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Abstract. HIRFL-CSR, a new ion accelerator complex, is under construction at IMP, Lanzhou, China. It is equipped with two electron cooling devices. This article describes the commissioning of cooler at electron energy 300 keV. The cooler is one of the new coolers with some unique manufactured in BINP, Russia. It has a new electron gun producing a hollow electron beam, electrostatic bending and a new structure of solenoid coils at the cooling section. The test results of cooler obtained in Novosibirskand Lanzhou are reported.

INTRODUCTION

HIRFL-CSR is a multi-purpose system that consists of HIRFL (injector), main ring (CSRm) and experimental ring (CSRe) [1]. It is planned, that the heavy ion beams with the energy range of 8-50 MeV/u from the HIRFL is accumulated, cooled and accelerated to 100-450 Mev/u in CSRm. After that the ions is extracted fast to produce RIB or highly charged heavy ions. The secondary ions are stored by the experimental ring for many internal-target experiment or high-precision spectroscopy. Two electron coolers are manufactured for CSR complex. In CSR-m, ecooling will be used to increase the beam intensity at injection energy. It was commissioned in Lanzhou in Spring, 2003 [2]. In CSRe, e-cooling will be used to compensate the growth of beam emittance induced by internal target processes and to provide high-quality beams for the high-resolution mass spectroscopy experiment. The main parameters of the CSRe cooler are shown in Table1.

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Table 1. Parameters CSRe

Operation Energy: Ion [MeV/u] Electron [keV]	10-450 5-300
Max. electron current [A]	3
Cathode diametr [cm]	3
Magnetic field of cooling section [kG]	0.5-1.5
Length of cooling section [m]	4
Beta-functions at cooling section [m]	12,16

CSRE ELECTRON COOLER

The cooler EC-300 consists of cooling section solenoid, two bending toroids, electron gun and collector with solenoids forming magnetic field near cathode and collector body (see Fig. 1). Pumping system produces vacuum value 3.10^{-11} mbar. Dipole magnets and set of special coils are included to provide correction of both electron and ion trajectories. The location of the electron beam is measured by system of pick-up electrodes.

ELECTRON GUN WITH VARIABLE ELECTRON BEAM PROFILE

The electron gun with a control electrode was designed to produce hollow electron beams[4]. The electron gun under consideration is shown on Fig. 1. By digits on the figure are marked: 1 – cathode, 2 –forming electrode, 3 – control electrode, 4 – anode. The gun is immersed into the longitudinal magnetic field of 700-1000 Gs. Convex oxide cathode Ø29 mm is used.

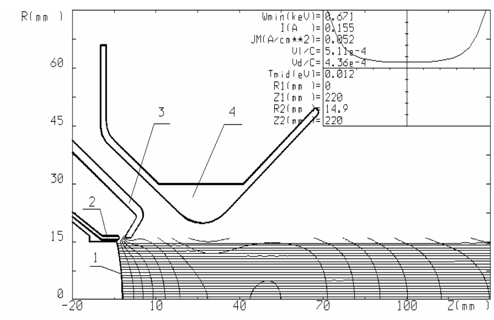

Figure 1. Electron gun calculation.

The control electrode is situated near the cathode edge, so its potential strictly influences on the emission from this area. By varying the potential of this electrode it is possible to obtain on the gun output the beam with parabolic, flat or hollow profile. The potential of the forming electrode is equal to the cathode potential; the purpose of this electrode is to dump exceeding emission from the cathode edge.

ELECTROSTATIC BENDING

The electron and the ion beams convergence before entrance at cooling section base on bending at electric field. Advantage of using electric field instead of usually used transverse magnet field is compensation of drift shift at bending for both direction of moving electrons from cathode to collector and reflected electrons moves from collector to gun. First experimental testing of this idea was made Tim Ellison at Indiana University cooler.

The electrostatic field affects equally on both primary electrons of beam and secondary electron reflected from collector. Thus, the secondary electron from collector has a number of attempts for absorption in collector. The leakage current is very small in this case. The figure 3 shows the dependence of the leakage current versus voltage of the electrostatic bending plates for different value of suppressor voltage. In this experiment the voltage of the electrostatic plates and the current in the correction coil was chosen in such a way that the electron beam doesn’t shift in the collector and cooling section. So, the integral of drift motion of electron in the toroid section was constant. From figure 3 one can see that the optimum of the electron loss is changed with suppressor voltage. The energy of the electron reflected from the collector is slightly changed. So, the electrostatic bending should be adjusted with the energy of secondary electrons.

The obtainable value of the recuperation efficiency is better than 10_{-6} in optimum. It leads to high vacuum condition of cooler, the pressure of residual gas was better than 10_{-11} at commissioning in BINP. There are no electrons falling on the vacuum chamber and inducing the degassing process. Really, after some training procedure the switching on of electron beam improves the vacuum pressure.

The small leakage current decreases the problem with the radiation condition. The energy 300 keV is enough for producing radiation level 25 ∝Rem/sec/mA at not shielded place of cooler device. But this effect was observed at magnetic bending only. At electrostatic bending the radiation level was less than noise level.

Pan-Cake Structure of the Cooling Solenoid

Main solenoid of the cooling section consists of 68 pancake coils connected in series. All of them are adjustable because of tree points of support. After several iterations of measurement and adjustment the sufficiently high level of magnetic field homogeneity was achieved. A Fig.2 show practical solution of this idea at BINP coolers.

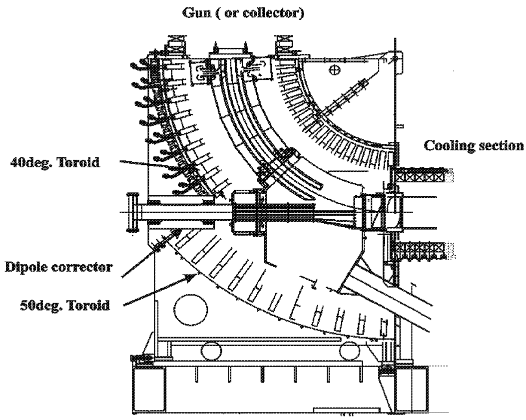

Figure 2. Design of electrostatic bending plates for electron and ion beams convergence.

Absent drift motion for electrons oscillated between electron gun and collector results to very high efficiency capture its at collector after few attempts. The force on bending orbit is:

$$F = \frac{\gamma\beta^2 m_e c^2}{R} = \frac{q[B \times V]}{c} + qE\,, \quad (14)$$

where B,E magnet and electric field for moving electron at trajectory with radius R. It is possible to have pure magnet bending B=Bmax, E=0 and pure electrostatic bending B=0, E=Emax. At case magnet bending electrons reflected from collector have twise large drift from geometric trajectory by action cenrifugial and magnet force at the same direction instead compensation. The figure 3 show losses current versus voltage on electrostatic bending plates (0→2kV). The magnet field at this experiment simultaneously change (Bmax→0) so that orbit of the primary electron beam is not change.

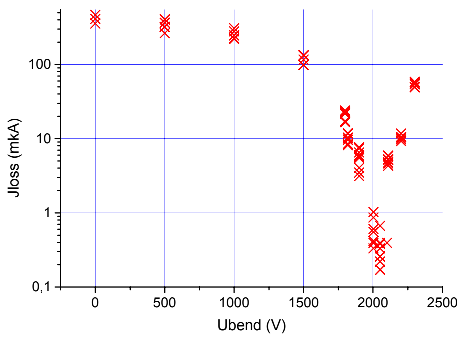

Figure 3. Losses current at EC-35 versus voltage on electrostatic bending plates. (The electron beam 15 keV*1A.).

From this figure clear see that the recuperation efficiency change from 4×10^{-4} for pure magnet bending to $6\text{-}7\times10^{-7}$ for pure electrostatic bending.

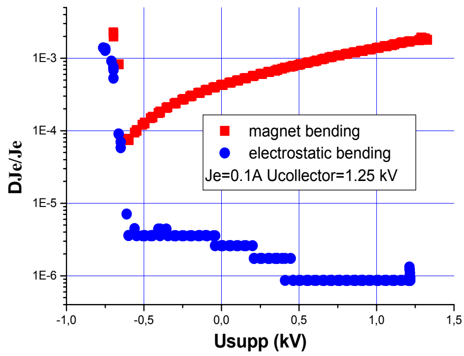

Figure 4. Relative losses electron current versus suppresser voltage for magnet and electrostatic bending.

The minimisation of the electron beam losses current differ for electrostatic and magnet bending (fig. 4). At case the magnet bending using the suppresser electrode for more effective capture electron help decrease relative losses from 2×10^{-3} to 8×10^{-5} when voltage on the suppresser change from collector voltage to –0.7 kV. At the voltage less them –0.7 kV the tails of the primary beam reflected from collector and losses very sharp increased. But at case the electrostatic bending more impotent to have free enter at collector then suppress reflection from the surfer collector . The multiply coming the electrons at the collector made requarement on capture efficiency not so significant. This phenomena open new possibility for operation with the low voltage on collector without strong suppression at the entrance.

Decreasing bombarding the vacuum chamber the electrons with high energy on few order magnitude decrease outgasing and radiation problems for high energy cooler. For example if we need vacuum 10^{-12} Torr and have losses current 400 mkA the pumping power of the cooler vacuum system should be 50000 l/s but for electrostatic bending and loss current 1 mkA we need only 130 l/s pumping power that at many times easy. Figure 5a and 5b show experiments with measuring vacuum pressure at LEIR cooler with switch of ion pumps. At this case gas components with weak pumping by NEG produced fast increasing pressure at cooler with rising time near 0.6E-9 Torr/(175-75 s).

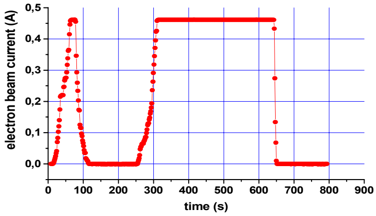

Figure 5a. Electron current versus time at LEIR cooler.

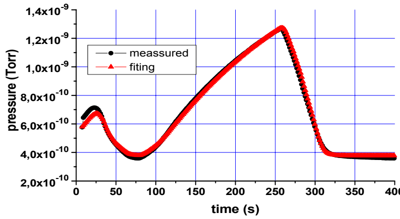

Figure 5b. Pressure versus time with switch off ion pump.

The combination low voltage on collector and low losses the electron current open perspective to have good vacuum at the electron cooler. After relatively short time operation with the electron beam the out gassing inside cooler becomes so low that electron beam switch on improve vacuum at cooler.

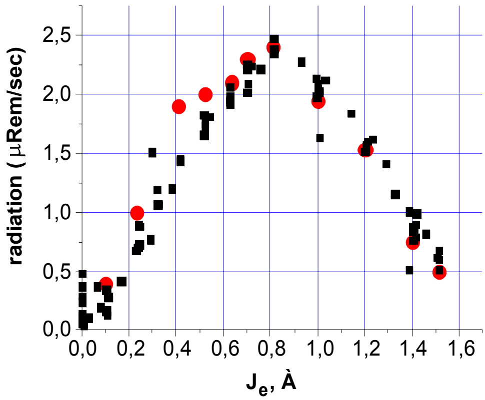

Figure 6. Radiation level near cooler with beam energy 260 keV and losses current (at units 1=40 mkA) versus electron beam current.

Figure 6 show results of measuring radiation at EC300 cooler before final tuning capture efficiency. The radiation level is proportional of loss current and equal to 25 µRem/mkA (for 260 keV). Fast increasing the radiation with increasing cooler voltage made this problem important for the next generation high voltage coolers.

CONCLUSION

The commissioning of cooler with electron beam demonstrated high performance. The electron current up to 3 A was obtain that few times high that can used for the cooling ion beams. The nearest future these coolers will tested at experiments with cooling ion beam and it can open many interesting physics pheromones. The development new generetion of the electron coolers are the result of effort high intellectual team of sciences, engineers, workers at BINP with using world experience technique of the electron cooling.

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