ISBN: 978-3-95450-197-7 doi:10.18429/JACoW-RUPAC2018-TUCBMH02

STATUS OF THE 2.5 MeV ELECTRON COOLING SYSTEM FOR NICA COLLIDER

V. Parkhomchuk, M. Bryzgunov, A. Bubley, A. Denisov, A. Goncharov, N. Kremnev, V. Panasyuk, A. Putmakov, D. Skorobogatov, BINP SB RAS, Novosibirsk, Russia
Vladimir Reva, BINP SB RAS, Novosibirsk, Russia and NSU, Novosibirsk, Russia

Absract

Status of the development of the 2.5 MV electron cooling system for the NICA collider is reported. The goal of the system is to cool both ion beams during experiment. Cooling of beams during collision prevents grows of beam emittance by compensation of heating effects (intra-beam scattering, beam-beam effects etc.) that increases luminosity of the NICA collider. The system consists of two independent electron coolers in order to meet the requirement of cooling of two independent beams. Each cooler contains high voltage system, transport channels and cooling section. Construction of main parts of the cooling system, results of testing of some prototypes and status of production are described in the article.

INTRODUCTION

Electron cooling was proposed 62 years ago by G.I. Budker at 1966 in BINP [1,2]. As it is generally known, the first estimation of the electron cooling was made with the plasma model of the temperature relaxation and the first experimental results confirmed this fact. But after modernization of the experimental setup the cooling time was decreased significantly from 10 s to 0.1 s. The theoretical and experimental investigation show that the reason is difference in the collision dynamics of electrons and ion at the presence of the strong longitudinal magnetic field that distinguish it from the usual relaxation of two-component plasma. The ion doesn't interact with a single electron but with a blur Larmor circle. The initial temperature of Au ion beam in NICA is about $3\cdot10^9$ degree of Kelvin. The electron cooling should suppress IBS, noise at NICA system heats ion beams. There are many the electron cooling devices, which operate now at low and middle energy (SIS-18, CSRm, CSRe, LEIR, ESR, etc). The 2 MeV electron cooling system for COSY-Juelich has the highest energy from all coolers that were made with using idea of the magnetized intensive electron beam. Figure 1 demonstrates cooling of 1.66 GeV proton beam by 0.908 MeV electron beam with current 0.8 A. The initial temperature 10^7 degree of Kelvin dropped down at 10 times and beam size decreased from 3 mm to 1 mm. The experience of COSY cooler used for designing and construction of 2.5 MV electron cooling system for NICA [3]. The biggest problem was design of the cooling section with two counters solenoids with only 32 cm between centres of electron beams with low electric power consumption.

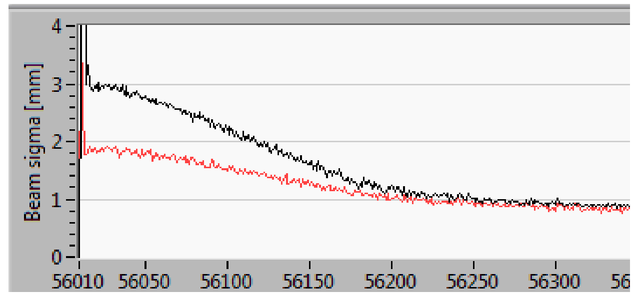

Figure 1: The proton beam cooling at COSY (Julich). The cooling time is about 100 s.

Basic ideas for cooler design:

1. An electron gun was put into a solenoid producing the longitudinal guiding magnetic field, which accompanies the beam until it reaches the collector. The all operated coolers have solenoid field at cooling section. The strong magnet field suppressed transverse motion of electrons.
2. The effect of magnetization the own transverse motion of the electrons help to reach the Kelvin range of the ion beam temperature [4-7]. The nice features solenoid field is the free motion of the light electrons along magnet lines. It help to have the fast cooling by absorbing the kinetic energy of the moving ions. The kinematic suppression of longitudinal motion of electrons after acceleration gives temperature close to 0 at the cooling section. The transverse motion by the space charge of

$$V_{drift} = c\frac{2\pi e n_e}{B} r \quad (1)$$

the electron beam should be suppressed by the high longitudinal field (B).

The vessel for 2.5 MV electrostatic column p<10bar SF6. The electron gun and collector inside HV terminal. The electron gun with low energy bending for protection the cathode from secondary ion beam bombarding.
The collector equipped filter with crossing electrostatic and magnet fields for suppression reflected from collector electrons (see Fig. 2).

The first 3 high voltage sections were produced and tested at air for corona current and sparking (see Fig. 3). Maximum voltage was obtained near 20 kV. If SF6 gas increase voltage by a factor of 2 and pressure is 4 bar, for 40 section it corresponds to full maximum voltage 6.4 MV. This estimation gives hope to reach working voltage of cooler 2.5 MeV.

ISBN: 978-3-95450-197-7 doi:10.18429/JACoW-RUPAC2018-TUCBMH02

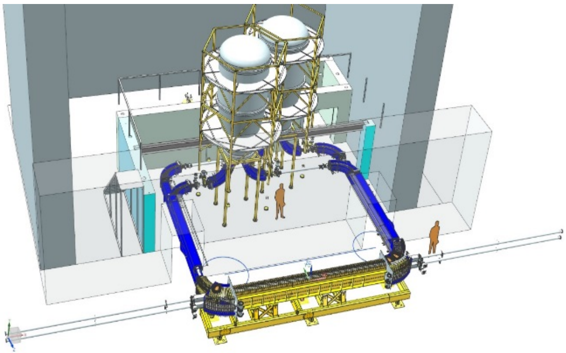

Figure 2: The birds view of 2.5 MV cooler at NICA tunnel with ion beam canal.

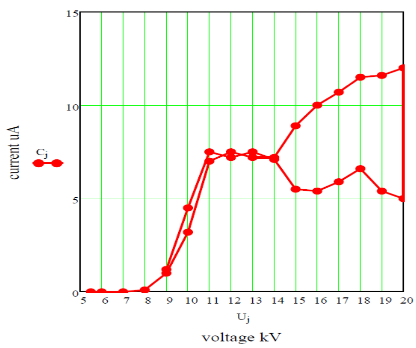

Figure 3: The corona current versus voltage.

The cooling section length is 6 m and Fig. 4 demonstrates first 1 m two window section under magnet measurement.

Figure 4: The magnetic measurement of the 1 m cooling section.

The results of magnet field measurement shown on the Fig. 5. At this measurement coil current was only 200A.

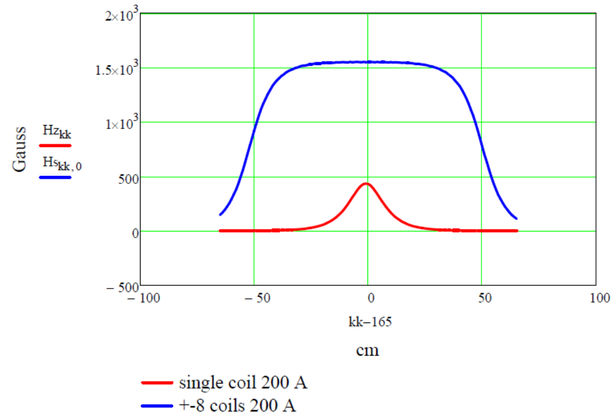

Figure 5: Results of measuring magnet field along cooling section by the hall probe.

HIGH VOLTAGE TERMINAL

The high voltage terminal of the cooler is installed in the top of the electrostatic column and contains electron gun, electron collector, solenoids, power supplies and electronics for their control. The second cascade transformer will power all devices in the terminal. Connection with control computer will be provided with wireless interfaces (Wi-Fi, ZigBee).

Electron Gun

Standard electron gun in coolers, produced in BINP, has cathode with diameter 3 cm. Similar gun was installed in the HV cooler for COSY [7]. For the NICA cooler such beam size looks too big. In main regimes of the collider work mean square size of ion beams will be about 1.5÷2.5 mm. It means that only small part of the 3 cm electron beam will cool ions. In the NICA coolers we suppose to install new gun with 1 cm cathode with maximum current about 1 A.

Experience, received during operation with COSY HV cooler, showed that at high voltages there is a risk of deterioration of the cathode properties due to its bombardment by secondary ions obtained as a result of ionization of the residual gas by electrons. Such ions, which have a positive charge, are accelerated by the field of the electrostatic tube in the direction of the cathode. When they hit its surface it lead to degradation of the emitting film. In addition, when the voltage at the high-voltage terminal is about 1.5 MV, there is a situation (which is still poorly understood) in which the vacuum in the gun tube deteriorates sharply and relatively strong radiation is registered. In this case, the gun is in a locked state. Since such effect was not observed in the collector tube, it is most likely that this effect is related with the cathode.

To avoid these problems in the NICA HV cooler, it was decided to shift the cathode to the side. In this case, the ions accelerated in the tube, due to their large mass, continue to move almost straight in the gun and do not hit the cathode. Electrons from the gun have a small energy and move

ISBN: 978-3-95450-197-7 doi:10.18429/JACoW-RUPAC2018-TUCBMH02

along the magnetic field line slightly shifting transverse the plane of rotation due to the centrifugal drift.

In Fig. 6 a design of the gun with 1 cm cathode in bent solenoid is shown.

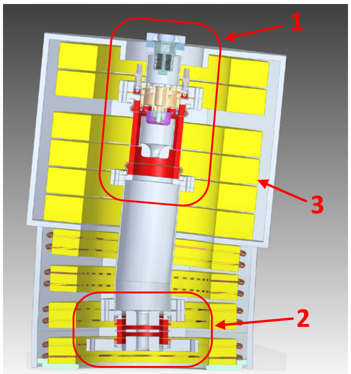

Figure 6: Electron gun for the NICA cooler. 1 – electron gun, 2 – electrostatic lens, 3 - gun solenoid.

Electron Collector

Its design is based on collector of the COSY HV cooler (Fig. 7). It consists of ordinary collector (similar to collectors used in other coolers, produced in the BINP) and special insertion before it with crossed magnetic and electric fields (Wien filter). For main beam, action of fields compensate each other but for secondary beam, which moves back, magnetic field acts in opposite direction and secondary beam is deflected to a special electrode (secondary collector). The collector with Wien filter is placed in longitudinal magnetic field that is related with features of the cooler.

Results of COSY HV cooler operation show that such collector with insertion allows significantly improve collector efficiency from $3 10^{-4}$ to $10^{-5} \sim 10^{-6}$

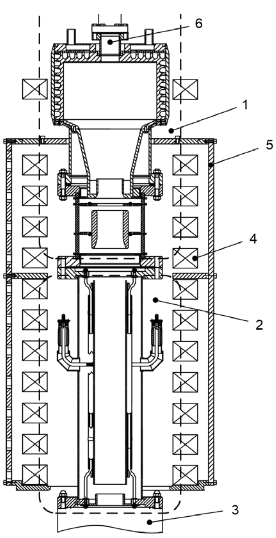

Figure 7: Collector for the COSY cooler. 1 – main collector with the suppressor and pre-collector electrodes, 2 – vacuum chamber of the Wien filter, 3 – electrostatic tube, 4 – coil for longitudinal magnetic field, 5 – magnetic shield, 6 – flange for additional vacuum pumping

LUMINOSITY ESTIMATIONS

Magnetic field in the NICA cooling section is about 2 kG. The drift velocity (at beam rest system) according to (1) for electron beam current 1A does not exceed 0.1 $V_{x\,ion}$ and cooling will be effective. The electron cooling rate increases with electron beam current until drift velocity of electron by space charge is less then ions velocity at beam rest system [7,8]. Calculation equilibrium beam size by electron cooling and different process of heating: by Laslet tune shift, beam-beam effects, IBS was made at very simple approximation. The changing of luminosity by cooling demonstrate in Fig.8. As easy to see from Fig. 8 just only 0.2 A the electron beam current have potential substantially increase luminosity of collider NICA.

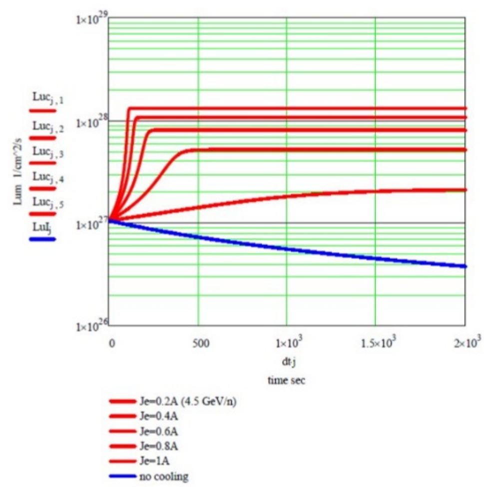

Figure 8: The estimation of NICA luminosity for different electron beam current cooling.

ACKNOWLEGMENTS

Authors thanks colleges who help in development of ideas of the electron cooling in cooler for NICA collider A.N.Skrinsky, I.N.Meshkov, E.Syresin, J. Dietriech and BINP team.

REFERENCES

[1] G.I Budker, Efficient method for damping of particle oscillations in proton and antiproron storage ring Atomnaya Energiya **22** p.346-348, 1967.

[2] Ya. S. Derbenev, A.N. Skrinsky, Plasma Physics, **4**, №3, pp 492-500 (1978) (in Russian) Particle Accelerators, **8**, №4, pp 235-243 (1978).

[3] V. Kamerdzhiev on behalf of the COSY team IKP-4, Forschungszentrum Jülich Electron cooling at COSY - status and perspectives Sept. 19, 2017 | COOL 17 |

[4] Ya.S. Derbenev, A.N. Skrinsky, B.N., Magnetization effects in electron cooling, Fizika Plasmy 4,492-500(1978).

[5] V.V Parkhomchuk, A.N. Skrinsky, Electron cooling: physics and prospective applications, Rep. Prog. Phys. 54 (1991), p.919-947

ISBN: 978-3-95450-197-7 doi:10.18429/JACoW-RUPAC2018-TUCBMH02

[6] The electron gun with variable beam profile for optimization electron cooling, A. Bubley, A.Ivanov… http://accelconf.web.cern.ch/AccelConf/e02/PAPERS/WEPRI049.pdf

[7] New generation of the electron cooling systems, A. Bubley, V. Reva, V. Parkhomchuk, http://accelconf.web.cern.ch/AccelConf/a04/PAPERS/MOP15008.PDF

[8] N.S. Dikansky, I.N. Meshkov, V.V. Parkhomchuk, A.N. Skrinsky. Development of heavy ion cooling techniques, UPhN 188 (5) 481-492 (2018).