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ELECTRON COOLING DEVICE FOR TARN II

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Abstract: Light to heavy ions accelerated by a synchrotron TARN II are planned to be cooled by the electron cooling method. A device to cool these ions up to energies of 200 MeV/A is under construction. The electron energies are variable from 15 to 120 keV and the maximum current density is 0.5 A/cm^2. The length of interaction region between electrons and ions is about 1.5 m. Design of the electron guiding coils and high voltage system is described as well as the calculated electron trajectories. The status and prospect for the cooling project are given.

General Description of the Cooling Project

This electron cooling project aims primarily at the study of the cooling process itself and is intended to extend the technology of proton cooling already exploited in other laboratories to heavier ions. The cooled ion beams will be also used for the researches in physics. First description of the electron cooling project is given in ref. [1].

The synchrotron TARN II consists of a ring of 78 m circumference with regular hexagonal layout. The two of the six long straight sections are prepared for the electron cooling and internal target station. The maximum energy corresponding to the maximum magnetic rigidity of dipole magnets is 1.3 GeV for proton and 450 MeV/A for ions with Q/A=1/2.

The ring can be operated in two modes. The first mode corresponds to the ordinary synchrotron acceleration followed by slow extraction. For the second mode, on the other hand, ions are cooled by the electron cooling device after acceleration with sufficiently long flat-top time. The lattice parameters are different for these two modes despite the same magnet configurations. For the lattice of the latter mode, the design has been made especially taking account of the following conditions: The dispersion function is zero at the cooling section and the amplitude function is as small as possible at the internal target section, holding the 3-fold symmetry of the ring. The details of the parameters are described in ref. [2].

Beams are injected by the existing SF cyclotron with K=68 [3]. This can supply with fully stripped ions from proton to neon, after stripped in a thin foil. The numbers of ions injected into the ring by the multi-turn injection method are about 10^8 and 10^6 for light and heavy ions, respectively. If we apply the RF stacking method as well as the multi-turn injection, intensity is expected to increase by one order of magnitude. In this case, however, the momentum width of the stacked ions should be decreased to the values narrow enough to capture them by the usual RF voltage. For such a pre-cooling, application of the electron cooling method seems to be possible, if we sweep electron energies over the wide velocity range of the ion beam.

Electron Cooling System

Layout

The main parameters of the electron cooling device are listed in Table 1. The maximum energy of electrons is limited by the high voltage holding capability in the space of

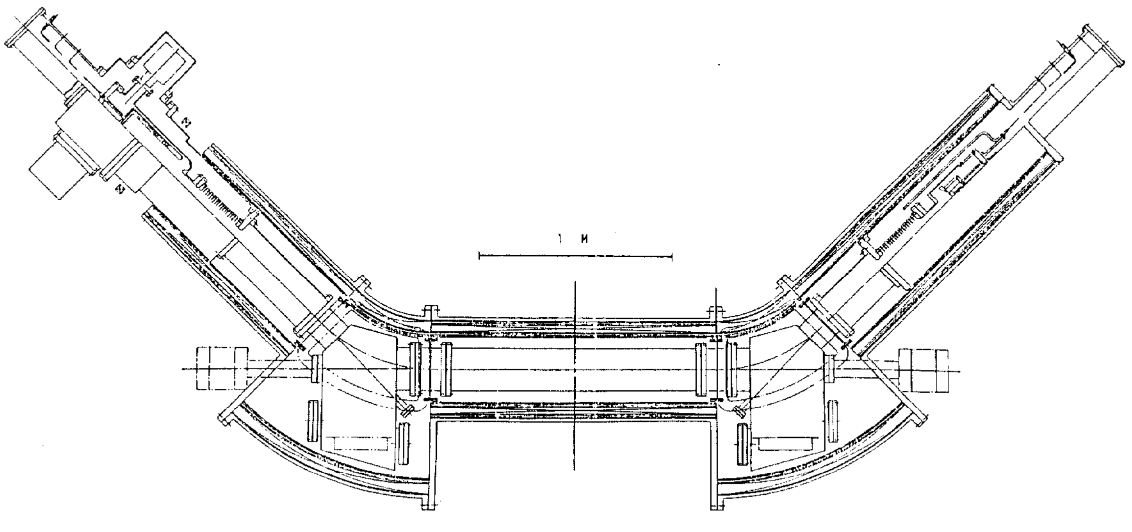

Fig. 1 Layout of the electron cooling device.

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Table 1 Parameters of electron cooling system

Cooled ions		H^+ - $^{20}Ne^{10+}$
Maximum working energy	ions	200 MeV/A
	electrons	120 keV
Length of interaction region		1.5 m
Maximum electron current density		0.5 A/cm^2
Cathode diameter		50 mm
Maximum solenoid field		1.2 kG
Cathode type		flat
Electron gun perveance		1.0 $\mu A/V^{3/2}$

the electron gun. The length of the interaction region between electron and ion is limited by the length of the long straight section (4.2 m). The electron beam diameter of 50 mm almost covers the maximum size of accelerated ion beam at the cooling section. A schematic assembly drawing of the electron cooling device is shown in Fig. 1. The shape is so-called U-scheme in which electrons are injected and ejected over the beam line of the ring. By using this system, we can expect the transverse cooling time of about 1-10 sec, although it depends on kinds of ions and their energies.

Electron gun

Gun optics consists of a Pierce-type electrode and resonance focusing electrodes. The flat cathode is immersed in a uniform solenoid field. The design of the electron gun has been studied by computer simulation with the help of the SLAC program [4]. An example of electron trajectories in the region of the electron gun is shown in Fig. 2. The transverse temperature of electrons after acceleration depends on their distance from the axis of the electron beam. The outermost electron has generally its highest value. The temperature also changes periodically with the variation of the solenoid field and the minimal values of the temperature decrease with the increase of the solenoid field. Figure 3 shows such a dependence of the temperature on the magnetic field. In this calculation, we set the anode voltage to 45 keV which produces 10 A of electron current and the final electron energy is the maximum value of 110 kV. As seen in this figure, the maximum field level of 1.2 kG is high enough to obtain the electron temperature less than 0.2 eV. Electron current density is determined by the gun anode voltage for the fixed perveance and the acceleration voltage is usually higher than that of the anode voltage. However, if we want a high electron current even at the low energies to reduce the cooling time, the acceleration voltage has to be set to the lower value than that of the anode voltage. We studied electron orbits in such an unusual use of the electron gun in which electrons are accelerated and then decelerated. Results of the calculations show that the transverse temperature is also low enough under the correct choice of the magnetic field.

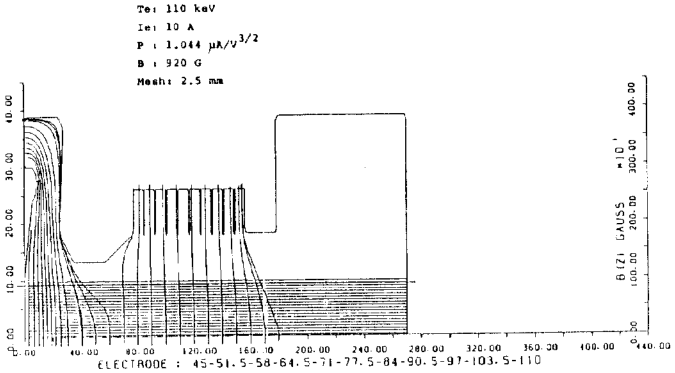

Fig. 2 Calculated electron trajectories in gun. The solenoid field is 0.92 kG.

Electron guiding coils

Electron beam guiding coils are summarized in Table 2. The main parts of the guiding coils consist of three solenoids and two 45°-toroids. The solenoid and toroid coils are made by two and three layers of 15×15 mm^2 copper hollow conductor, respectively. The diameter of the solenoids is a minimum size to ensure the stable high voltage holding capability at the maximum voltage in the gun and collector regions. The other correction coils are mostly wound on to the outer circumference of the main coils. The transition coils and one of the collector correction coils are installed separately from the main coils. The uniformity of the magnetic field is essential to obtain the low-temperature beam for the transversal component. The solenoid coils

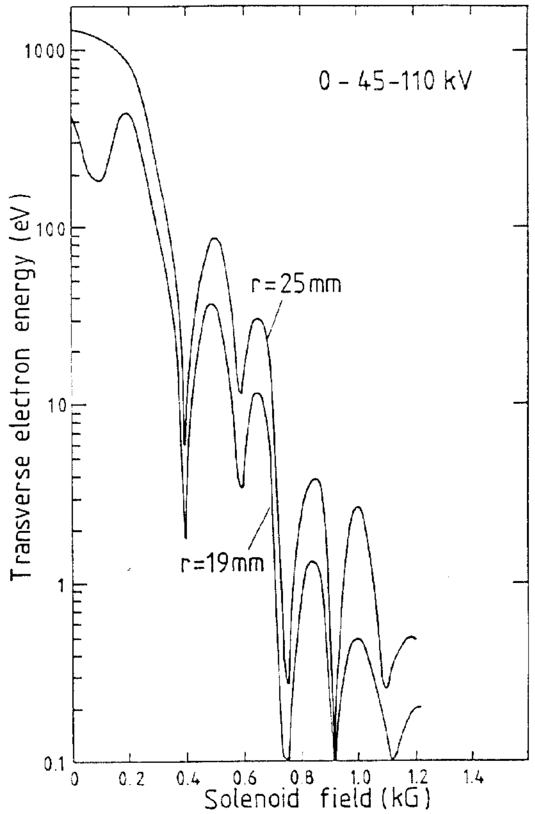

Fig. 3 Final transverse energy of electrons at the radii of 19 mm and 25 mm. The calculation is at 45 kV anode voltage and 110 kV acceleration voltage.

Table 2 Electron beam guiding coils

coil	field	function(size)
Central solenoid	B_z=1.2 kG	Guide field in cooling section (1.5 m-0.36 mϕ)
Gun solenoid	B_z=1.2 kG	Guide field in gun section (1.4 m-0.36 mϕ)
Collector solenoid	B_z=1.2 kG	Guide field in collector section (1 m-0.36 mϕ)
45° Toroid (×2)	$B_z=B_0R/r$ B_0=1.2 kG R=0.75 m	Bend electron beam into/away from ion beam
Toroid drift dipole (×2)	B_x=17 G	Cancel drift in toroid region
Alignment dipole (×3)	$B_x=B_y$ =20 G	Alignment of electron beam axis in solenoids
Gun correction coil(3 coils)	B_z	Fine adjustment of solenoid field in gun region
Collector correction coil (2 coils)	B_z	Fine matching of electron beam to collector
Transition coil (×4)	B_z	Matching solenoid-toroid transition region

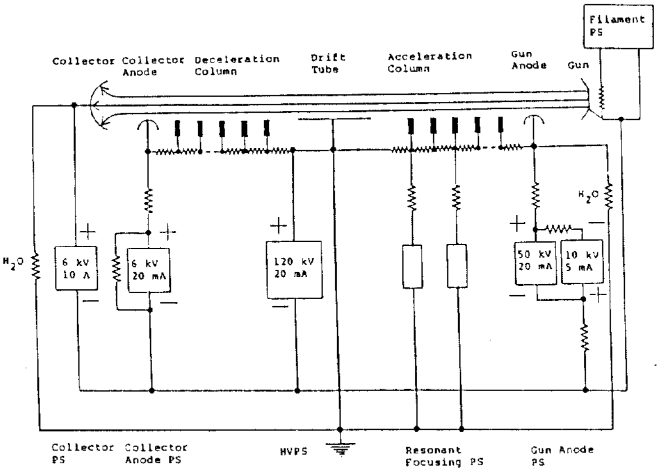

Fig. 4 Schematic diagram of the high voltage system for electron cooling.

are designed to realize a good homogeneity of the field less than $\Delta B/B=5\times10^{-4}$. Most serious field errors arise in the transition region between solenoid and toroid coils due to the difference in size of each coil and the missing turns at the edge of the coils. These field errors will be corrected by the transition coils designed on the basis of the infomation of detailed field measurements. The whole coils are covered by iron cases 15 mm thick except the windows needed for the passage of the electron and ion beams. These are used for the purpose of shielding the inside from the external magnetic field and providing the return path of the magnetic flux.

The toroidal field also deflects the ion beam from the beam axis mainly in the horizontal plane. Such an unwanted bending of the ion beam is compensated by a pair of correction dipoles at each end of the cooling device.

High voltage system

Figure 4 shows a block diagram of the high voltage system for the cooling device. It consists of high voltage power supply (HVPS) for acceleration of electrons, gun anode PS, collector PS and collector anode PS. A high stability is required for the HVPS since the longitudinal temperature of electron beam is mainly determined by the variation of the acceleration voltage. This power supply consists of high-frequency Cockcroft circuits and its stability is less than $\pm 2.5\times10^{-5}$, which seems to be the best value any manufacturer of high voltage power supply can guarantee. The electron space charge gives rise to an unwanted tune shift to the ion orbits especially at the low energy during injection and acceleration. In order to suppress electron current during such periods, the gun anode PS which determines the electron current is designed to allow fast switching off the electron beam synchronized with the cycling of the TARN II. It is driven by a series tube with fast rising time.

Status and Time Schedule of the Cooling Project

The design and construction work of the cooling device started in 1984. The magnet system and the high voltage PS have already been manufactured. The gun, collector and vacuum system shall be completed in the next spring. The electron beam can be tested in 1986. So far we still hope, that the first beam from the TARN II will be accelerated in 1986 and that the cooling of ion beam will be studied in 1987.

References

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