AN ELECTRON COOLING DEVICE IN THE ONE MEV ENERGY REGION

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Summary

The project of an electron cooling device at 700 KeV electron kinetic energy will be reported. The single parts of the device will be described in detail. Finally, electron beam diagnostics and technical problems will be discussed.

Introduction

The use of an electron beam to compress the phase - space density of a stored proton beam was suggested by G. Budker [1] in 1966. The first experiments began in the early seventies at the Institute for Nuclear Physics in Novosibirsk [2]. The goal was to demonstrate the usefulness of this method to increase the phase - space density of stored beams and, if successful, to apply it to ion / antiproton accumulation and the generation of intense ion / antiproton beams for low and intermediate energy physics.

The detailed experimental studies yielded many valuable results for the application of this method to a wide range of accelerator projects.
Although it will still be used to cool antiprotons, its major application is found in cooler rings for light and heavy ions at medium energies.

In this paper we present the project of an electron cooling device at 700 keV electron kinetic energy [3]. This device can be used to cool $\bar{p}$ - p collider beams at intermediate energy in order to improve the experimental resolution and increase the luminosity [4,5].

Electron Cooling Device

We discuss here the electron cooling device actually in construction [3] (fig.1a).
In order to obtain a powerful electron cooler with time constants of the order of a few minutes, for electron energy beam up to 700 keV, we are constructing an electron beam with the following characteristics:

Beam energy	0.1.- 0.7 MeV
Electron current	3.5A at 0.7 MeV
Beam diameter	3 cm
Momentum spread	10E-3
Transverse temperature	0.5 eV
Collector voltage	1 - 6 kV
Magnetic field	3 kG
Drift region length	1.5 m
Vacuum in drift region	10E-12 Torr

The power is supplied by a high voltage electrostatic generator. In order to compensate the space charge effect, the electrons, from cathode to collector, are immersed in an axial magnetic field.

High voltage system

The high voltage system (fig. 1a, b) consists of three stainless steel high voltage terminals (1.4 m diameter, 90 cm high) connected together through two stainless steel tubes (20 cm diameter, 3 m long). The terminals are located at 1.3 m from the ground level by means of insulating columns. In the first HV terminal the power supplies of the Pierce electrode, ion pump and NEG pump are located. In the second one the high voltage rectifier (0 - 6 kV, 25 kW) to be used for energy recovery takes place. Finally, the third HV terminal contains the pump power supplies for the decelerating tube and the collector, and the alternator (380 V three-phase, 50 Hz, 30 kW) used to produce the power necessary in the HV terminals. The power is transmitted to the alternator through an insulated rotating shaft, driven by a motor.
A symmetrical cascade Cockroft-Walton electrostatic generator of 760 kV nominal voltage permits to accelerate electrons up to 700 keV. It consists of 19 stages, 40 kV each, driven by a 40 kHz - 20 kV square wave oscillator of 3 kW power. The high voltage generator has been tested in air up to 350 kV, giving very promising results. The measured ripple was less than 10E-4 . For electric insulation reason, all the HV system is contained in a SF6 tank at a pressure of 3 atmospheres. The controls and power supplies needed to operate the cooler were completely built to conform to the requirements of computer control.
A special crate at electron gun potential performs all interfacing for command and acquisition of parameters. This crate is connected to the ground level crate by means of a fibre optic serial branch. Power supplies, including the gun/collector bias supply, has been made fully programmable.

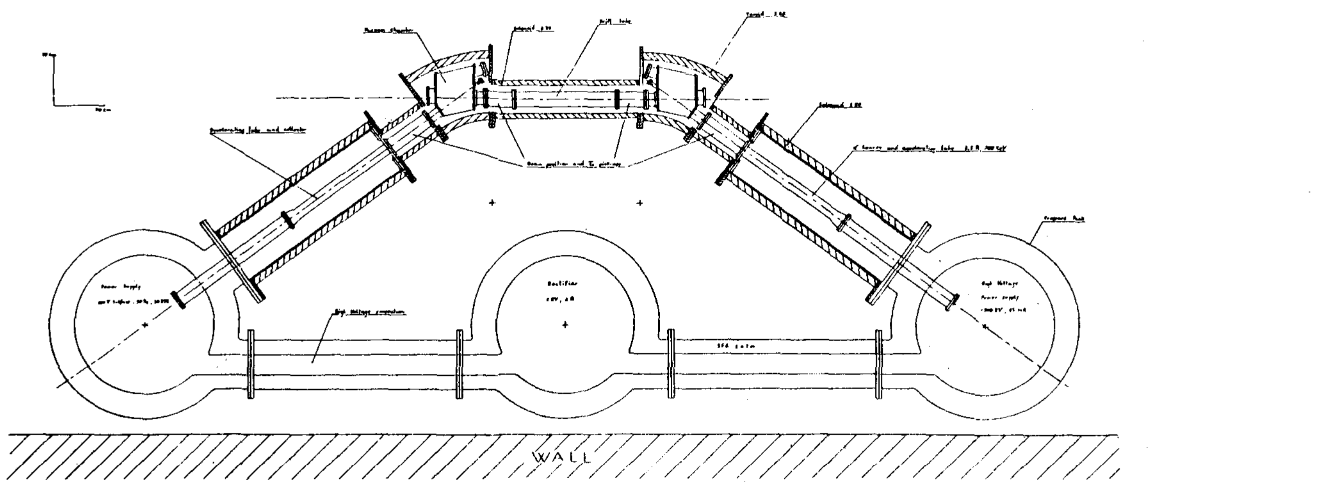

Fig. 1a. A scheme of the electron cooling device.

Electron gun, energy recovery system and beam optics

The electron gun uses a reserve cathode, heated at 1050 C and produces a 3.5 A, 7 cm^2 beam at 700 keV As the electron beam must have a temperature less than 0.5 eV, the first electrodes have to be designed with a classic immersed flow Pierce geometry, followed by standard "resonant optics", aimed to minimize the electron spiral. The Pierce region is composed of 5 electrodes; the anode is located at 2.5 cm from the cathode and activated at 12 kV. The other electrode are spaced of 3 cm and potentials of 34 kV, 62 kV 93 kV and 126 kV are respectively applied. The electrode shape has been studied by computer using the Herrmannsfeldt program [6] in a version modified by M. Sedlacek [7] .

At the end of the Pierce region a diverging lens effect exists, which has to be compensated by an appropriate graduation of the electric field. The acceleration up to 700 keV is accomplished by a further accelerating tube.

The accelerating tube consists of a column of 33 COVAR electrodes (1 mm thick) spaced (3 cm) by ceramic rings and develops a total length of about 1.2 m. A special shape of the electrodes has been studied to protect the ceramics from ion current.

The electrodes are polarized through a resistive voltage divider, made of special resistances wrapped around the tube and protected by guard rings.

After coming out of the gun, the electron beam is bent to be superposed with the hot stored ion beam.

The bending is accomplished by means of a toroidal and a dipole magnetic field. The cooling occurs in the 1.5 m long drift region.

In order to avoid an electron dump of the order of 2.5 MW and to save the installed power, a very efficient recovery of the electron energy is needed.

The energy recovery system consists of a decelerating tube, which optics is the same of the accelerating one, where the electrons are decelerated down to about 30 kV. The further energy decrease can take place according to existing successful methods. We consider sufficient to use a single plate water cooled collector operating from 1 to 6 kV, expecting thus an energy dissipation of the order of 20 kW. In this way, we think to minimize the relative current losses around 10E-4.

The electron cooling magnet

The common technique to generate the intense electron flow for electron cooling of stored ion beams makes use of a magnetic field in the direction of the electron beam.

This longitudinal magnetic field prevents the electron beam from blowing up owing to its space-charge. The field strength is chosen in order to obtain a value of the electron cyclotron frequency which is large compared to the plasma frequency of the electron beam, and in order to match the requirements of the electron gun for producing a cold beam. The magnetic field properties are important for the operation of the electron cooler. In fact, the magnetic field lines determine the direction of the electron flow, and their curvature can excite the transverse motion of the electrons.

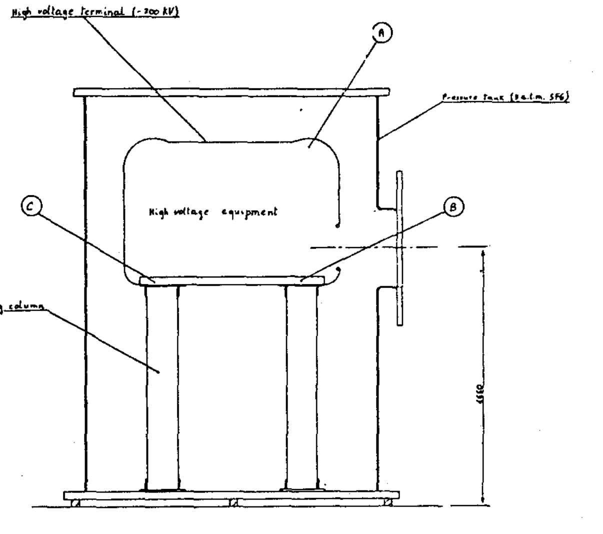

Fig. 1b. A side wiev of the high voltage terminal.

In the cooling region where the electron and ion beams overlap, any variation of the magnetic field direction larger than about 5 x 10E-5 rad deteriorates the cooling effect. The assembly of magnets which we speak about is shown in Fig. 1 a and the most important characteristics are listed in Table. The figure shows the path of the electron beam which is generated in the two meter long "gun solenoid" and recovered by the collector located inside a two meters long "collector solenoid", where the magnetic field is properly shaped. Gun and collector solenoids are connected to the toroids by means of two "short" (0.5 m long) solenoid.

Table. The most important characteristics of the electron cooling magnet:

Cooling solenoid	length 1.5 m inner diameter 284 mm
Short solenoid	length 0.5 m inner diameter 284 mm
Gun/collector solenoid	length 2 m inner diameter 520 mm
Max. current density	13.4 A/mm
Max. current	1920 A
Max. voltage to ground	350 V
Max. cooling water pressure	25 bar
Max. magnetic field	3 kG
Flux in the steel jackets	14 kG

The toroidal magnets conduct the electron beam in and out of the cooling region situated in a 1.5 long solenoid. As it is only slightly deflected by the electron cooling magnet, the ion beam enters and leaves the solenoid in the cooling region by passing almost straight through the toroids.

The solenoidal and toroidal coils are surrounded by a soft iron screening tube that renders the field inside the coils independent of the magnetic environment of the device. Solenoids and toroids are bolted together at iron flanges in relative positions defined by dowel pins. Owing to the interruption of the coil, the longitudinal field strength in the magnet is slightly reduced near these flanges. In order to compensate this discontinuity, correction coils are mounted on the flanges of the solenoid in the cooling region and of the "short" solenoids.

Solenoids, toroids and correction coils are connected in series to the same power supply.

Ultra-high vacuum system

The most serious ultra-high vacuum (UHV) problem in an electron cooler is to achieve very low pressure while the gas throughputs and loads are high with the system active. The gas produced results primarily from thermal degassing and chemistry of the hot cathode of the gun, from the collector, and from impact desorption of gases sorbed on surfaces by electrons lost from the primary beam.

While careful choice of materials, cleaning and bulk degassing treatments can help, it is still necessary to provide a very large pumping speed and capacity for the gas species normally desorbed. Morover, little flexibility exists in the space available for pumping due to the geometrical arrangement, leading to small conductances from the main gas source (gun and collector) to the drift tube where the lowest pressure (10E-12 Torr) is required. The argument of the rigidity of boundaries has some consequences the choice of the principle of pumping.

Given these tight conditions, an analysis of the existing pumping principles while designing the electron cooler led to the choice of cryopumping and sputter ion pumps, with in addition the NEG (Non-Evaporable Getter) pumps. The NEG pumps are distributed in the system and, in particular, provide a strong differential pumping between the gun/collector and the drift tube.

Numerous tests and measurements have shown that the use of NEG pumps can be an answer to the requirement of obtaining UHV in our electron cooler.

The chosen solution will be tested in the near future in real life with the cooler fully assembled and operating.

Diagnostics

To optimize the beam properties and achieve satisfactory cooling performance, it is essential to have adequate diagnostic system both for use on a test stand and in the operational environment.

Beam position and electron temperatures are very important informations to be picked-up.

As in the first stage of our work no electron-ion beam matching is foreseen, methods based upon cooling and correlated phenomena cannot be considered. A first low-current diagnostics, not necessitating energy recovery, will be used for testing optics tuning, alignements and magnetic field uniformity. Diagnostics at full intensity require application of a non-destructive method.

An effective, but crude, method of partially optimizing the beam is to monitor the electron loss current. However, a minimal loss current may not necessarily correspond to an optimal beam for cooling.

Beam position and electron transversal temperature can be measured by using the synchronous wave pick-ups [3] located inside the two "short" solenoids and at the entrance and at the exit of the cooling region. The pick-up principle is based on the fact that the particle beam excites an evanescent wave on a dielectric (or on a corrugated surface) which is detected by a probe. Pick-ups matched on the electron cyclotron frequency, typically 3.5 - 7 GHz, give information on the electron transverse temperature by measuring the power emitted by the electrons and transformed in an evanescent wave.

Backscatter of laser light sent head-on into the beam gives a sensitive, non-destructive measurement of the electron density and of the longitudinal electron temperature [9]. In order to detect the scattered light in the visible spectrum, or around the visible range, we think to use two different laser beams (Nd and CO_2) of about 3 J/pulse energy, as incident radiation. The choice of the laser depends on the electron beam energy. The measure of the beam density and of the longitudinal electron temperature can be carried out, in principle, by means of a simple apparatus. The laser light is focused and aligned parallel to the incoming electron beam in the cooling section. The laser can be displaced parallel such that it can illuminate all the beam cross-section. The backscattered light is collected by the laser path by a specially coated mirror and directed to the monochromator, travelling across an appropriate optical system consisting of lenses and filters. The expected counting rate of scattered photons is high enough.

Background is suppressed by the Doppler shift in the backscattered light and by pulsing the laser.

Present status and conclusions

The electron gun, the accelerating/decelerating column and the collector have been studied by means of the Herrmannsfeldt's program and at present are under construction.

The high voltage system and the electron cooling magnet are also under construction.

Vacuum tests with both hot and cold cathodes have demonstrated that the vacuum requirements as discussed in a previons paragraph can be attained by the use of non-evaporable getter (NEG) pumps between gun, collector and the cooling region.

Both kinds of diagnostics for longitudinal and transversal electron temperature measurements are in progress. A first prototype of the synchronous pick-up was successfully tested at CERN SPS. At present the diagnostic with laser beam is in preparation.

During the next year the device will be assembled and the laboratory test will be started.

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Discussion

Салимов Р.А. Какой материал катода вы использовали?

Tecchio L. Торированный вольфрам. Сейчас мы думаем использовать импрегнированный катод.

Салимов Р.А. Какой длины у вас ускорительная трубка?

Tecchio L. 1,2 м.