The 320-keV ESR-Electron Cooler

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1 Summary

An electron cooler has been constructed as part of the heavy ion experimental storage ring (ESR) at GSI. The design principles and technical data have been described elsewhere[1]. In this paper results from a linear test arrangement consisting of gun- and collector-sections will be discussed together with the results of the fine-tuning of the magnetic structure. In addition, we report upon the construction and commissioning of the complete cooler system. First cooling tests have been made with a 50 keV, 1 A electron and a 91.8 MeV/u Ar^{18+} beam.

2 Introduction

For the ESR heavy ion storage ring at GSI an electron cooler was designed and constructed.

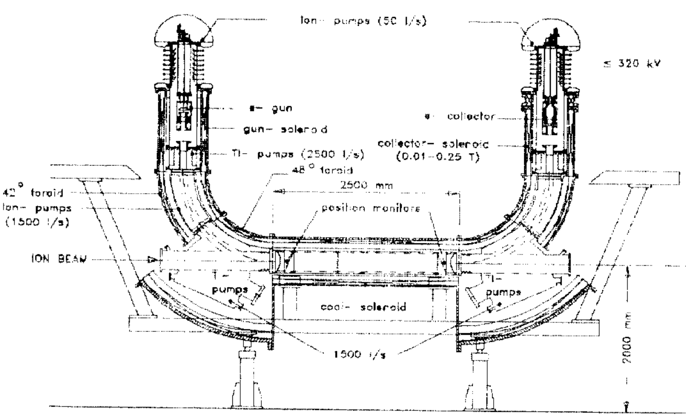

Fig. 1: shows a cross sectional view of the electron cooler. It is built up vertically and the electron beam is bent 90° into and out of the ion beam.

The electron beam energy should be up to 320 keV, the electron current up to 10 A. The main parameter of the cooler are listed in the table below.

ion energy	30 to 560 MeV/u
electron energy	16.5 to 320 keV
electron beam current	10 A (above 30 kV)
electron beam density	$2 \cdot 10^8$ cm^3
electron beam diameter	50 mm
electron beam temperature	0.3 eV
length of cooling section	2500 mm
diameter of cooling section	250 mm
magnetic guiding field	0.1 to 0.25 T
bending angle of toroids	90^0
bending radius in toroids	1200 mm
transversal magnetic field component	10^{-4}
power consumption collector	$\leq$ 50 kW
power consumption total (max)	500 kW

The quality of the electron cooler depends strongly on low electron temperature i.e. low transversal energy. This transverse energy is determined by the cathode temperature and inaccuracies of power supplies, geometry and magnetic field.

Therefore field errors must not be larger than 10^{-4}. But, to keep purchase costs low, it was decided to specify for the manufacturer much weaker tolerances, 10^{-2} to 10^{-3}, and to compensate field errors later with the help of small correcting windings.

For these measurements we prepared a system which allows a determination of the local field harmonics along the axis of the solenoid. The radial field components at each position were determined as a function of the azimuth with the help of a hall probe, which was moved at a constant radius around the axis. The measured values were Fourier analysed. With these results it was possible to eliminate each multipole with the help of a single set of correcting windings (and a single power supply) by choosing the local number of windings and their orientation properly[2].

A constant value of the horizontal and/or vertical dipole field components along the solenoid (dipole components are easily extracted from the amplitude A_1 and phase α_1) is, if present, caused by a small angle between the axis of the solenoid coil and the mechanical axis of the cooler setup. The latter was used as a reference during alignement of the measurement system. During several measurements after dis- and remounts of the cooler, and the measurement setup such fields were reproducable only within $\pm$ 2 Gauss, which is 0.1% of the longitudinal flux density. We refer this to unavoidable alignement imperfections. The cooler solenoid will, therefore, contain special dipole coils to steer the field direction.

Fig. 2 shows some results of the measurements and what could be achieved by adding above mentioned correcting windings. As one can see, the horizontal dipole component B_x could be flattened to $\pm$ 0.1 Gauss (at 2 kG axial flux density), and was stable after dis- and remount. On the other hand, the vertical component was, even after a second correcting measurement, reproducable only

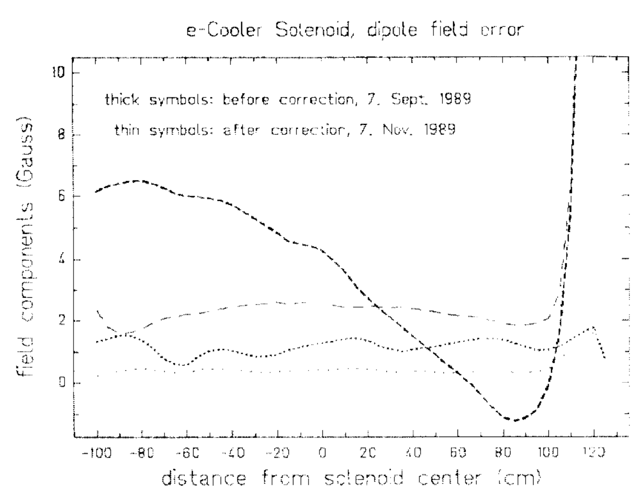

Fig. 2: Transversal field components B_y and B_x before and after correction.

within ± 0.5 Gauss. This we refer to small mechanical deformations of the solenoid when the toroidal sectors were attached to the system. The cooler is built up vertically.

3 The Linear Test Arrangement

To test the gun and the collector under realistic conditions in advance of the cooler commissioning a linear test facility was assembled from the complete gun and collector section. Both parts were flanged together and mounted vertically on a 3 m high platform, with the gun at the top.

The resulting linear beam path length from gun cathode to the collector pot was approx. 1.6 m and the grounded drift tube in the centre (from main acceleration to deceleration gap) was 70 cm long (Fig.3).

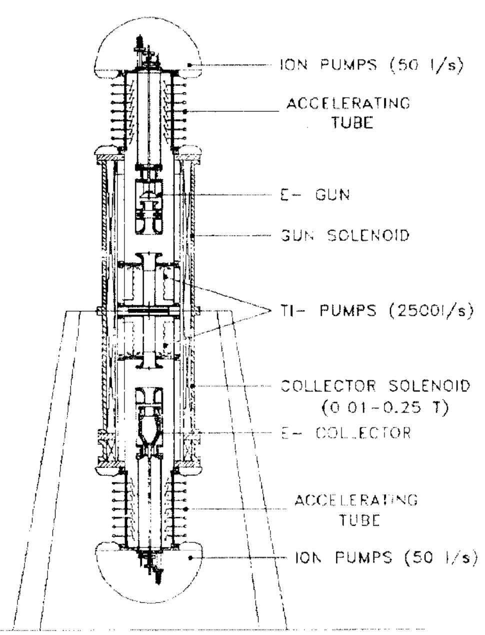

Fig. 3: Test Assembly

We started investigations with magnetic field measurements and pyrometric measurements of the cathode temperature versus heating power. Next we shot a weak (≈ 100 μA) pilot beam onto a phosphor target to visually confirm the straightness of the beam path. An estimate of the power distribution inside the collector was obtained (with some mA of beam current) by a special five-ring-arrangement in place of the normal inner surface of the collector. We found a fair agreement with previous computer simulations.

Then the gun was equipped with a fresh cathode, the collector was installed and the tank pumped down to a pressure around 10^{-8} mbar by a small turbopump.

There followed a series of extensive high voltage tests (without e-beam): In the beginning serious difficulties were encountered with penning discharges (especially at high magnetic fields: 1-2.5 kG) and it took a tedious period of conditioning and cleanup to reach nominal voltage on all inner electrodes. The gun to ground was tested to 100 kV and the collector was conditioned to 220 kV. The current drain at this voltage was some hundred μA (including the current over the voltage dividing resistor) and lead shrouds were necessary to shield the emanating x-rays.

A thorough bakeout (200^0 C, 30 h) of the whole system then brought us down to the 10^{-9} mbar range, where we startet outgassing of the new cathode. It was again a time-consuming job to keep the pressure below 10^{-7} mbar. After reaching the activation temperature (1200^0 C) of the cathode, the heating power was reduced and the internal titanium pump (2 x 2500 l/s nom.) fired.

The system was then disconnected from the turbopump and with four additional (50 l/s) sputter ion pumps (for noble gas pumping) the pressure dropped to approx. 2×10^{-10} mbar which was the base pressure for the following beam experiments.

Although there were no serious problems with the gun or the collector we only slowly increased the beam current from a few milliamps to the ampere range always keeping the pressure below 10^{-8} mbar. With increasing current, degassing of the collector was always less problematic than the gas load from the gun, but normally cleanup was quick and the pressure came down again to some 10^{-10} mbar. Clearly the system showed some sort of conditioning or training: a current level once reached normally could be reproduced the next day within minutes. A longer shutdown period required a more careful startup. Therefore, preceeding and following cooler operation, it seems advisable to keep a standby beam of 1 A or so running at a voltage between 50 and 100 kV.

The maximum current and voltage level reached at the test stand was 5 A at 50 kV which was close to the limits of our isolation transformer. The gun perveance came out as 1.85 μPerv (1.85 A @ 10 kV anode voltage) compared to a calculated 1.95. At the thermal load of approx. 20 kW the pressure in the collector chamber was well below 5×10^{-10} mbar.

One aim of the tests was to look for a loss current to ground. Although there was some doubt if a linear test arrangement could give reliable results concerning collector efficiency it came as a surprise that even at 5 A, the beam induced load to the HV power supply was less than 10 μA (the resolution of the digital amperemeter).

Unfortunately that does not mean that the collector is perfect. We deliberately caused beam reflection by varying the srceen and collector voltage. Thereby the load to the anodes (gun and collector) increased from microamperes to milliampere values (dependent on the magnetic field strength) but loss to ground was not detected. Thus with our electrode geometry[1] (anodes: 60 mm diam.; drift tube: 80 mm diam.) current loss to ground could not be used to obtain information on collector efficiency.

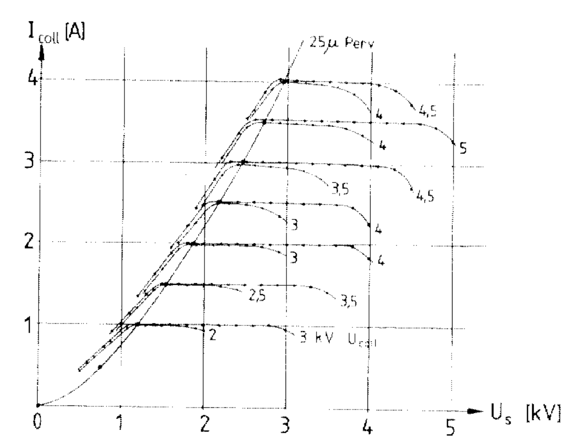

Fig. 4: Collector characteristics.

Fig. 4 shows a series of collector characteristics (i.e. collector current as a function of screen voltage for various collector voltage settings). The decrease of current at the right end of the curves is interpreted as the escape of secondary electrons from the collector when the screen voltage approaches the collector voltage, the decrease at the left is caused by beam reflection in front of the collector. From these measurements a collector perveance around 25 μPerv can be extracted. The current to the screen electrode was always near zero with some indication of a reverse current in the 1 μA range. This could be a hint of an ion current signaling some space charge compensation, though the onset of beam reflection shows that it cannot be of appreciable amount.

4 Cooler Assembly and Installation

In November 89 cooler assembly started in the test area with the mounting of drift tubes, heating jackets, cooling devices and the solenoid and toroids. Only minor modifications were necessary and progress was quick. The linear test stand was dismounted and the gun kept under vacuum in a special storage tank. All power supplies were moved to the high voltage terminal at the ESR in January 90.

In February the cooler (without gun and collector) was transferred to the ESR hall and installed in the ring (Fig. 5). Gun- and collector steerer had to be replaced by two preliminary ones, because the foreseen coils did not fit into the gun and collector solenoids. In March gun and collector were installed and the cooler came under vacuum. After bakeout and titanium pump activation a pressure in the 10^{-10} mbar range was reached.

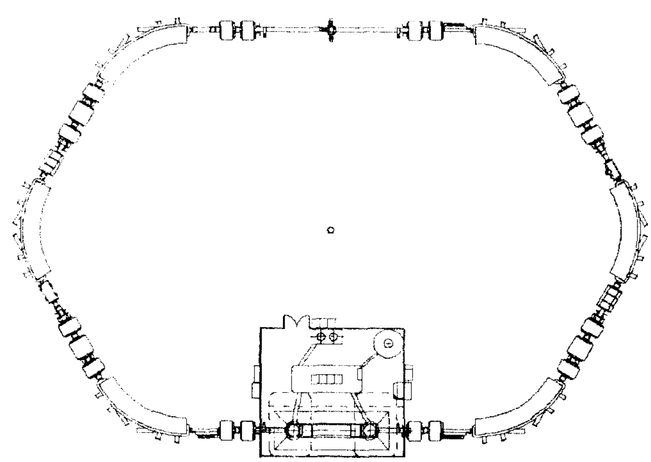

Fig. 5: Heavy ion storage ring ESR with cooler and Faraday room.

5 First Operating Results

All power supplies of the cooler are connected into the GSI-wide control-net[3] The operating program works with DEC-windows. Therefore, all functions of the cooler are controlled with a mouse. Slider, push buttons and VU meter are realized with that software.

It turned out in the first operation experiences that a change of parameter (beam current, energy up to 60 keV) was as easy to perform, as computer simulations have promised. No resonances could be observed. The operation of the cooler is easy: all power supplies (beside the anode) can be set to their correct values. Then the high voltage is switched on and with the anode voltage the electron current can be controlled. After optimization of the steerer no finetuning was necessary up to the 1 A beam.

6 First Cooling in the ESR

Cooler preparation started with cathode heatup and formation in April. The first high voltage tests reproduced the difficulties with penning discharges which were already encountered at the test stand, but we hope that the system can be conditioned in the same way as before.

A voltage of 50 kV was chosen for the first cooling experiments. Due to the missing steerers the main solenoid field had to be kept below 700 G up to now for beam operation. Optimization of the various steerer and compensation coil settings was done for the first runs by trial and error only with minimum losses as a guiding principle. Beam position measurements by the pick-ups using a modulated (20 kHz) beam are still preliminary, but the beam seems to be quite well on axis. Maximum beam current is now around 1 A with losses below 1 mA.

Although we are still a good way from routine operation of the machine the effort of the passed years was rewarded on May 31 by the first Schottky spectra (Fig. 6) of an electron cooled Argon beam of 91.8 MeV/u circulating in the ESR, indicating a longitudinal momentum spread of 10^{-4} for the cooled beam. The next night $3 \cdot 10^{-5}$ could be achieved by improved tuning[4].

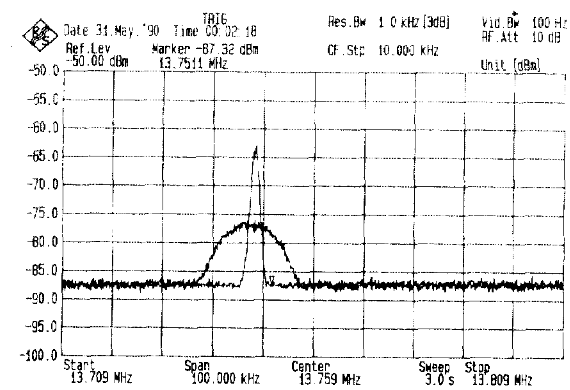

Fig. 6: Schottky signal of the ion beam before and after cooling. The plotted $\Delta f/f$ corresponds to $\eta \cdot \Delta p/p$.

References

[1] N. Angert et. al. ; EPAC 1988, Proc. of the 1st European Particle Accelerator Conference, Rom (1988)

[2] T. Odenweller; GSI Report in preparation

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