scraper tests

In order to test the principle of the scraper to measure the electron beam size, a prototype set-up was built at TSL. The CELSIUS cooler, which is now taken out of operation, was use as a test bench. One section was added to accommodate the electron beam scraper prototype. The extra section is based on two pancake solenoid prototypes and includes a scraper plate with an orifice mounted on a transfer rod. A stepper motor is used to move the scraper into the beam position.

The principle of using the scraper as a way of measuring the beam size is that x-rays are generated when the beam hits the scraper. A photodiode was used as detector. The objective of the test was to verify that we could determine the electron beam diameter with sufficient resolution using this set-up.

The tests were carried out with an electron beam of 35 keV energy and current 10 mA. The longitudinal magnetic field was 0.1 T. The electron beam was moved using steering coils until the beam hit the scraper edge. In order to test the resolution of the beam size the beam was moved in small steps, around 70 µm, and the x-ray signal from the photodiode was measured. The step size was limited by the The result is shown in Figure 7. The shape of the curves is due to oscillations of the electron beam at 100 Hz due to ripple in the power supplies of the steering coils. From the results it can be concluded that the resolution of our set-up is about 50 µm. This means that the prototype fulfils our required resolution of 100 µm.

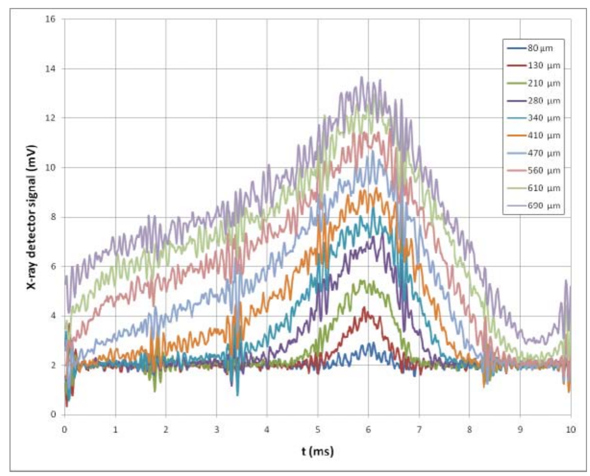

Figure 7: The x-ray signal as a function of position of the beam.

CONCLUSIONS

A prototype for magnetic field straightness measurements has been tested. One of the conclusions is that the system gives an accuracy of the straightness measurements which is better than $1x10^{-5}$. Prototype tests of a scraper for electron beam diagnostics have also been carried out. The conclusion is that the system can be used for determining the electron beam radius with a resolution of 50 µm.

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