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ELECTRON COOLING ON THE TARNⅡ AT INS

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Abstract An electron cooling device which was designed to cool ion beams up to the energy of 200 MeV/u was completed and installed in the synchrotron-storage ring TARNⅡ. Outline and status of the cooler are described.

INTRODUCTION

Electron cooling has been becoming an important and practical technique to improve the quality of beams stored in the storage-ring. It will also open up new experimental possibilities. In 1984, a decision was made to develop a cooling device at INS.[1] The motivation for the electron cooling was to extend the proton cooling technique to heavier ions, which was not realized yet at that time. It was intended to study the fundamental cooling technique for light to heavy ions at a wide range of energy up to 200 MeV/u while profiting from the extensive experience for the proton cooling already exploited in other laboratories. In 1985 construction work began and the first electron beam was obtained in 1988.[2-5] The cooling device was then installed in early summer of 1989 in the TARNⅡ ring which has been constructed in parallel and has already succeeded in the beam injection and accumulation test.[6]

In the following, the electron cooling device is summarized and the status of the cooler after rolled in the storage-ring is described.

THE ELECTRON COOLING DEVICE

The layout of the electron cooler is shown in Fig. 1. Electrons are extracted from a cathode by means of an anode and then accelerated to the nominal energy by an acceleration column. The whole system is immersed in a longitudinal magnetic field which serves as a guiding field for the electron beam while suppressing the divergence due to the space charge.

After bent by a toroidal field by 45° , electron beam enters a 1.5 m long cooling section where it overlaps with ion beam. At the end, the electron beam is separated from ion beam in a toroid, decelerated and collected in an electron collector. The emphasis is placed on the generation of a cold electron beam with small transverse energy and well-defined longitudinal energy. The device is designed to work from 11 to 110 keV electron energy. The size of the electron beam is 5 cm in diameter, which was chosen to match a rather large ion beam size. The gun perveance is 1.1×10^{-6} AV$^{-3/2}$.

The electron cooler is equipped with three pick-up stations for the measurement of the position of the electron in both horizontal and vertical directions. Electron beam positions are observed by modulating the electron beam current, which was achieved by modulating the gun anode with a few volts at the same frequency at which ion beam is bunched in order to remove the systematic errors. The two pick-up stations in the cooling region are used to measure both the ion beam and the electron beam positions. In the cooling region antennas are installed to measure the microwave radiation emitted by the electrons

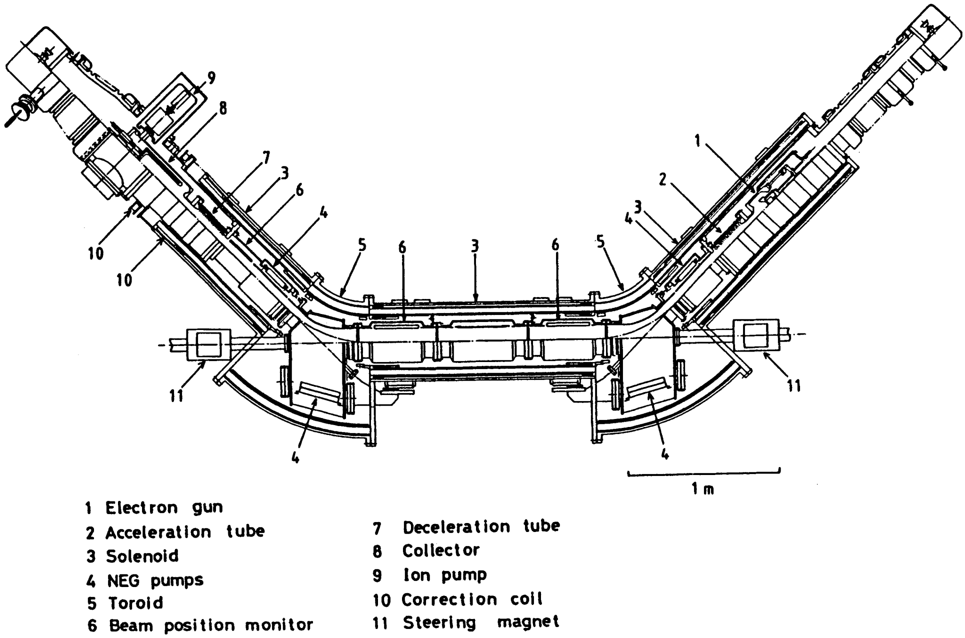

FIGURE 1 Layout of the electron cooling device.

spiralling in the longitudinal magnetic field.

The potential for the cathode is provided by a highly stabilized power supply (HVPS) which is connected to a high voltage terminal in a Faraday cage. In the terminal, power supplies for the cathode heating, for the anode in the gun and for the electrodes in the collector are installed. A schematic control system is shown in Fig. 2. Parameters which have to be set or be read on high potential level are controlled through CAMAC ADCs and DACs in the ground potential via local controllers. Fiber optic links allow the communication between the local controllers at ground level and supplies in the high voltage terminal. The magnet system for the cooler including different correction coils is powered by 14 different supplies, which are also connected to the CAMAC system. The CAMAC crates are operated by an M-16 computer. About 30 supplies including those for the steering magnet system are thus made fully programmable. Status and voltage levels of all high voltage power supplies are also fed to an interlock system to ensure safety in the events of a discharge and a computer failure, together with the status of the main magnets, vacuum meter and water flow switch. The cathode, the gun-anode, the collector-anode and the collector are cooled by pure water to reduce the leakage current of the high voltage power supply.

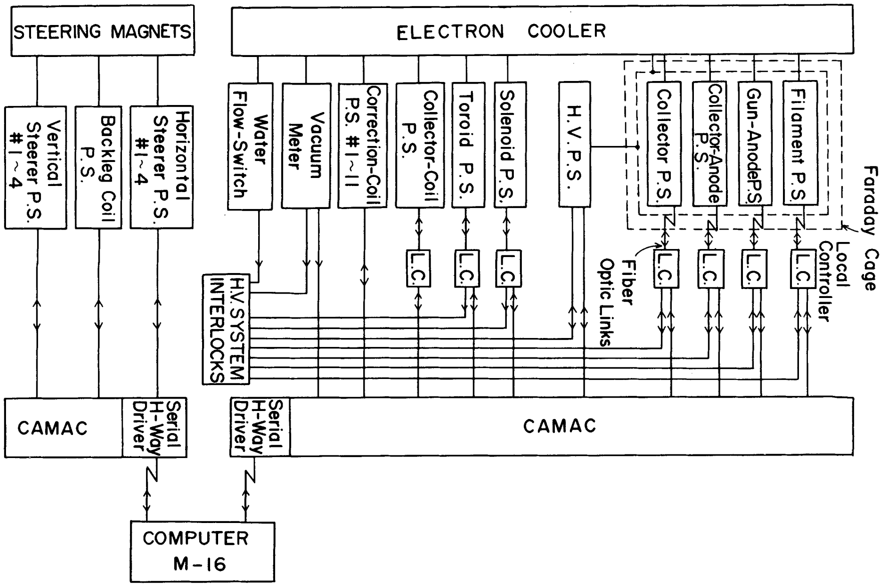

FIGURE 2 Electron cooling control system.

The complete electron cooling system was assembled as shown in Fig. 1 and the first electron beam was produced in the entire system in December 1988. So far the electron beam operation has been tested up to the energy of 70 keV with the electron current of 2 A at a typical collection efficiency of 99.95 %. The results of the off-line electron beam test are summarized in Ref. 5.

INSTALLATION OF THE COOLER IN THE RING

The components of the magnetic field perpendicular to the ion beam axis bring the closed orbit deformation. Main component is the vertical magnetic field in the toroids. It bends the ion beam axis in the horizontal plane to opposite directions for the entrance and the exit toroids. The total bending angle which the ion beam receives depends on the strength of the toroidal field and the beam energy. For example, it reaches 24 mrad for the toroidal field of 600 Gauss and for the 20 MeV proton beam. Such a large deformation is corrected by six steering elements as shown in Fig. 3. They are four steering dipoles (ST#1~4) and the dipoles at both ends excited by backleg windings in the main dipole magnets for the ring.

On the other hand, weak horizontal component comes from the dipole

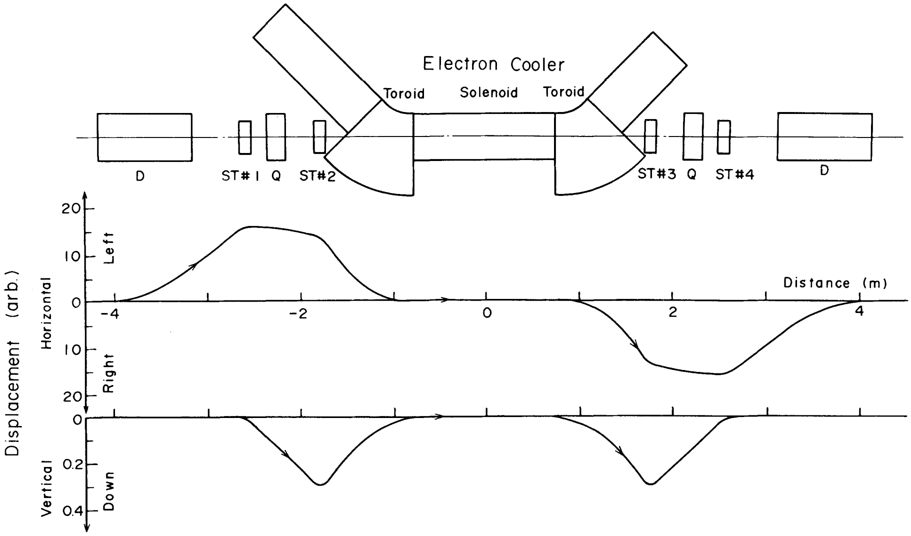

FIGURE 3 Correction scheme for the influence of the magnetic field of the electron cooling device on the closed orbit in the ring.

field in the toroidal region which is used to cancel the drift motion of the electron beam due to the centrifugal force. This component steers ion beam in the vertical plane to the same directions for both toroids. The bending angle due to this component is, however, smaller than the horizontal one by about two orders of magnitude. Each steering magnet can generate both horizontal and vertical field components by exciting two pairs of coils wound on to the same steel core. The orbit corrected by these steering magnets (ST#1∼4) in the vertical plane is also schematically shown in Fig. 3.

The insertion of the alien elements of electrons and solenoidal magnetic field into the symmetric ring lattice produces unwanted perturbations of the ion beam motion : 1) tune-shifts and changes of the β-function mainly due to the electron space charge and 2) coupling of vertical and horizontal betatron oscillations due to the solenoid field. The presence of electrons is equivalent to focusing quadrupoles in both planes. For example, with I_e=0.5 A, T_p=20 MeV, β_H=10 m and β_V=4 m the corresponding tune shifts in the horizontal and vertical planes are +0.007 and +0.003, respectively. The reduction of β function in the cooling region is less than 1 m. Although the tune shifts are rather large especially at high current operation of the electron beam, they will be compensated by changing the tunes. At present, however, we have no elements to compensate the coupling motion due to the solenoid. The influence may not be neglected for different beam sizes and close tunes in the horizontal and vertical directions like our operating parameters of the ring.

Figure 4 shows a schematic diagram of the vacuum system at the

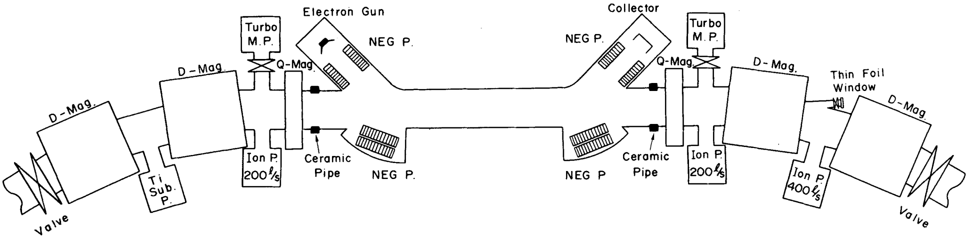

FIGURE 4 Schematic diagram of the vacuum system at the electron cooling section.

section including the electron cooler. In order to avoid frequent exposure of the electron gun to atmosphere, the vacuum system of the electron cooler was separated from the other vacuum system of the ring by a pair of all-metal gate valves with aperture of 20 cm. These valves were installed rather far from the electron cooler due to the limited length of the straight section. The pumping system comprises 4 groups of non-evaporable getter (NEG) pumps of the type ST707, a 1500 l/s titanium sublimation pump, 3 ion pumps (2-200 l/s and a 400 l/s) and 2 turbo-molecular pumps. The vacuum pipes inside the dipole magnets are bakeable at 300 ℃, which are heated by a direct passage of current through the chamber wall. So these pipes are electrically isolated from the grounded electron cooler through short (1 cm) ceramic pipes. The chamber in the cooler is bakeable at 250 ℃ by heating sheath heaters wound on to the chamber wall. The pressure at present is 8×10^{-10} Torr without baking of the beam pipes except those of the cooler. In order to observe neutral beams produced in the cooling process, a thin stainless-steel window (100 μm) was installed downstream of the cooler.

Figure 5 shows a photograph of the cooler after installed in the ring.

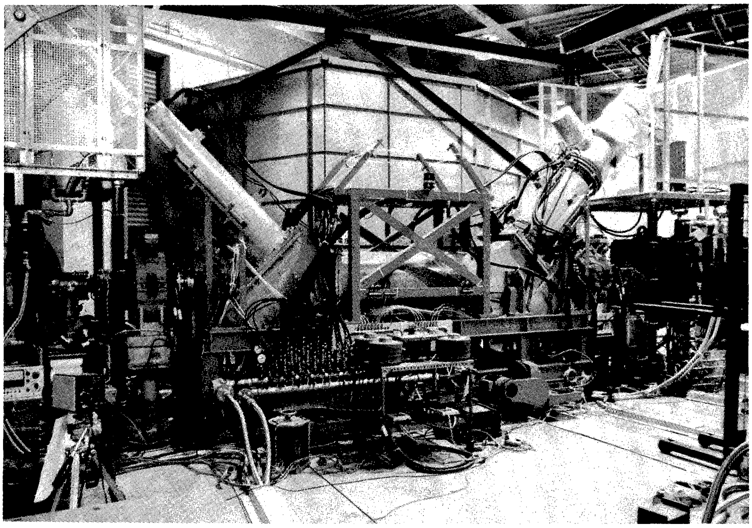

FIGURE 5 Photograph of the electron cooler installed in the TARN II ring.

STATUS OF THE COOLER

The entire cooling system was preliminarily tested: the correction of the closed orbit deformation (COD) due to the toroidal field and the effect of the electron beam were studied for the 20 MeV proton beam. Proton and electron beams were first aligned independently in the cooling region by tuning the steering magnets and the correction coils, respectively, while using position monitors as feedback. Typical bunched beam lifetimes with electron system off were about 5 to 10 seconds. Lifetime of 5 seconds could also be achieved with all the electron system magnet on. However, with 0.5 amp of electron beam on (but detuned in energy) proton beam lifetime was approximately 1 second. The lifetime with electron system off is shorter than the one estimated from the residual gas scattering at the average working pressure of 2×10^{-9} Torr by about one order of magnitude. This seems to be due to the imperfection of the COD correction especially in the vertical plane. The reason of the shorter lifetime with electron beam on is not well understood, but it appears to be caused by the imperfection of the beam axes alignment in the cooling region and/or ions trapped in the electron space charge cloud. Anyway the lifetime seems still too short to observe electron cooling. In order to make beam lifetime longer, vacuum will be improved by baking the beam pipes and also fine orbit tuning will be tried for the circulating beam in subsequent tests. Electron cooling experiment is scheduled in this autumn.

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