AN ADIABATIC ELECTRON GUN FOR THE CRYRING ELECTRON COOLER

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Abstract

An adiabatic electron gun for the Cryring electron cooler is described. The criteria for adiabatic acceleration are briefly summarised and results from calculations of the transverse electron temperature as a function of gun perveance and magnetic field are presented.

Cooler

The electron cooler for Cryring [1] will cool highly charged heavy ions with energies from 3.6 MeV/u, requiring 2 keV electrons, up to the highest ion energies in Cryring, corresponding to 13.5 keV electrons. It shall also be able to work as an electron target for atomic-physics experiments at electron energies up to 20 keV. The main design parameters, still preliminary, of the cooler are given in table 1. Other particular features of this cooler are the high vacuum required to avoid charge exchange of the ions and the fast ramping of the cooler field together with the rest of the magnets in the ring.

Electron energy	2 – 20 keV
Perveance	0.1 – 5 μA/V$^{3/2}$
Electron current	1 – 3000 mA
Beam diameter	40 mm
Magnetic field	0.2 T
Cooling length	1.1 m

Table 1. Main (still preliminary) design parameters of the cooler

Electron gun

In order to have high cooling rates and an electron target which is dense and allow precision measurements the electron beam should be intense and at the same time have a small energy spread. Furthermore, it may be valuable in an experimental situation to have full control over all parameters influencing the experiment, such as magnetic field, electron current and electron energy and to be able to vary these parameters over a wide range. These properties are combined in the electron gun that will be used for the Cryring cooler. It is based on the principle of adiabatic acceleration [2] where, in this context, adiabatic means that the distances (along the symmetry axis of the gun) over which the radial electric fields from the acceleration anodes vary appreciably (on a scale set by the magnetic forces) are small compared to the gyro wavelength of the electrons. If this adiabatic condition is satisfied the action variable $J_r = \oint p_r \, dr$, integrated over one turn of the cyclotron motion, is an invariant. The turning points of the radial motion then are the same before and after the acceleration, except for a small increase of the turning-point radii due to the space charge of the freely propagating electron beam.

For an ungridded gun with high perveance (up to 5 μA/V$^{3/2}$ in our case) rather high radial electric fields are unavoidable in the region around the first anode. To reduce these fields the diameter of the first anode has been made rather small while the other anodes have a larger diameter ensuring a smooth acceleration (or deceleration) field. The gun has eight anodes altogether, but some of them can be connected via voltage dividers, reducing the number of power supplies necessary. Since the current is determined essentially by the voltage of the first anode the purpose of the additional anodes is, apart from making the transition betweeen the first acceleration gap and the drift region smoother, to allow a variable perveance. Without these additional anodes the gun would have a perveance of roughly 1.8 μA/V$^{3/2}$; the design of fig. 1 allows a continuous variation of the perveance between at least 0.1 and 5 μA/V$^{3/2}$. At perveances above 1 or 1.5 μA/V$^{3/2}$ the electron temperature is decreased if the gun is operated with a positive voltage (relative to the last anode) on some of the intermediate anodes. Fig. 2

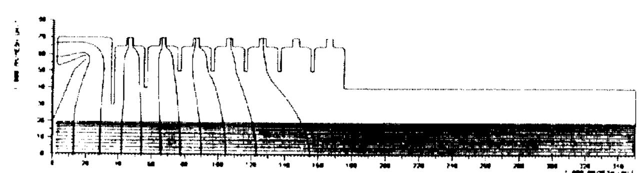

Figure 1. Schematic diagram of the electron gun with electron trajectories and equipotential surfaces at a perveance of 0.2 μA/V$^{3/2}$ and a magnetic field of 400 G.

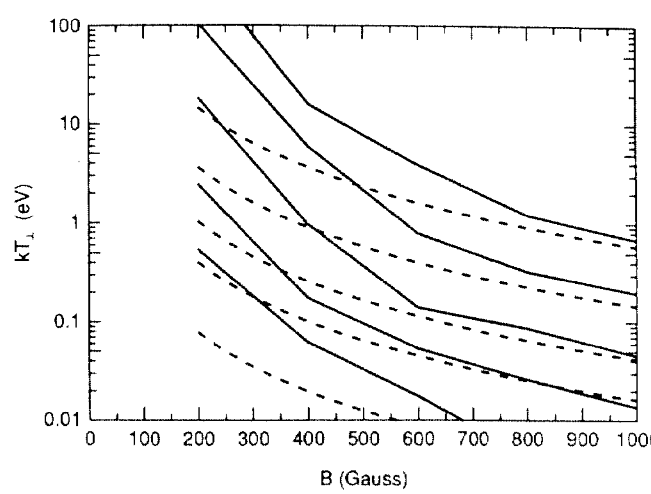

Figure 2. Transverse temperatures at $r = 10$ mm for the gun of Figure 1. The full-drawn curves are calculated values for perveances (from below) equal to 0.2, 0.5, 0.8, 1.5 and 3 μA/V$^{3/2}$ and dashed curves are the temperatures for the same perveances but due to the magnetron drift alone.

shows the transverse temperature for this gun as a function of the magnetic field. The five full-drawn curves are calculated values [3] for five different perveances (the same anode voltages are used for all points along a curve). The dashed curves are the temperatures, for the same perveances, resulting from the magnetron drift alone, i.e., temperatures for a perfectly adiabatic gun. All values are at an electron energy of 20 keV and at a radius of 10 mm. It can be seen that the electron temperatures approach the adiabatic limit at magnetic fields between 500 and 800 G. In fig. 3 the ratio between the radial electric and the longitudinal magnetic fields are shown together with the transverse velocity for a 20 keV beam at 800 G a perveance of 0.8 $\mu A/V^{3/2}$ and at three different radii. Clearly, the adiabaticity is reached at lower fields for small radii since the radial electric fields are smaller there. Note that E_r/B_z is the transverse velocity for a particle in pure magnetron motion.

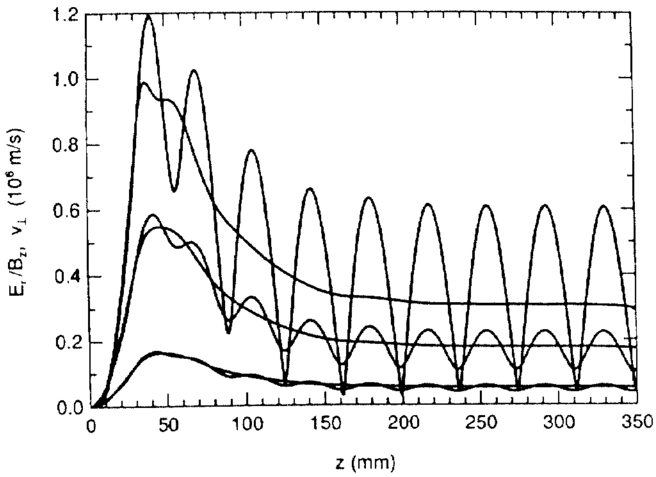

Figure 3. Ratio between radial electric field and longitudinal magnetic field (smooth curves) and transverse electron velocity (oscillating curves) for the gun of Figure 1 at a perveance of 0.8 $\mu A/V^{3/2}$ and a field of 800 G. The three pairs of curves are for radii (from below) of 3.5, 11.5 and 19.5 mm.

The pronounced difference in electron temperature between the centre and the edge of the beam (which to a large extent also is present in guns using resonant focusing) indicates that it may be desirable to change the perveance during the cooling process. In the initial stage, while the ion beam still has its full diameter, the perveance can be relatively low and then increased as the ion beam shrinks. The requirements on the accuracy of the anode voltages during the change of perveance are not very stringent since the electron temperature is rather insensitive to small errors in these voltages.

References

[1] C. J. Herrlander, K. G. Rensfelt and J. Starker, "Cryring–a heavy-ion storage and accelerator ring," in these Proceedings

[2] V. A. Lebedev and A. N. Sharapa, "Formation of an electron beam with low transverse velocities in systems with a longitudinal magnetic field," Sov. Phys. Tech. Phys., vol 32, pp. 594 – 595, May 1987

[3] W. B. Herrmannsfeldt, "Electron trajectory program," SLAC – 226, Stanford, 1979