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DEVELOPMENT OF THE ELECTRON COOLING SYSTEM FOR NICA COLLIDER

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Abstract

The high voltage electron cooling system for the NICA collider is now under development in the Budker Institute of Nuclear Physics (Russia). The aim of the cooler is to increase ion beams intensity during accumulation and to decrease both longitudinal and transverse emittances of colliding beams during experiment in order to increase luminosity. Status of its development and results of tests of the cooler elements are described in the article.

INTRODUCTION

The NICA project is aimed to provide experiments with highly compressed baryonic matter with the help of colliding ion beams. In order to achieve project luminosity it is planned to use electron and stochastic cooling, which will help both during accumulation (to increase beam intensity) and during experiment (to compensate beam's emittance grow due to beam-beam effects, intra-beam scattering etc.).

Budker INP has big experience in production of electron cooling systems for different energies and now it develops project of high voltage electron cooling system (HV ECS) for the NICA. In Fig. 1 a 3-D model of the ECS is shown. Its design is based on design of HV electron cooler for COSY, produced by BINP [1]. The system consists of two almost independent coolers, which cool both colliding beams. Each cooler consists of high voltage system (which is placed in high pressure vessel, filled with SF_6, and which contains electron gun, electron collector, electrostatic tubes and HV power supplies), cooling section and transport channels (consisting of linear and bend magnets). Electron beam, emitted by cathode in electron gun, is accelerated by electrostatic tube to working energy. After that, it moves through transport cannel to the cooling section, where it interacts with ion beam. After the cooling section it moves back (through another transport channel) to high voltage system where it is decelerated and absorbed by collector surface. Such not standard scheme of ECS with whole high voltage system in one vessel is usual for high energy electron coolers and besides the COSY cooler it was realized on 4.3 MeV Fermilab electron cooler of the Recycler ring [2].

On whole trajectory from gun to collector electron beam moves in longitudinal magnetic field, which provides transverse focusing of the beam. In the cooling section longitudinal field provides, so-called, “fast” (or magnetized) electron cooling [3].

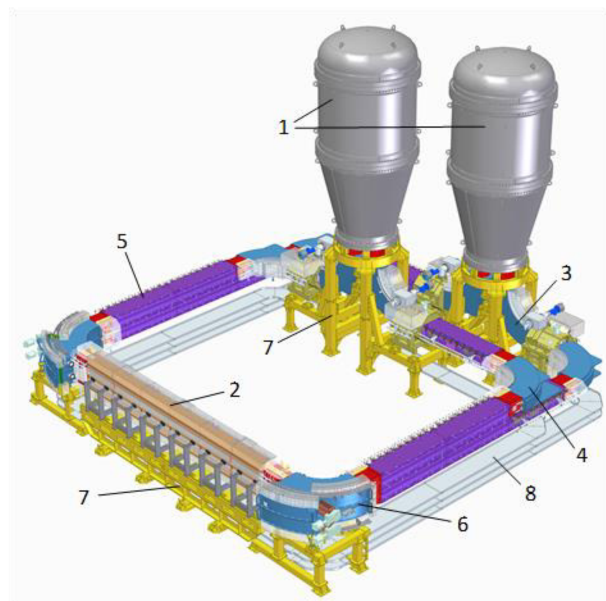

Figure 1: 3D model of the electron cooling system for NICA collider. 1 – high-voltage vessels, 2 – cooling section, 3 – vertical bend, 4 – horizontal bends, 5 – linear sections, 6 – toroid magnet, 7 – supports, 8 – cable channels.

HIGH VOLTAGE SYSTEM

The HV system of the cooler (Fig. 2) generally consists of HV column and HV terminal on its top. The column consists of 42 identical sections (Fig. 3). Each section contains 2 HV 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. 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 small winding.

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

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In the centre of the column there is a special middle section of about 30 cm height, which contains magnetic elements and does not contains HV power sources. This section was added for diagnostic reasons (with BPMs) and for additional vacuum pumping.

High voltage terminal contains electron gun, collector, two solenoids (for gun and collector) and control electronics. The terminal is powered by upper winding of the cascade transformer.

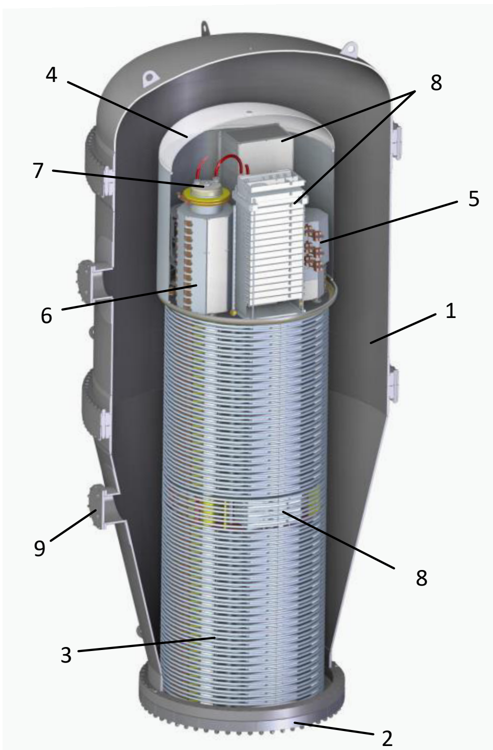

Figure 2: High voltage system of the electron cooler for NICA collider. 1 – pressure vessel, 2 – bottom flange, 3 – high voltage column, 4 – high voltage terminal, 5 – electron gun solenoid, 6 – electron collector solenoid, 7 – collector, 8 – middle section, 9 – side flange.

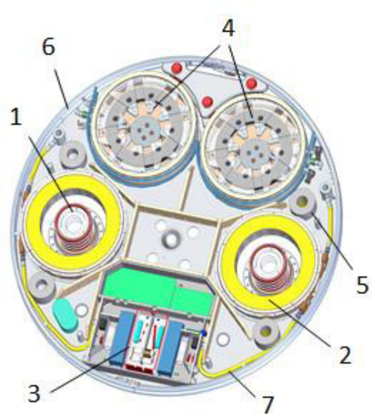

Figure 3: High-voltage section. 1 – electrostatic tube, 2 – magnetic coil, 3 – electronics unit, 4 – sections of cascade transformers, 5 – insulating supports, 6 – external ring, 7 – oil tubes.

In the COSY cooler one transformer was used for powering both column (consisting of 33 sections) and terminal. But efficiency of power transfer by cascade transformer decreases with increase of number of sections and, from experience, achieved during operation with the cooler, it look, that COSY variant is close to limits. In the NICA cooler it was decided to use 2 transformers in parallel: one for column and one for terminal.

CASCADE TRANSFORMER

The transformer consists of alternating ceramic and metal rings (Fig. 4). Inside the metal ring there is a magnetic circuit with two high-voltage sectioned windings and one winding under the potential of the magnetic circuit to power HV section. One high-voltage winding serves to transfer power to the next stage up, the other winding for connection with the lower section of the transformer.

The design of the cascade transformer is similar to the design of the COSY transformer, however, some changes have been made to improve its performance and simplify the manufacturing process. In particular, the primary and secondary windings are divided into 4 groups of 8 turns, instead of 2 groups of 14 turns. The metal rings are produced of aluminium instead of copper-covered stainless steel. Under the windings, directly on the core, a ring of thin fiberglass with a copper coating is placed to set the potential to the core.

To test the new design of the transformer, a 3-section prototype was made. According to the results of measurements, the parameters of the transformer are similar to parameters of the transformer of the COSY cooler. After the tests production of the transformer was started. Fig. 4 (c) shows first transformer after assembling.

a) c) b)

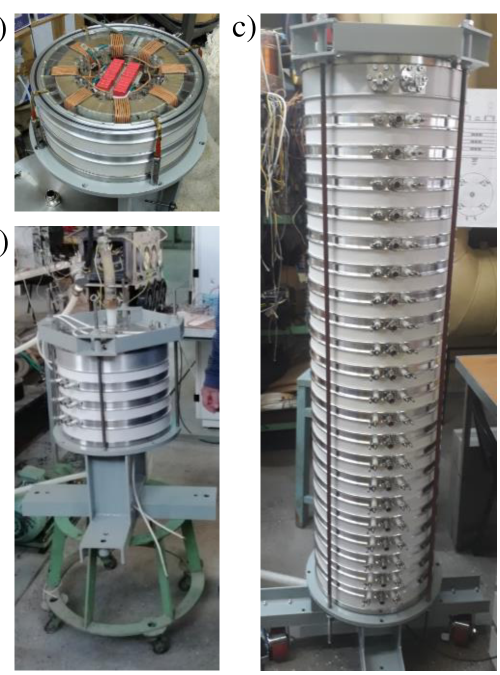

Figure 4: Cascade transformer production: a) transformer prototype during assembling, b) assembled prototype during tests, c) cascade transformer of the cooler.

"GUN-COLLECTOR" TEST BENCH

Since ion beam diameter in the NICA is small, 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 and special test bench was built for its testing (Fig. 5). 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 measurement the vacuum chamber contains special diagnostic node with wire profile monitor and BPM inside. The monitor provides measurements both electrical signal and optical (due to wire heating by electron beam).

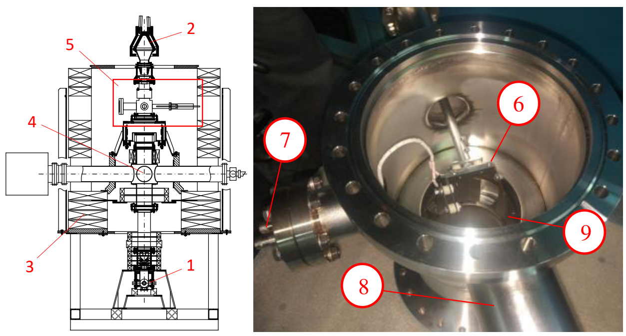

Figure 5: "Gun-collector" test bench (left) and diagnostic node of the test bench (right). 1 – electron gun, 2 – electron collector, 3 – solenoid, 4 – vacuum chamber, 5 – diagnostic node, 6 – wire support of the monitor, 7 – electric feedtroughs for the monitor, 8 – tube for vacuum window, 9 – BPM.

From electron cooling theory one can obtain, that cooling rate is inversely proportional to ion velocity to the 3-rd power [3]. As result, particles with smaller betatron amplitudes are cooled faster, then those with higher amplitudes. This can result is appearance of overcooled centre of ion beam.

According to [5], the controllability of electron current density profile is essential to prevent instability development in ion beams caused by overcooling of beam centre. By increasing electron emission from the cathode edges using the control electrode, the emission from the centre of the cathode can be suppressed by the space charge electrical field. In this case, the electron beam becomes "hollow". The cooling rate for ions with small amplitudes of betatron oscillations decreases; therefore, the ion beam cools more evenly.

Because of this, one of the most important goal of the test bench is testing the ability to vary the beam profile. On Fig. 6 first results of beam profiles measurements for different regimes of gun work are shown (the measurements are made from electrical signal). One can see, that the gun provides effective control of the beam. The results generally prove calculation results [6].

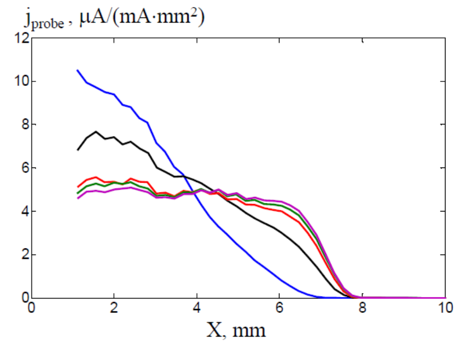

Figure 6: Beam profiles for different regimes of gun work.

CONCLUSION

Budker INP is actively developing project of the high voltage electron cooling system for the NICA collider. The most part of the design stage is passed and many elements of the cooler are already produced. At the same time, prototypes of some critical elements are produced and tested. Some prototypes (such as electron gun), are still being tested.

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