ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB182

THE ELECTRON COOLING FOR HIGH ENERGY

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Abstract

The project of new accelerator complex NICA relating to nuclear and hadron physics require a more powerful longitudinal and transverse cooling that stimulates searching new technical solutions. The new accelerator complex NICA is designed at the Joint Institute for Nuclear Research (JINR, Dubna, Russia) to do experiment with ion-ion and ion-proton collision in the energy range 1-4.5 GeV/u for studying the properties of dense baryonic matter at extreme values of temperature and density with planned luminosity 10^{27} cm^{-2}s^{-1}. This value can be obtained with help of very short bunches with small transverse size. This beam quality can be realized with help of stochastic and electron cooling at energy of the physics experiment. The electron cooling system on 2.5 MeV consists of two coolers, which cool both ion beams simultaneously. The Budker Institute of Nuclear Physics (BINP SB RAS) has already built and commissioned the electron cooling system for the NICA booster, and now it develops the high voltage electron cooling system for the collider. The article describes the construction and status of the cooler development.

INTRODUCTION

High energy electron cooling is rapidly developing now in the world. First of all, one should mention an electron cooler for the Recycler ring in the Fermilab accelerator complex (USA) with the electron energy up to 4.3 MeV [1], that is the highest energy among all existed electron cooling systems. Also there is a cooler for COSY synchrotron (Germany) with the electron energy up to 2 MeV which has the highest energy among all coolers with magnetized electron beam [2]. The electron cooler project for RHIC (BNL, USA), where a bunched electron beam is planned to be used [3] is under development now. The experiments conducted with its prototype shown very promising results. Also, one should mention a project of cooler for the HESR ring in FAIR project (Germany) with the electron energy up to 8 MeV [4].

The NICA project (JINR, Russia), which is now under active construction, will provide experiments in ion-ion collisions for investigation of the phase diagram of highly compressed baryonic matter. For the project success it is important to achieve the project luminosity 10^{27} cm^{-2}c^{-1}. For this purpose, the collider ring will be equipped by both stochastic and electron cooling systems, which will allow to increase beams intensity during the beam accumulation and to decrease the ion beams sizes in the interaction point during the experiment. From this point of view, cooling systems have key role in the project.

The Budker INP has extensive experience in production of electron cooling systems, starting from the very first electron cooler for the NAP-M ring [5]. The Budker INP already produced and commissioned the electron cooler for the NICA booster and now it develops the electron cooling system for the NICA collider.

CONSTRUCTION

The scheme of the electron cooling system for the NICA collider is based on the electron cooler for COSY synchrotron [2]. The main feature of the cooling system for the NICA the collider is the necessity to cool both ion beams, travelling in the opposite directions in the collider, simultaneously. Theoretically, it can be done using a single electron beam, which first cools one ion beam and then, after bending to 180º, cools the second beam (Fig. 1), as it is implemented in the project of LEReC cooler in BNL [3]. But experience, achieved during experiments with high voltage electron cooling on COSY, shows, that to achieve effective cooling it is important to adjust electrons energy to ions energy (which can be slightly different for two ring) with high precision. Moreover, electron energy depends not only on ion energy, but also on relative angle between beams, electron current, relative beams position, effective electron beam temperature etc. It means, if we try to implement the scheme with one electron beam, there is very high probability, that improving cooling in one beam will spoil cooling in another. That would significantly complicate operation of the electron cooling system.

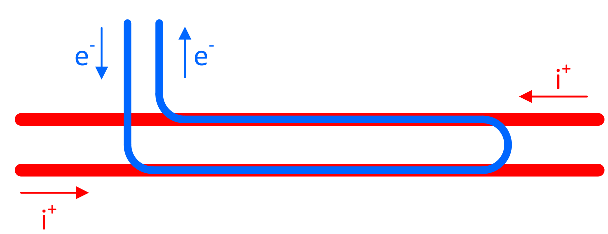

Figure 1: Scheme of cooling with one electron beam.

To avoid this problem it was decided to produce the system as two independent electron coolers. Due to this approach almost all systems of the coolers are independent. But coolers are strongly connected mechanically because of necessity to install cooling sections of both coolers one above one with distance only 32 cm.

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On Fig. 2 one can see the 3D model of the system. The main parts of the coolers are: high voltage systems, placed in pressure vessels (1), cooling sections (2), where electrons interact with ions and transport channels (consisting of bends (3, 4), linear magnetic elements (5) and toroids (6) for electron beam transportation between high voltage systems and cooling sections. On whole trajectory from gun to collector electron beam moves in longitudinal magnetic field (ranged from 0.5 to 2 kG) in order to provide transverse focusing. In the cooling section magnetic field provides so called "fast electron cooling" [6].

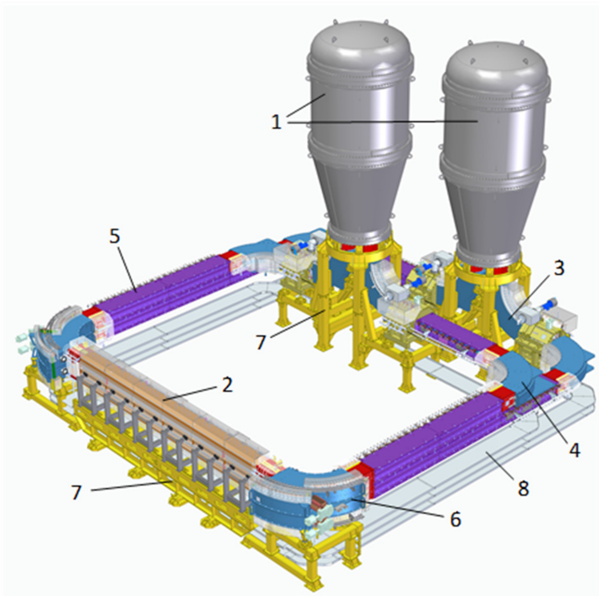

Figure 2: 3D model of the electron cooling system for NICA collider. 1 – high-voltage vessels, 2 – cooling section, 3 – vertical bend, 4 – horizontal bends, 5 – linear sections, 6 – toroid magnet, 7 – supports, 8 – cable channels.

On Fig. 3 the model of the high voltage system is shown. Purpose of the high voltage system is production of electron beam in electron gun and acceleration for working energy in electrostatic tube. After interaction with ion beam electrons move to high voltage system again where they are decelerated in another electrostatic tube and dumped in electron collector. Main parts of the high voltage system are HV column and HV terminal on its top. The HV system is placed in a vessel, filled with SF_6 under pressure up to 10 bar. The column consists of 42 identical HV sections. Each section contains 2 coils with current source for production of longitudinal magnetic field in electrostatic tubes, high voltage PS for voltage 0.1-60 kV and control electronics for operation with power supplies and communication with control PC. The sections are installed one above one and HV PS are connected in series in order to produce up to 2.5 MV of acceleration voltage. Magnetic coils of the sections provide up to 500 G magnetic field in electrostatic tubes. In the middle of the column special section is installed for additional vacuum pumping and for beam diagnostics with BPMs. The section contains magnetic coils, but does not contains HV PS.

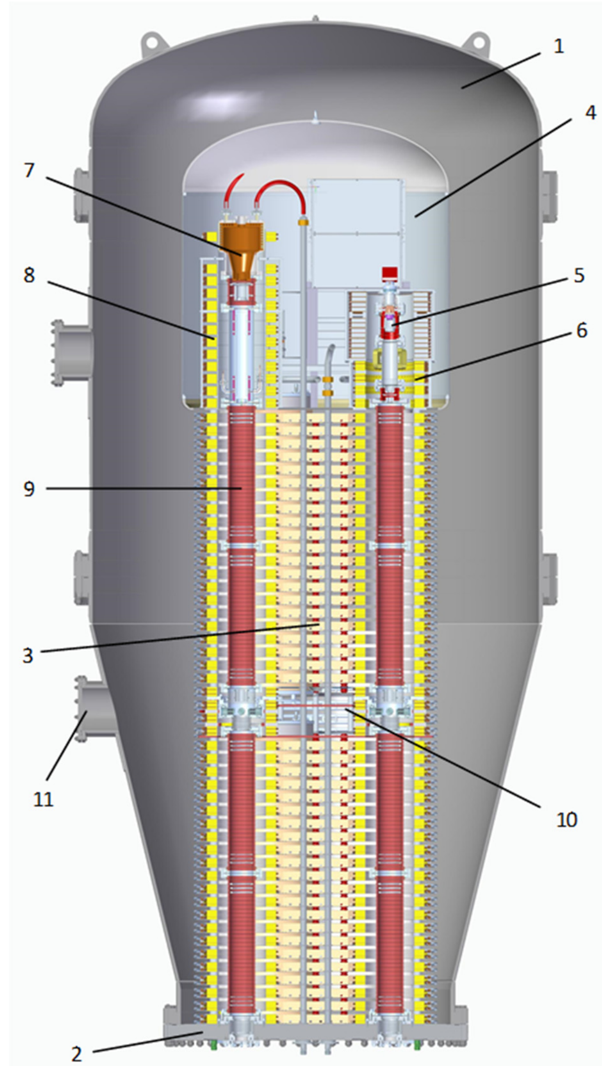

Figure 3: High voltage system of the electron cooler for NICA collider. 1 – pressure vessel, 2 – bottom flange, 3 – high voltage column, 4 – high voltage terminal, 5 – electron gun, 6 – gun solenoid, 7 – electron collector, 8 – collector solenoid, 9 – electrostatic tubes, 10 – middle section, 11 – side flange.

The HV terminal contains electron gun and collector and all electronics for their operation and control (Fig. 4). Also, there are two solenoids in order to provide longitudinal magnetic field in gun and collector.

TEST AND PRODUCTION OF ELEMENTS

Design stage for almost all elements is passed and they are currently in production. Some elements are already produced and their testing is started. Some elements as cooling section, high voltage section and some electronics prototypes were produced and tested.

For the NICA high voltage electron cooler a new electron gun was designed. The main feature of the gun (relative to other guns, produced for BINP electron coolers) is 1 cm diameter of cathode (instead of 3 cm) [7]. It was decided to decrease beam diameter since 3 cm is too big for the beam in NICA collider and most part of electrons

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would not effectively interact with ions. Also, decrease of beam size allows to increase electron density for the same electron current. Moreover, it is obvious, that smaller beam is easier to pass though the cooler.

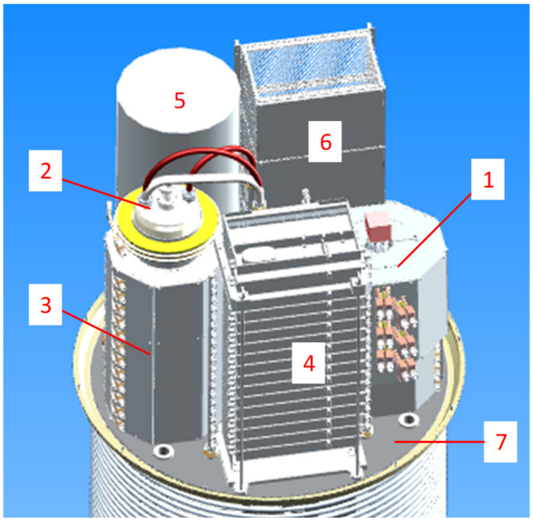

Figure 4: Scheme of cooling with one electron beam.

In order to test the gun prototype the special test bench was assembled (Fig. 5).

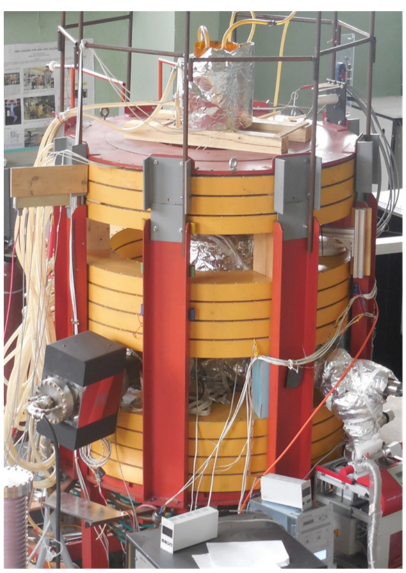

Figure 5: Test bench for electron gun.

The test bench contains gun, collector, straight transport channel, diagnostics elements, magnetic system and electronics. Such electronics as new Interlock system, corrector power supplies, BPM amplifiers and new CAN-Ethernet gateways, which were designed for the cooler are also being tested on the test bench.

Diagnostic elements of the test bench contains BPM and wire profile monitor. The monitor provides measurements both electrical signal and optical (due to wire heating by electron beam). On Fig. 6 an example of profile measurements result is shown. The profile is measured with the help of optical signal registration.

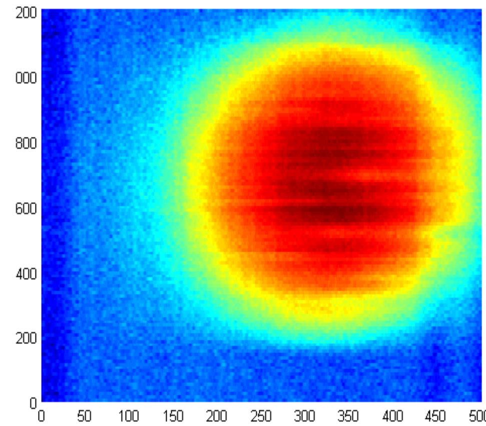

Figure 6: Electron beam profile.

CONCLUSION

The high voltage electron cooling system for the NICA collider is its very important part, which will help in achieving of needed luminosity in ion-ion collision experiments. The Budker INP now actively develops the system.

REFERENCES

[1] S. Nagaitsev, L. Prost, and A. Shemyakin, "Fermilab 4.3 MeV electron cooler", *J. Instrum.*, vol. 10, p. T01001, 2015. doi:10.1088/1748-0221/10/01/t01001

[2] M. I. Bryzgunov, V. S. Kamerdzhiev, V. V. Parkhomchuk, and V. B. Reva, "Features of cooling dynamics in a high-voltage electron cooling system of the COSY", *Tech. Phys.*, vol. 60, pp. 1227-1233, 2015. doi:10.1134/S1063784215080046

[3] A. Fedotov *et al.*, "Experimental demonstration of hadron beam cooling using radio-frequency accelerated electron bunches", *Phys. Rev. Lett.*, vol. 124, p. 084801, 2020. doi:10.1103/PhysRevLett.124.084801

[4] D. Reistad *et al.*, "Status of the HESR Electron Cooler Design Work", in *Proc. 10th European Particle Accelerator Conf. (EPAC'06)*, Edinburgh, UK, Jun. 2006, paper TUPLS067, pp. 1648-1650.

[5] G. I. Budker *et al*, "Experimental Studies of electron Cooling", *Part. Accel.*, vol. 7, pp. 197-211, 1976.

[6] V. V. Parkhomchuk and A. N. Skrinsky, "Electron cooling: 35 years of development", *Physics–Uspekhi,* vol. 43, no. 5, pp. 433-452, 2000. doi:10.1070/PU2000v043n05ABEH000741

[7] A. P. Denisov *et al.*, "Compact Electron Gun for High-Voltage Electron Cooling Systems", *Phys. Part. Nuclei Lett.*, vol. 16, pp. 876–884, 2019. doi:10.1134/S1547477119060128