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ELEMENTS OF HIGH VOLTAGE ELECTRON COOLING SYSTEM FOR NICA COLLIDER

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Abstract

Beam cooling plays a key role in the project of the NICA collider. In order to achieve needed luminosity it is important to provide effective cooling during beam accumulation and during experiment. For this purpose, the ring will be equipped with both electron and stochastic cooling systems. The article describes construction of the electron cooler and status of its production by Budker INP.

INTRODUCTION

The collider ring will be the main element of the future NICA complex (JINR, Russia), where experiments with colliding ion beams in the energy range 1÷4.5 GeV/u will be provided in order to investigate properties of dense baryonic matter at extreme values of temperature and density with planned luminosity 10^{27} cm^{-2}s^{-1}. In order to achieve such luminosity the collider ring will be equipped with two cooling systems: stochastic and electron. The systems will provide increase of beam intensity during accumulation and decrease bunch length and emittance during experiments. The electron cooling system for the NICA collider now is under construction in the Budker Institute of Nuclear Physics (Novosibirsk, Russia).

In order to provide electron cooling in full range of ion energy the electron cooling system must produce electron beam with energy up to 2.5 MeV. Experience, achieved during experiments on the high voltage electron cooling system of the COSY synchrotron [1] and results of operation of electron cooler of the Recycler ring [2] in Fermilab (USA) show, that for effective cooling it is enough to have electron beam with current about 1 A.

Main parameters of the system are shown in Table 1.

Table 1: Electron Cooling System Parameters

Parameter	Value
Electron energy	0.2 ÷ 2.5 MeV
Energy stability	$<10^{-4}$
Electron current	0.1 ÷ 1 A
Cooling section length	6 m
Magnetic field in the cooling section	0.5 ÷ 2 kG
Vacuum presure	10^{-11} mbar

SYSTEM OVERVIEW

Figure 1 shows 3-d layout of the NICA high voltage electron cooling system. The construction is based on high voltage electron cooling system for the COSY synchrotron. In order to cool both ion beams simultaneously, the system consists of two independent coolers. Every cooler contains independent high voltage system, cooling section and transport channels.

Electron beam, emitted by electron gun, is accelerated by electrostatic tube to working energy and moves (through transport cannel) to the cooling section, where it interacts with ion beam. After the cooling section electrons move back to high voltage system where they are decelerated and absorbed by collector surface. On whole trajectory from gun to collector electron beam moves in longitudinal magnetic field, which provides transverse focusing of the beam.

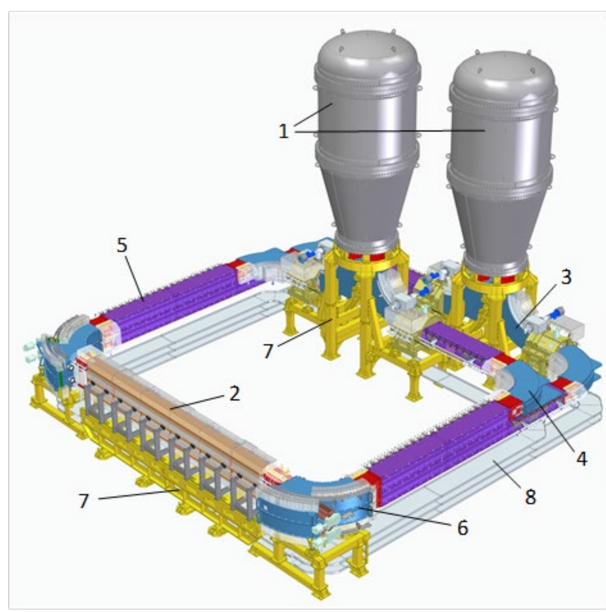

Figure 1: 3D model of the electron cooling system for the NICA collider. 1 – high-voltage vessels, 2 – cooling section, 3 – vertical bend, 4 – horizontal bends, 5 – linear sections, 6 – toroid magnet, 7 – supports, 8 – cable channels.

Figure 2 shows construction of the high voltage system. Its main parts are high voltage column (which generates accelerating voltage and provides electron acceleration to working energy) and high voltage terminal (which contains

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electron gun [3], electron collector and electronics for their control). For high voltage insulation the system is placed in hermetic vessel with SF_6 gas under pressure of up to 8 bar.

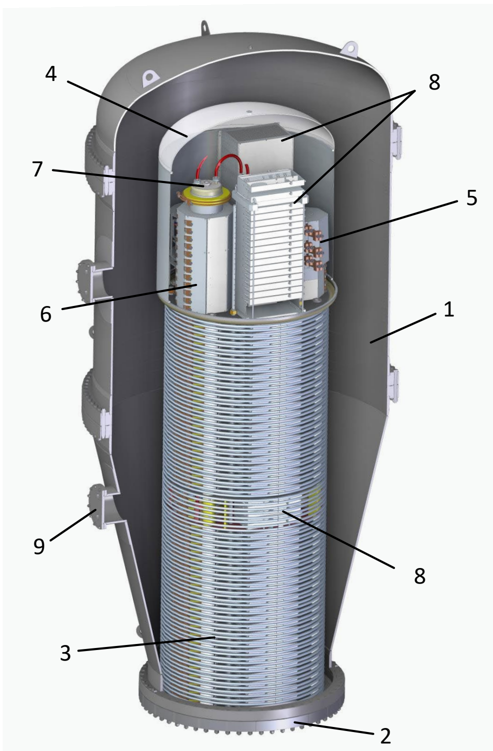

Figure 2: High voltage system of the electron cooler for NICA collider. 1 – pressure vessel, 2 – bottom flange, 3 – high voltage column, 4 – high voltage terminal, 5 – electron gun solenoid, 6 – electron collector solenoid, 7 – collector, 8 – middle section, 9 – side flange.

Length of the high voltage column is 3 m and it consists of 42 high voltage sections (Fig. 3) and one special middle section (Fig. 4).

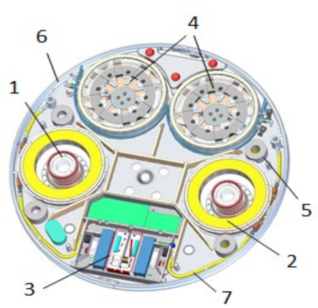

Figure 3: High voltage section. 1 – electrostatic tube, 2 – magnetic coil, 3 – electronics unit, 4 – sections of cascade transformers, 5 – insulating supports, 6 – external ring, 7 – oil tubes

Each high voltage section contains 2 high voltage power supplies (up to 30 kV), connected in series, magnetic coils for longitudinal field, power supplies for coils and control electronics. The sections are separated from each other with insulating (plastic) supports. Section height is 48 mm, period is 64 mm. High voltage power supplies of all sections are connected in series in order to form full accelerating voltage. Connection of every section with control computer is realized with the help of wireless interface ZigBee. All sections are powered with the help of cascade transformer [4]. For this purpose each section of the transformer has additional small winding.

Two electrostatic tubes for beam acceleration and deceleration are installed in magnetic coils.

The middle section of the column is intended for additional vacuum pumping and beam position measurement with the help of pickup electrodes (BPM). The section does not contain high voltage power supplies, but it has magnetic coils in order to provide homogeneous magnetic field in whole electrostatic tube. Coils support allows to incline them mechanically in order to improve beam transition through the electrostatic tube in case of tube and coils misalignment.

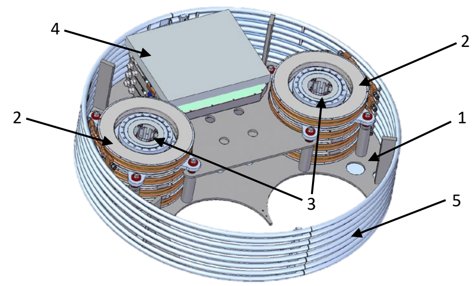

Figure 4: Middle section of the high voltage column. 1 – section's base, 2 – magnetic coils, 3 – vacuum chambers, 4 – electronics, 5 – external rings.

In Fig. 5 a vacuum chamber of the middle section is shown. Top and bottom vacuum flanges are used for connection with 2 parts of electrostatic tube. In order to avoid mechanical load on tubes, there is a bellow, installed in bottom of the chamber. BPM consists of 4 electrodes, and its construction is usual for electron coolers, produced in BINP. For vacuum pumping 4 side flanges can be used. It is planned to install there small getter pumps (NEG).

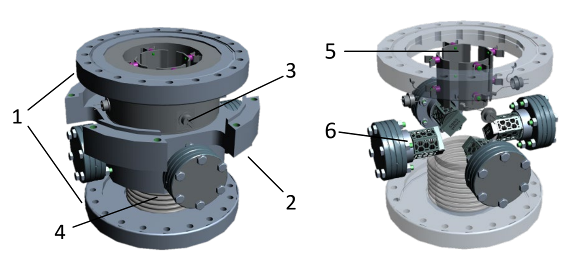

Figure 5: Vacuum chambers of the middle section: left – outer view, right – inner view. 1 – flanges for electrostatic tubes connection, 2 – mechanical support, 3 – BPM's feedthough, 4 – bellow, 5 – BPM's electrodes, 6 – NEGs.

During assembling of the COSY high voltage cooler it was recognized, that electrostatic tubes, with length of more than 2 m, which are fixed only on the bottom flange of vessel, need very careful work with surrounding devices in order not to damage the tubes. Electrostatic tubes of the

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NICA high voltage cooler have length more than 3 m, that worsens this problem. Another problem is cascade transformer of big length. During assembling of the transformer one needs first to connect all electrical circuits and after that it is tightened in order to make it hermetic. The tightening is very complicated process and its complexity significantly increases with length increase. In the NICA high voltage cooler length of the transformer is higher and it was decided to divide it to 2 parts.

Because of this another important goal of the middle section is to simplify system assembling providing place, where two parts of electrostatic tubes and 2 parts of cascade transformers can be connected.

As it was said above, electrostatic tubes are connected via vacuum chamber of the middle section, which also provides intermediate support for the electrostatic tubes. The cascade transformer connection is shown in Fig. 6. Supports for the top transformers are installed on the bottom transformers and have units for transformers alignments. Since transformers are cooled with oil, there are tubes (bellows) for their oil connection. Electrical connection is made with additional wires (not shown).

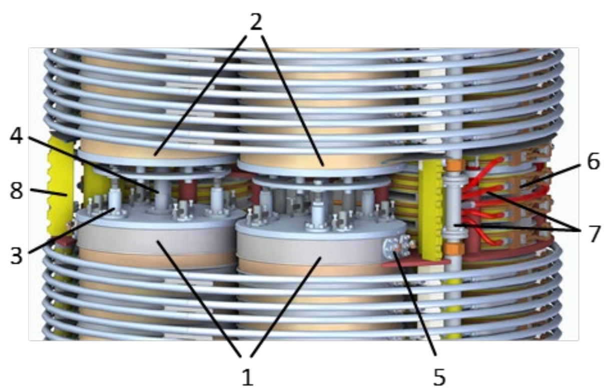

Figure 6: Connection of transformers in the middle section. 1 – bottom transformers, 2 – top transformers, 3 – supports for top transformers, 4 – oil connector, 5 – feeed-through for final winding of transformer, 6 – magnetic coils, 7 – tubes for cooling, 8 – support for external rings.

MAGNETIC MEASUREMENTS

As it was said, for transverse focusing the electron beam moves in longitudinal magnetic field on whole trajectory from gun to collector. For this purpose, the transport channel of the cooler consists of a set of linear and bent solenoids. Before assembling of the cooler its all magnetic elements will be tested. New magnetic measurement system, based on 3-d Hall probe, was produced. The Hall probe is installed on carriage, which moves inside magnetic element along special aluminium rail with the help of stepping motor by special tape. The rail consists of set of different linear and bent segments, which can be assembled in different way in order to install it in part of transport channel of the electron cooler. In Fig. 7 the measurement system, installed in part of transport channel is shown. The part consists of 3 elements (2 linear solenoids and 1 bend solenoid).


Figure 7: Part of cooler's transport channel during magnetic measurements. The assembling consists of 3 solenoids (called "INSERT" (red), "BEND" (blue) and "LINE-08" (yellow)). Aluminium rail of needed bent shape is installed inside the solenoids.

Figure 8 shows first results of field measurements. Here one can see 3 graphs corresponding to longitudinal field measurements in cases, when only one element is powered. Such measurements allow us to obtain elements field map and to find error in elements production and connection.

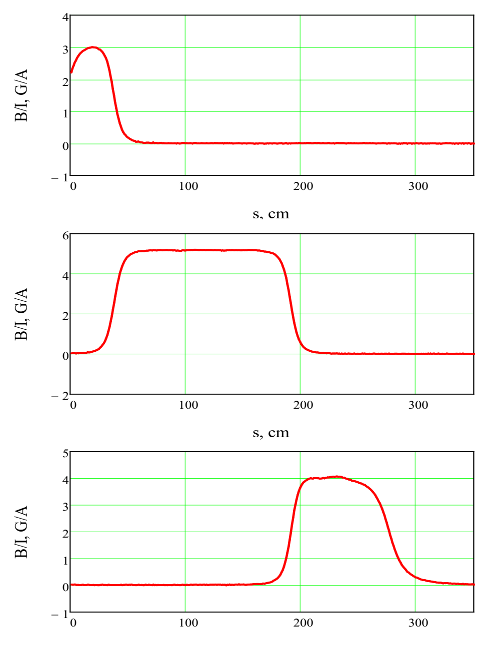

Figure 8: longitudinal magnetic field in the system with current only in "INSERT" solenoid (top), in "BEND" solenoid (middle) and in "LINE-08" solenoid (bottom).

In addition to Hall measurement system a high precision, compass-based system [5] is also being prepared. The system is needed for magnetic field line measurements in the cooling section. It is based on special compass probe, which moves along the cooling section through the special segmented titanium rail of round shape (Fig. 9). Maximum length of the rail is 10 m, that is enough for measurement in whole solenoid.

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Figure 9: titanium rail for compass-based measurements

For probes testing and adjustment and for new measurement electronics testing a test bench was prepared.

ELECTRON GUN TESTS

Since ion beam diameter in the NICA is small In comparison with accelerators with low energy electron coolers, it was decided to decrease cathode diameter from 3 cm (as it was in previous coolers, produced by BINP) to 1 cm. For this purpose a new gun was constructed [3] and special test bench was built for its testing (Fig. 10). The main magnetic element of the test bench is straight solenoid. Vacuum chamber with gun and collector is installed along solenoid's axis. For beam property measurements the vacuum chamber contains special diagnostic node with wire profile monitor and BPM inside. The monitor provides measurements of both electrical and optical signals (due to wire heating by electron beam).

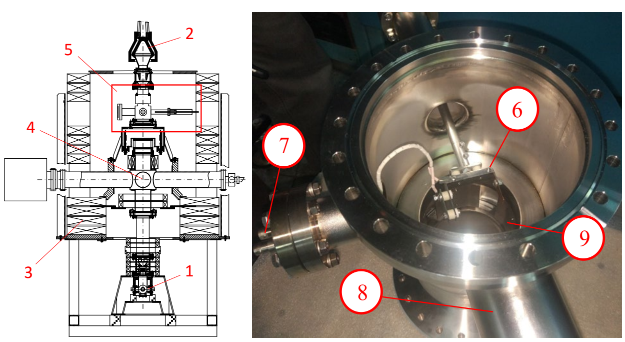

Figure 10: "Gun-collector" test bench (left) and diagnostic node of the test bench (right). 1 – electron gun, 2 – electron collector, 3 – solenoid, 4 – vacuum chamber, 5 – diagnostic node, 6 – wire support of the monitor, 7 – electric feedtroughs for the monitor, 8 – tube for vacuum window, 9 – BPM.

Figure 11 shows results of profile measurement for different regimes of the gun work. One can see, that (depending on gun electrodes voltage) it is possible to obtain narrow beam, hollow beam, or beam with homogeneous current distribution. Such profile variability will be useful for effective cooling adjustment in future [6].

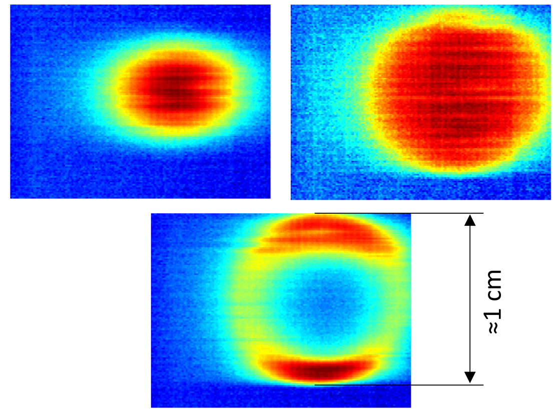

Figure 11: beam profiles for different gun regimes, measured on the test bench.

CONCLUSION

High voltage electron cooling system is important part of the NICA collider, which is needed for achieving of project luminosity in ion-ion collision experiments. Now the Budker INP is produces elements of the cooler and starts testing of already produced elements. Gun prototype testing shows possibility of beam shape control in wide range from narrow to hollow beam. Hall magnetic measurement system is ready for active work and first measurements were started.

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