COMMISSION OF ELECTRON COOLER EC-300 FOR HIRFL-CSR

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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 Novosibirsk and 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, e-cooling 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.

Table 1.

Parameters	**CSRe**
Operation Energy: Ion [MeV/u] Electron [keV]	10-450 5-300
Max. electron current [A]	3
E beam radius at cooling section [cm]	2.5
Cathode radius [cm]	1.5
Beta-functions at cooling section [m]	12.5, 16.0
Magnetic field of cooling section [kG]	0.5-1.5
Length of cooling section [m]	4.0
Installation length [m]	7.2
Collector voltage, kV	1-5
Magnetic filed of collector, kG	0.5-2.9
Magnetic filed of gun, kG	0.5-5
Pressure of residual gas, mbar	3×10^{-11}

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

The electron gun of EC-300 has the ability to control the beam profile by changing the control electrode potential [3]. The control electrode is located near the cathode edge, so its potential strictly influences the emission from this area. At negative voltage on the control electrode the emission is strongly suppressed on the beam edge of cathode so the pencil beam is formed. At positive voltage the main part of the beam is emitted on the cathode edge so the ring beam is formed. The measured value of perveance $I/U_{anode}^{3/2}$ of the electron gun versus the control electrode potential is shown on Figures 2.

The formation of a virtual cathode takes place at point about $U_{grid}/U_{anode}\approx1.5$. The control electrode potential causes such a big current that it cannot pass over the anode due to the sagging of potential and part of it is reflected back, whereupon the gun output current remains constant regardless of the further growth of the control electrode potential – only the position of the virtual cathode is moving. At U_{grid}/U_{anod} less than threshold of virtual cathode the electron beam is very stable and no fluctuation of space charge was observed very close to threshold yet.

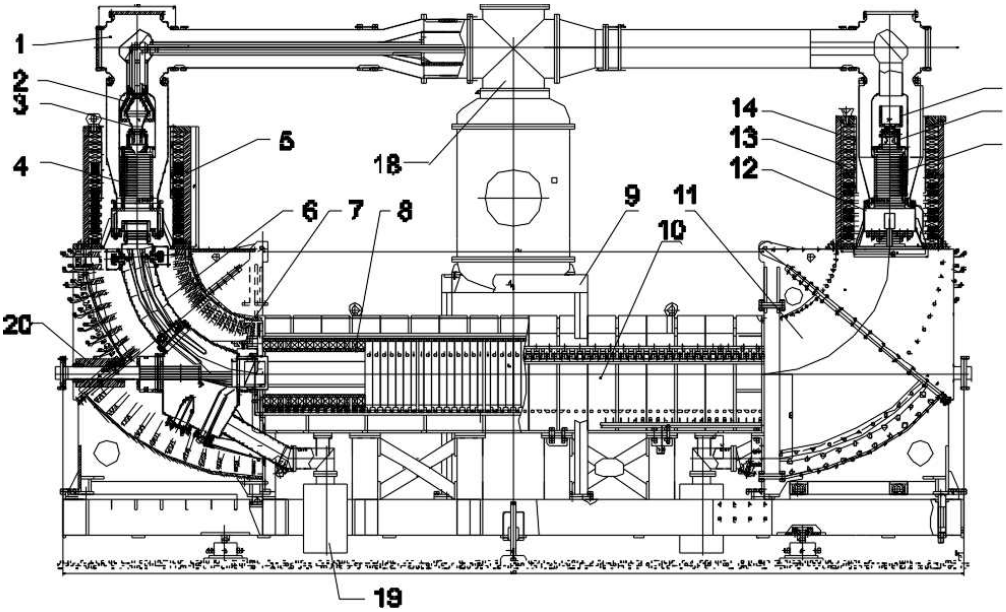

Figure 1: General view of EC-300 cooler device. 1 – high-voltage feeder, 2 – magnetic flux concentrator of collector, 3 – collector, 4 – acceleration (deceleration) tube of collector, 5 – coils of magnetic field of collector, 6 – toroid section with electrostatic bending, 7 – coils of toroidal magnetic field, 8 – coils of cooling section, 9 – vessel of high-voltage power supply, 10 - magnetic circuit of cooling section, 11 – magnetic circuit of toroid, 12 – titanium getter pumps, 13 – coils of electron gun magneyic field, 14 – magnetic circuit of electron gun section, 15 – acceleration tube of electron gun, 16 – electron gun, 17 - magnetic flux concentrator of electron gun, 18 – high-voltage terminal for the electronic equipment, 19 – ion pump, 20 – dipole correction for ion beam.

Electrostatic bending

An electron has drift under the centrifugal force at bending. It can be compensated by the additional magnetic field with opposite direction

$$B_{corr} = \frac{p_0 c}{eR} \; . \qquad (1)$$

This is the correction of forward electron trace only. The backward electron has double shift in the toroid section. During the time of several oscillations from the gun to the collector and back the electron escapes from the beam and losses.

Another idea is to complete compensation of the centripetal force by the electric field in the bending section. In this case there is no drift of the electron crosswise the driving magnetic field. The value of the electric field is

$$E_{\perp} = \frac{pV}{eR} = \frac{\gamma + 1}{\gamma} \cdot \frac{E_e}{eR} \; . \qquad (2)$$

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 μRem/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 special compass-based sensor [4] was used for precise magnetic measurement at cooling section with resolution 1 mG which corresponds to 10^{-6} of magnetic force line distortion.

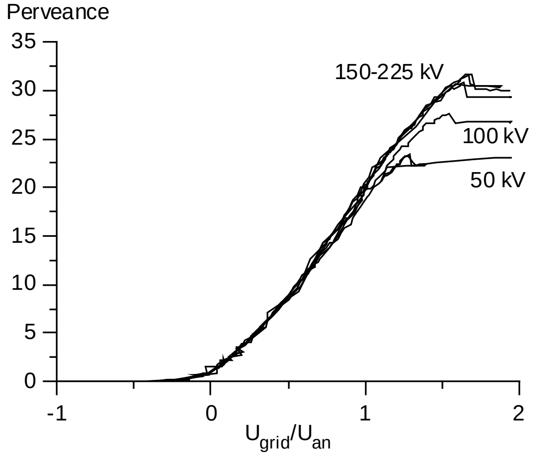

Figure 2. Perveance of the electron cooler device as a function of ratio between grid and anode voltage

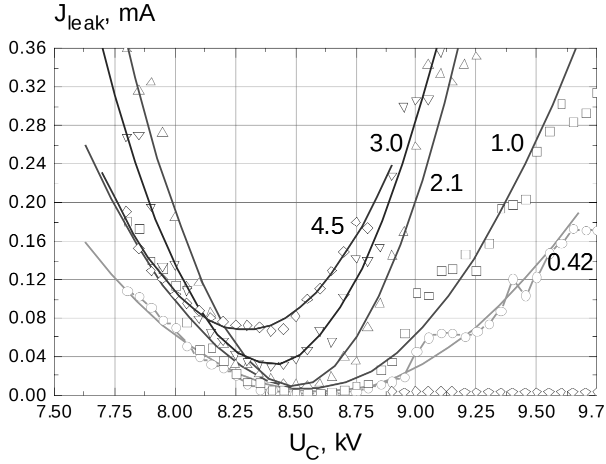

Figure 3. Leakage current versus voltage of the electrostatic bending plates for different value of suppressor voltage. Electron current is 0.5 A, anode voltage is 3 kV, the grid voltage is 0.5 kV, the collector voltage is 4.1 kV.

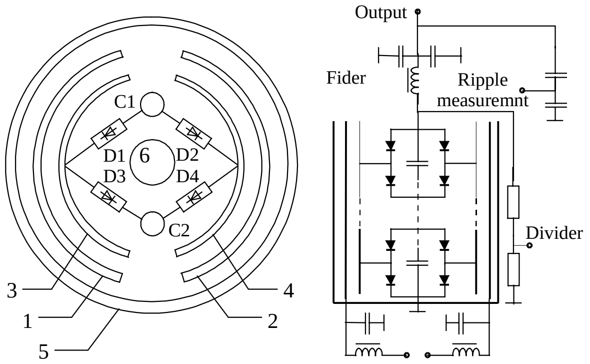

Figure 4. General view of HV power supply and simplified electrical circuit.

HV power supply

High – voltage system (5 – 300 kV) is sectioned rectifier with parallel supply of power with capacity coupling. The section is connected in series relative to loading. The parallel power supply of all section with high – voltage gap enables the uniform working load of all rectifier diodes.

The working frequency of HV rectifier is 350 kHz. This value is chosen for decreasing the energy stored in the device and for decreasing of noise level of output voltage. Moreover the internal resistance of the rectifier decreases with increasing of working frequency. Thus the load characteristic becomes better. The general construction of the rectifier is shown in Figure 5.

The launching electrodes – plates 1 are located inside the vessel 5 along whole height. The high – frequency excitation voltage is applied to plates 1. Farther inside the rectifier section is located. Each section consists of receiving electrodes 3 and 4, rectifier diodes VD1-VD4 and filtering circuit of capacitance C1 and C2.

For exciting of the launching electrode symmetrically about ground two series-tuned circuit is used. The exciting circuit has enough high quality for obtaining high efficiency and sufficient voltage on the section. The circuit has the special inductance made from the high-frequency wire LESHO 49*0.1. The simplified circuit is shown in Figure 4.

COMMISSIONING EC-300 AT IMP

The HIRFL-CSRe cooler EX-300 was commissioned at IMP (Lanzhou) in March-May 2004.

Main parameters achieved are following:

- Vacuum 3×10^{-11}mbar,
- High voltage 250 kV,
- Electron beam current 2.0A,
- Collector efficiency >99.99%,
- Angle of magnetic field line in cooling section: $\approx 2\times10^{-5}$.

Now the cooler is under permanent testing. Long-term stability of all main parameters is studied.

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