ELECTRON COOLER AT INS

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Abstract: An electron cooling system for compressing phase spaces occupied by the ion beams stored in the heavy-ion synchrotron-storage ring TARN II has been developed. The cooling device was designed to cool ion beams up to the energy of 200 MeV/u, which requires an equivalent electron energy of 110 keV. All the components of the device were assembled and the first electron beam was obtained in the complete cooler. The overall design of the electron cooling system is described and the results of the electron beam experiments are presented.

Introduction

Electron cooling, which is an excellent technique for rapidly compressing phase spaces occupied by hot ion beams, can offer many new possibilities regarding accelerator technology and physics research. In nuclear physics strong phase space compression will realize the use of internal targets and also the storage of intense exotic nucleus beams. For both atomic and plasma physics, electron-ion-laser interactions will be studied under ideal experimental conditions. In an ultimate extreme situation of electron cooling, if a phase transition of ion gas occurs the ion beam can have ordered or crystalized structures. An experimental understanding of the cooling process of heavy-ion beams is an important step towards such a wide utility of the electron-cooling method. An electron cooler aiming at the research and development of electron-cooling technology of medium-energy heavy-ion beams has been constructed. The first electron beam in the complete cooler was obtained in the late 1988. In the following a brief summary is given of the cooling device and results of the off-line electron beam test are described.

The Electron Cooler

Electrons are extracted from a cathode by an anode potential and then accelerated by an acceleration tube to the nominal energy. The electrons then enter into the drift region which extends to the collector. At the end of the drift motion, the electrons are decelerated with a deceleration tube to energies of about 1 keV and then distributed over the collector surface. The whole system is immersed in a longitudinal magnetic field which suppresses the electron motion in the transverse direction due to the space charge and also guides the electron beam from the gun to the collector. The electron beam merges with the ion beam at the 1.5 m long cooling straight section. The design values for the electron cooler are shown in Table 1.

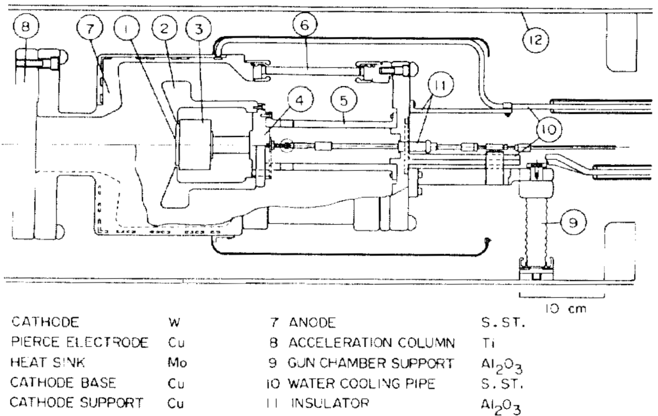
The magnet system [1] was designed taking account of various factors for the correct handling of the electron beam. A careful mapping of the magnet system was performed and the detected field errors $\Delta B/B$ at the central solenoid were below $\pm 2 \times 10^{-4}$ [2]. The uniformity was further confirmed by the observation of trajectories of electrons emitted from a small electron gun [3].

Table 1 Electron cooling design parameters.

Electron energy	11-110 keV
Equivalent nucleon energy	20-200 MeV/u
Cooled ions	H^{+}-Ne^{10+}
Length of cooling section	1.5 m
Cathode diameter	50 mm
Solenoid field (max.)	1.2 kG

The electron gun and the acceleration system [4] were designed based on the results of computer simulation studies of electron trajectories. Figure 1 is a design sketch of the electron gun region. A flat dispenser-type cathode which has a diameter of 5 cm is mounted in a cylindrically symmetric Pierce geometry on the axis of the gun solenoid. The gun-anode geometry gives a perveance of 1.1 $\mu A/V^{3/2}$. Copper was chosen for materials of the Pierce electrode due to its good heat conductivity. An electron beam which passes the anode hole is further accelerated into the acceleration column which consists of an 18 electrode NEC high-gradient accelerator tube. The whole assembly is connected with an interface flange and is also supported by a ceramic column. The end of the vessel containing the system is sealed with a high-voltage feedthrough and the area surrounding the gun system is maintained at 2 atmospheres of SF_6 gas in order to prevent corona discharge. The anode and the flange supporting the gun are cooled by water.

The collector shown in Fig. 2 was also designed based on numerical calculations of electron trajectories. The beam is decelerated by the deceleration column, the same as the acceleration column, to energies defined by the potential of the collector-anode which acts as a suppressor for the



1	CATHODE	W	7	ANODE	S.ST.
2	PIERCE ELECTRODE	Cu	8	ACCELERATION COLUMN	Ti
3	HEAT SINK	Mo	9	GUN CHAMBER SUPPORT	Al_2O_3
4	CATHODE BASE	Cu	10	WATER COOLING PIPE	S.ST.
5	CATHODE SUPPORT	Cu	11	INSULATOR	Al_2O_3
6	GUN SUPPORT	Al_2O_3	12	SF_6-FILLED CHAMBER	S.ST.

Fig. 1 Cross section of the electron gun assembly.

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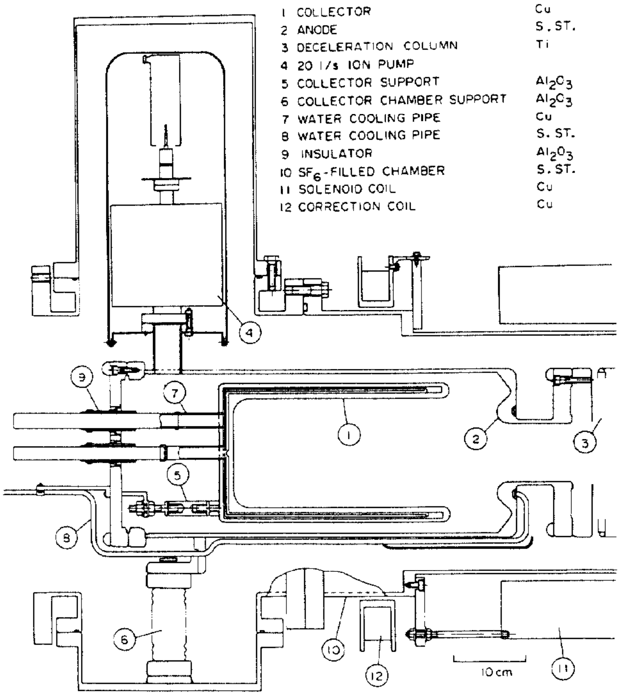

Fig. 2 Cross section of the collector assembly.

electrons backscattered from the collector. Again, it is accelerated into the collector. The collector diameter and depth are 15 and 31 cm, respectively. It is cooled by water through 15 cooling channels, each with a cross section of 0.6 cm^2. There are two trim solenoids in the collector region which control the magnetic mirror field.

The vacuum chamber and flanges are made of 316L stainless steel. Ceramic feedthroughs for the signal and current feeder are sealed with a non-magnetic alloy of nickel and copper instead of using a Kovar seal in order to avoid any magnetic field disturbance. Inside the vacuum chamber, drift tubes, electrostatic position monitors and antennae to pick up microwaves have been installed. The whole system, except the gun and collector chamber, is bakeable at 250 °C. The main pump for the device consists of non-evaporable getter (NEG) modules of the type SAES ST707. Four groups of the NEG pumping system, each of which consists of 4 modules, are set close to the gun and the collector and also inside both toroid chambers. Two 400 l/s ion pumps are also placed adjacent to the electron cooler in order to pump CH_4 and other non-active gases. A vacuum of 2×10^{-11} Torr (gauge reading) has been attained after bakeout.

A highly stabilized power supply [1] provides the negative voltage for the cathode via the high-voltage platform. The platform houses the power supplies for the cathode heating, for the gun-anode, for the collector and for the collector-anode. A fiberoptic link allows the communications between the power supplies on the high-voltage platform and corresponding controllers at the ground potential.The high-voltage holding capability has been tested. A negative high voltage of 100 kV has easily been applied to the gun and the collector. On the other hand, the voltage between the gun and the anode was raised up to 30 kV only after a long training time, due to stringent E× B drift motion of electrons.

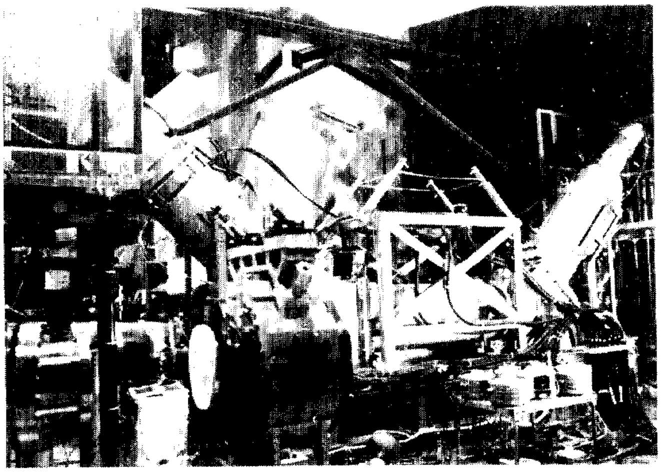

Fig. 3 Photograph of the electron cooling device.

The whole system is mounted on a steel frame, which is placed on a precision rail system. It can therefore be moved out of the cooling ring for off-line electron beam testing and maintenance work. Figure 3 is a photograph of the completed electron cooling device.

Results of Electron Beam Experiments

The cathode was operated at 960 °C in the space charge limited condition. The pressure under cathode heating was in the range of 10^{-10} Torr. From the first operation, a stable beam condition was realized for the calculated parameter setting except only fine current adjustment of collector entrance coils and a collector steerer. The pressure during operation was in the 10^{-10} - 10^{-8} Torr range, depending mainly on the beam current. It gradually decreased with operation cycles due to the decreasing outgas rate from the surface of the collector and other electrodes. Table 2 gives a list of the values of beam energy and intensity for the operations of the electron cooler. Relative current loss of the electron beam is typically in the order of 10^{-4}. Measured perveance agrees with the value calculated by the simulation program for the gun region within the measurement error of the gun-anode voltage.

Energies of secondary electrons emitted from the metal surface with bombardment of electrons are distributed up to the primary energy and their directions extend to extreme backward [5]. The electrons escaping from the collector surface with angles larger than $\theta = \arctan(B_{max}/B_{min}-1)^{-1/2}$ are repelled due to the magnetic mirror field. Furthermore the negative repelling potential of the collector-anode suppresses secondary electrons backstreaming from the collector. Figure 4 shows the relative current loss as functions of the collector and the collector-anode voltage. The current loss decreases with increase of the collector voltage. On the other hand, it decreases with decreasing collector-anode

Table 2 Measured parameters for operation of the electron cooler.

Electron energy [keV]	10	20	30	40	50	60	70
Equivalent nucleon energy [MeV/u]	18	36	55	73	91	109	128
Beam current [A]	.6	.7	1	2	2	2	1.5

voltage until the negative field due to the space charge cloud in the collector entrance causes beam reflection. Conductance of the collector is mainly a function of the collector-anode voltage and was much larger than the calculated values taking account of only a negative electron beam. This phenomenon seems to be caused by the presence of positive ions trapped in the electron cloud in the entrance of the collector.

Microwave radiation emitted from electrons due to their spiral motions was picked up by an antenna. Typical power spectra are shown in Fig. 5. The power level of this radiation is proportional to the average transverse electron energy. So such a measurement is helpful for the optimization of the electron system.

Expectation for Cooling Experiments

The electron cooler is now ready for installation in the TARN II. It will be joined to the ring after the completion of the beam test for the TARN II including multi-turn injection, long-time storage of beam and normal operation of diagnostic elements. For the cooling experiments, once electron cooling has been demonstrated with protons, we shall start cooling studies of ion beams heavier than protons. All these programs are expected to begin in 1989.

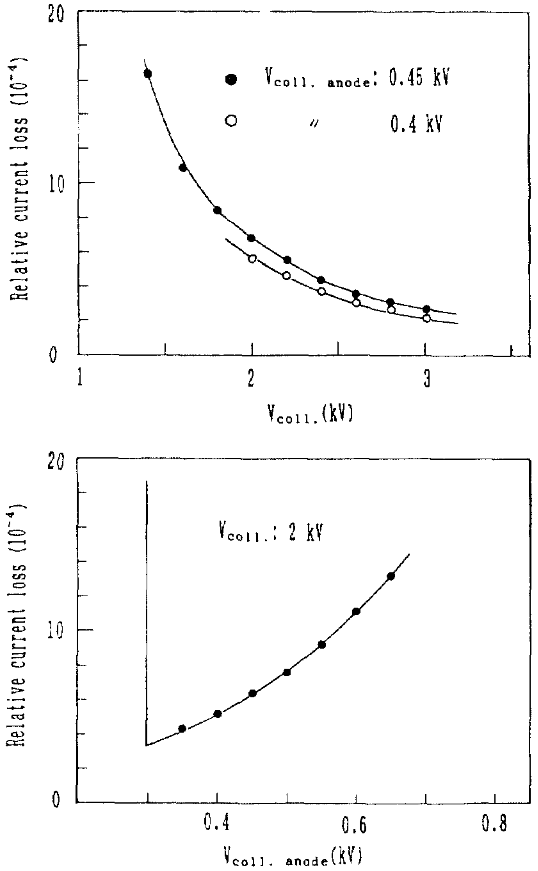

Fig. 4 Relative current loss of electrons as functions of collector and collector-anode voltages relative to cathode voltage. Electron energy and current are 20 keV and 0.5 A, respectively.

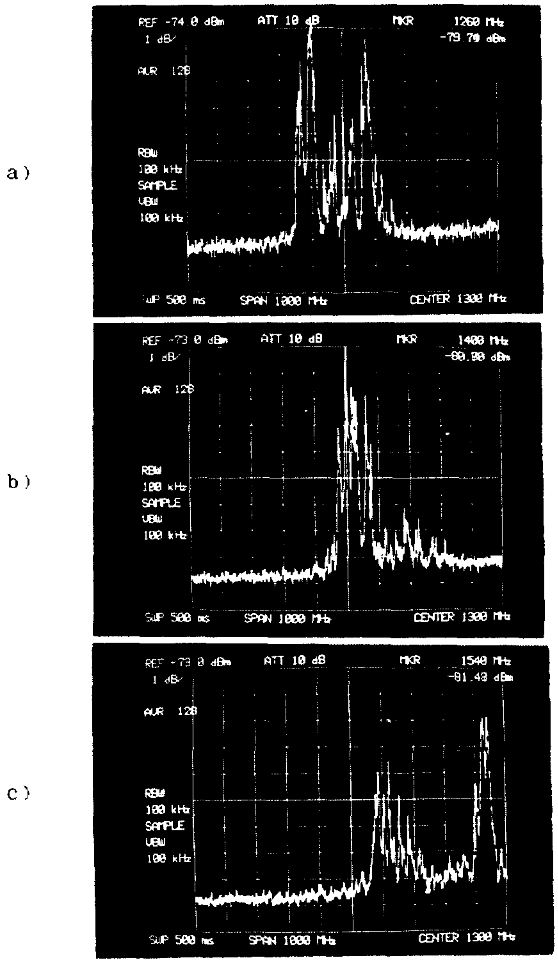

Fig. 5 Microwave spectra for different solenoid fields: a) 450 G; f_c=1.26 GHz, b) 500 G; f_c=1.4 GHz, c) 550 G; f_c=1.54 GHz. Electron energy and current are 10 keV (β =0.195) and 0.8 A, respectively.

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