Electron Cooling on the ESR at GSI

N. Angert, W. Bourgeois, H. Emig, B. Franzke, B. Langenbeck,
K.D. Leible, H. Schulte, P. Spädtke, B.H. Wolf

**GSI D-6100 Darmstadt, Postfach 11 05 52,
Federal Republic of Germany**

Abstract

An electron cooling device has been designed for the heavy ion storage ring (ESR) at GSI. The main parameters of the cooler are described in the table below:

ion energy	30 to 560 MeV/u
electron energy	16.5 to 320 keV
electron beam current	$\leq$ 10 A (above 30 keV)
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 within the toroids	1200 mm
power consumption:	
collector	50 kW
total	500 kW

In addition to stochastic cooling, the use of electron cooling is planned for the improvement of the ion beam quality within the heavy ion storage ring ESR[1] at GSI-Darmstadt.

Special design details like the single gap acceleration and the electron collector are presented in this contribution. The electron cooler will be installed in the storage ring at the end of 1989.

Magnetic Field Configuration. With the help of the programs POISSON[2], PE2D and TOSCA[3] the designs for the solenoids and toroids have been completed.

The solenoids (gun solenoid, two collector solenoids, cooling solenoid) have four layers of water-cooled copper conductor wound with reversed pitch. Calculations using the three dimensional program KOBRA3[8] predict only a small influence of field errors over the transverse energy of the electron beam, as long as they are adiabatic and symmetric. For this reason, a maximum field error of $\Delta B_z/B_z \leq 10^{-3}$ was taken as a basis for the design. In addition to ensure the collinearity of the field in the cooler solenoid correction coils will be added which should improve the field error to $\Delta B_z/B_z \leq 10^{-4}$.

Figure 1 shows the general layout of the electron cooling device. It is a vertical set-up, to get the main deflection of the ion beam due to the toroidal fields in the horizontal plane (the deflection can be as high as 20 mm), where correction by steering elements is convenient. In addition, the choice of a 90^0 deflection angle for the electron beam facilitates the construction and the service of the electron gun and collector.

The toroids (with deflection angles of 48.3^0 and 41.7^0) consist of 22 and 19 pancake coils, respectively, which have a rectangular shape to leave space for dipole coils. Special care is needed for the design of these dipole coils which effectively determine the increase of the transverse energy within the bending section[4].

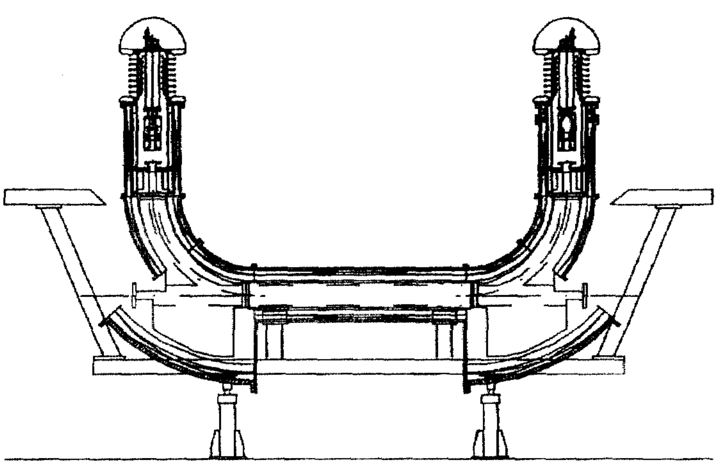

Figure 1: Electron Cooler

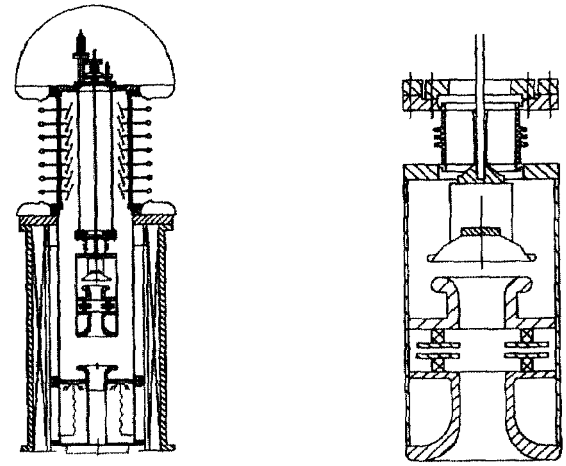

Figure 2: Electron Gun and Acceleration Gap

Electron Gun: The wide desired operating range of the cooler made it necessary to develop a special type of electron gun and acceleration gap geometry[5]. The design strategy was to treat the gun and the accelerator as seperated systems, isolated from each other by an appropriate drift space as shown in Fig. 2.
The gun is of the planar cathode Pierce type with 2 μP perveance (10 A at 30 kV) operating in an axial magnetic field of 0.1 to 0.25 Tesla. For energies less than 30 keV the current decreases with fixed perveance. The main acceleration gap following the gun can raise the electron energy up to 320 keV. The diameter of the electron beam is 5 cm.

To keep transverse energies low we do not rely on true resonance acceleration. Instead, extensive use has been made of the AXCEL-GSI[6] code to find electrode geometries which give an acceptably low transverse energy for the whole parameter field.

Fine tuning is accomplished by two additional electrodes (einzel lenses) which are located in the main anode, but are sufficiently far downstream from the cathode so as not to influence the cathode current.

As well, the electrode geometries of the main gap have been tailored according to computer simulations, which showed that a simple single gap accelerator of the appropriate shape can give a beam quality at least as good as a multi gap column.

Transverse energy (at 10 A) as a function of beam energy and magnetic field strength is plotted in fig. 3. At magnetic fields above 0.2 Tesla we expect a transverse energy of less than 0.3 eV for the whole operating range of the cooler.

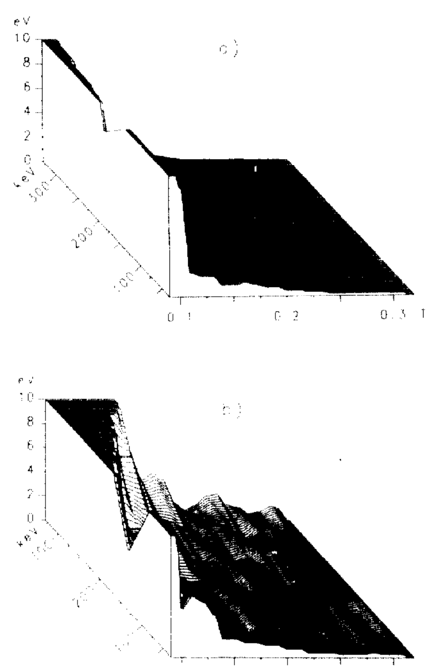

Figure 3: Transverse energy as a function of beam energy and magnetic flux density (a: single gap, b: multi gap)

Insulator Design: The potential difference between the electron gun and collector (-320 kV) to ground is made on air with ceramic insulators, which are positioned outside of the magnetic field of the solenoids. Thus, it is possible to use magnetic iron-nickel-cobalt material for the construction.

Eight ceramic rings on each side are welded together using a special design method to avoid mechanical stress during bake-out and operation.

Collector: The design[7] was mainly determined by two requirements: Collector efficiency must be high, (a loss rate of 10^{-4} seems to be acceptable, i.e. 1 mA at 10 A) and the collector potential must be as close as possible to the cathode potential to minimize the dissipated power (n.b. 5 kV at 10 A means already 50 kW of power loss).

These two demands are in conflict because good screening to attain low current loss requires a high collector potential (high power loss) whereas low collector potential gives poor collection efficiency and eventually leads to a reflection of the electron beam (unstable operation).

Again, the simulation code AXCEL-GSI was used for ray tracing (including space charge effects) in connection with the PE2D code for magnetic field calculations to tailor a collector (Fig. 4) that should meet the design specifications.
The deceleration gap in the collector section of the cooler is a replica of the accelerating gap on the gun side. The collector anode (CA) will be at the same voltage as the gun anode. The screen electrode (S) in front of the collector creates a potential barrier to stop the backstreaming of secondaries, the collector will normally be operated 5 kV above cathode potential (Fig. 5).

Collector cooling represents a severe technical problem. At 10 A and 5 kV the power density in the beam is so high, that it has to be distributed on a large surface. This is achieved by an appropriate shaping of the magnetic field by a soft iron shield (hatched area) and a seperate solenoid coil.

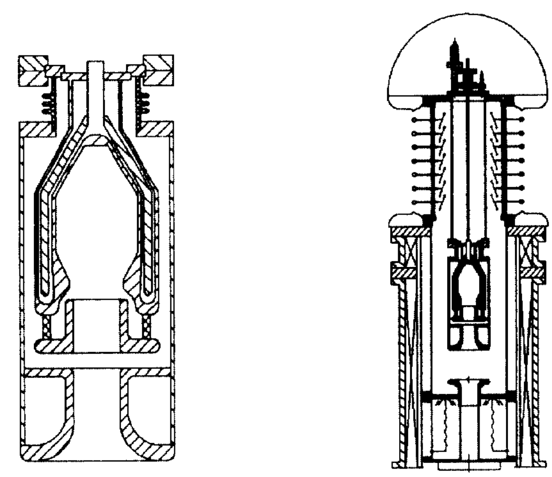

Figure 4: Deceleration gap and electron collector

Thermal calculations using the DOT code[10] indicate that the collector should be capable of handling 50 kW of beam power with a surface temperature of not more than 200^{0}C.

The Cooling Section itself has a length of 2.50 m and an inner diameter of 250 mm. A set-up of inner drift tubes, insulated from each other, is used to define the potential distribution along the cooler. It is possible to apply a pulsed voltage to these electrodes to rapidly change the energy of the electron beam within several keV for atomic physic studies.

Pick-up electrodes will be used to obtain the electron and ion beam position. Clearing electrodes can be used on secondary ions or electrons to be removed from or trapped in the beam line.

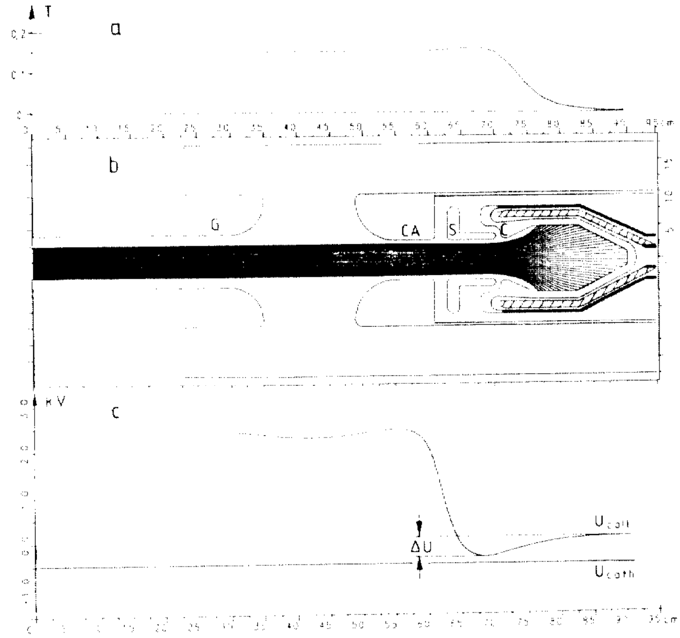

Figure 5: Computer simulation of the collector

a) magnetic induction on axis.
b) electrode geometry and trajectory plot.
C collector, S screening electrode, CA collector anode,
G ground electrode. Hatched part mild steel.
c) Potential on axis (beam 9.5 A, 30 kV)
ΔU is the potential drop in the screening electrode.

The UH-Vacuum required in the cooling section ($\leq 10^{-10}$mbar), to increase the ion beam life time will be provided by using specially designed ion getter and titanium sublimation pumps, located inside the gun and collector solenoids and the toroids respectively. Since the main gas source will be from the cathode (H_2, CO) and also the collector, titanium sublimators are installed there with a pumping speed of 2500 l/s each. The capacity of the pumps enables the operation of the cooler for more than one month per cylce. The vacuum pressure should be in the 10^{-9}mbar range in the gun and collector sections. A set of ion pumps using the magnetic field of the toroid will reduce the pressure in the 41.7^0 toroid below 10^{-10}mbar (pumping speed 1500 l/s). Additional titanium sublimators in the 48.3^0 toroids should guarantee an end pressure in the 10^{-11}mbar range within the cooling section. Four small ion pumps on the high voltage end of the gun, and at the collector insulator, help to reduce the gas pressure in that region. All main vacuum parts are bakeable to 300^0C.

Power Supplies. The solenoids and the toroids are powered by two power supplies ($\approx$ 360 V, 750 A). It is required that the high voltage power supply (320 kV, 10 mA) has a stability of $\leq 10^{-5}$. The main extraction power supply (30 kV, 40 mA) has similar stability considerations, whereas the power supplies for the collector (30 kV, 40 mA and 6 kV, 10 A) and all the other small power supplies are specified to within 10^{-4}. The power supplies for gun and collector are mounted on a 320 kV platform (6 $m \times 2.20\ m \times 2.20\ m$), powered by a 100 kW insulating transformer. This power is needed mainly for the collector.

Schedule. The electron cooler is now under construction at GSI. All the main components and power supplies have been delivered. First operation at the storage ring is planned in 1990.

References

[1] B. Franzke; *Information about ESR Parameters*; GSI-ESR-TN/87-02.

[2] A.M. Winslow; *Numerical Solution of the Quasilinear Poisson Equation in a nonuniform Triangular Mesh*; Journal of Computational Physics 2, p.149 (1967).

[3] C.C. Sahm et. al; *TOSCA-PE2D Programs at GSI*; GSI 87-1, p.331.

[4] P. Spädtke and H. Schulte; *Design of the Dipole Field for the Electron Cooler*; GSI 88-1, p.381.

[5] H. Schulte , P.Spädtke; *Investigations of Gun and Gap Geometries for the ESR Electron Cooler*; GSI 86-1, p.368.

[6] P.Spädtke; *AXCEL-GSI Interaktives Simulationsprogramm*; GSI 83-9.

[7] H. Schulte et. al; *Collector design for the ESR Electron Cooler*; GSI 87-1, p.343.

[8] P.Spädtke; *Numerical Calculations for the Electron Cooler*; GSI 87-1, p.342.

[9] C.C. Sahm; *Coil System for the Electron Cooler*; GSI 87-1, p.344.

[10] R.M. Polivka, E.L. Wilson, *DOT A Nonlinear Determination of Temperatures Program for Two Dimensional Planar or Axissymmetric Structures*; Berkeley, 1976.