ISSN 1547-4771, Physics of Particles and Nuclei Letters, 2016, Vol. 13, No. 7, pp. 792–795. © Pleiades Publishing, Ltd., 2016.
Original Russian Text © M.I. Bryzgunov, A.V. Bubley, A.D. Goncharov, V.M. Panasyuk, V.V. Parkhomchuk, V.B. Reva, 2016, published in Pis'ma v Zhurnal Fizika Elementarnykh Chastits i Atomnogo Yadra, 2016.

Status of Construction of the Electron Cooling System for the NICA Booster

M. I. Bryzgunov, A. V. Bubley*, A. D. Goncharov, V. M. Panasyuk, V. V. Parkhomchuk, and V. B. Reva

Budker Institute of Nuclear Physics, Siberian Branch, Russian Academy of Sciences, Novosibirsk, 630090 Russia

**e-mail: bubley@inp.nsk.su*

Received February 29, 2016

Abstract—According to the agreement, the electron cooling system for the NICA booster should be commissioned in late 2015. The degree of completion of various units and components of the installation as of September 2015 is characterized in the present report. Part of the report is devoted to discussing the performance parameters of the installation and the engineering solutions that had to be implemented to achieve such parameters.

DOI: 10.1134/S1547477116070165

INTRODUCTION

The results of work under contract with the Joint Institute for Nuclear Research (JINR, Dubna) on constructing the electron cooling system (ECS) for the booster of the NICA complex are reported in the present study.

Technical requirements: the ECS should provide the efficient cooling of heavy charged particles (from protons to $^{197}Au^{31+}$ ions) and have the following key parameters:

Electron energy E, keV	1.5–50
The potential to readjust the energy in the given range	
Electron-beam current I, A	0.2–1.0
Energy adjustment accuracy and its stability $\Delta E/E$	$\leq 1 \times 10^{-5}$
Beam-current stability $\Delta I/I$	$\leq 1 \times 10^{-4}$
Electron-beam energy regeneration mode	
Electron-beam loss current $\delta I/I$	$\leq 3 \times 10^{-5}$
Longitudinal ECS magnetic-field intensity, T	0.1–0.2

Permissible nonuniformity of the longitudinal magnetic field at the cooling section $\Delta B/B \leq 3\times 10^{-5}$ over a length of 15 cm (three periods of the Larmor spiral of an electron with an energy of 50 keV in a field with an intensity of 0.1 T).

Transverse electron temperature at the cooling section, eV ≤ 0.3

Correction of the ion orbit at the ECS inlet and outlet: displacement, mm ≤ 1.0; angular deviation, mrad ≤ 1.0

The electron cooling system designed at the Budker Institute of Nuclear Physics (BINP) in 2006 to shape lead-ion bunches at LEIR (LHC, CERN) served as the basis for the project.

1. REVIEW OF THE DEGREE OF COMPLETION OF SYSTEM COMPONENTS

—Magnetic system. Completely assembled; magnetic measurements with Hall sensors have been performed. The next stage is the adjustment of the central solenoid (“compass” measurements).

—Vacuum system. The construction of vacuum chambers of cooler elements is completed. The next stages are component assembly, the installation of heating elements, heating, and the production of the needed vacuum.

—Electron gun and collector: 70% complete. Fabrication of ceramic insulators; assembly of the gun (cathode unit, etc.).

—Power sources. High-current power sources have been supplied to the Joint Institute for Nuclear Research. Low-current power sources are 60% complete. Commissioning with the use of BINP power sources.

—High-voltage power source (gun/collector): the assembly of a part of the source with a transformer and an oil tank has been completed. Source components are 90% complete; assembly and tests of source components (high-voltage terminal, 60 kV high-voltage generator).

—Water cooling system: 60% complete. Commissioning with the use of a BINP water cooling system.

—Oil cooling system (high-voltage power source): assembled and tested.

—Blocking and signaling system (BSS). Electronics is 100% complete. Installation of cables for mounting; BSS integration into the control system.

—Control system: development (80%). Commissioning at the actual installation.

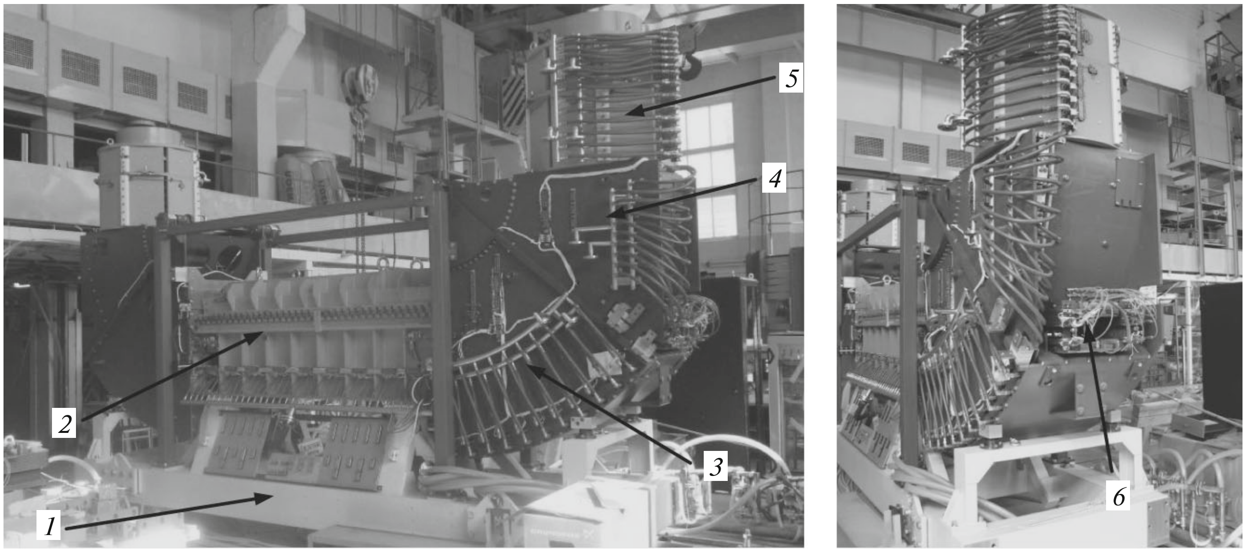


Fig. 1. Magnetic system of the electron cooling setup. Support frame *1*, central solenoid *2*, 50° toroid (bending) *3*, 40° toroid (bending) *4*, solenoid of the gun (collector) *5*, and dipole corrector *6* are indicated.

—Vacuum-chamber heating system: component assembly; trials with a test load.

2. MAGNETIC SYSTEM

The central solenoid (cooling solenoid) is the key element of the magnetic system. The requirements for magnetic-field quality determine the requirements for accuracy in manufacturing and adjusting solenoid parts [1].

The coil of the central solenoid is the most resource-intensive element. In addition to coil winding, strict requirements for the quality of manufacture and assembly of adjusting devices are imposed. The coil design was altered considerably relative to that of the previous versions (LEIR, COSY) in order to refine the quality while using the same technology. The core of the central solenoid is largely similar to the cores used in the previous cooler designs, but the differences in length, coil pitch, and positioning of supports translate into certain design modifications. The bending magnets (toroids) were designed in the same way as for LEIR (CERN) and serve to bend the electron beam by 90° with a trajectory arc radius of 1 m. The design of the support of 50° toroids was changed in order to simplify the assembly (disassembly) of the setup: they are now secured at the rotation axis, while guides and jacks were used in the earlier design variants to shift toroids horizontally and vertically. The coil of solenoids of the gun and the collector is a circular two-layer winding similar to the ones used in the LEIR cooler project [2].

The results of magnetic measurements with Hall sensors are shown in Fig. 2. These measurements were performed along the axis of the solenoid and covered the cooling solenoid, bending toroids, and correcting dipoles. The center of the setup was taken as the origin of coordinates.

According to the data, the effective magnetic length of the setup with respect to the longitudinal field is 4.31 m. This value is needed for calculating the "optics" of the booster, since the solenoidal field introduces additional coupling.

The vertical magnetic-field component is shaped by the field of toroids and correcting dipoles in such a way as to compensate the deflection of the ion beam from the axis (Fig. 3).

The ion beam is shifted horizontally in passing through the magnetic system of the electron cooling setup due to the interaction with the vertical component of the magnetic field of bending toroids. This shift should be compensated, or else the beam may hit the wall of the vacuum chamber, thus causing an accident. Two dipole correctors of the ion orbit were introduced into the electron cooling system in order to pre-

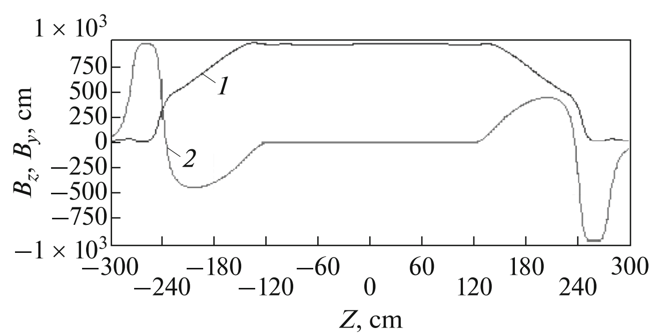


Fig. 2. Longitudinal (*1*) and vertical (*2*) components of the magnetic field along the axis of the setup.

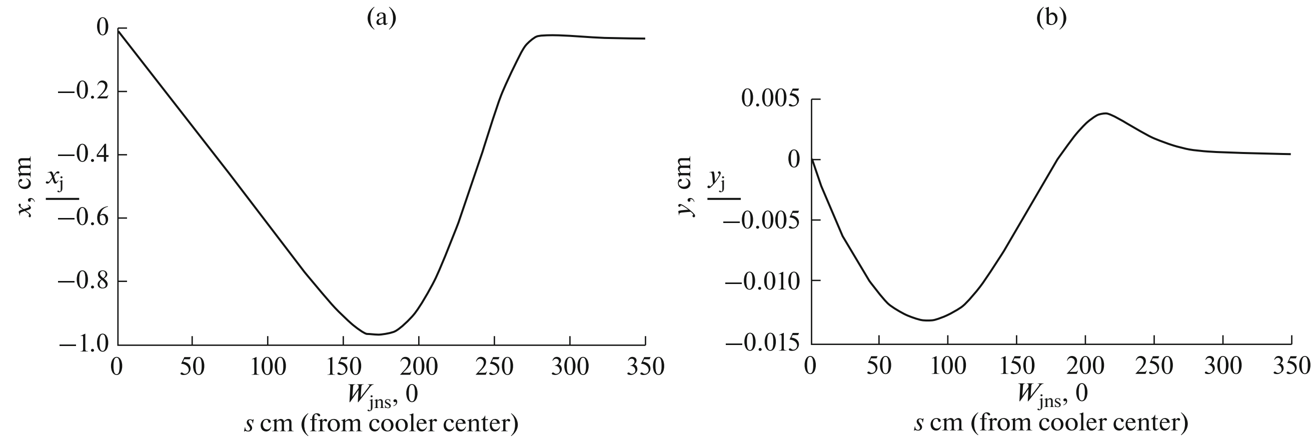


Fig. 3. Horizontal and vertical displacement of the ion beam. The center of the cooling solenoid is at the origin of coordinates.

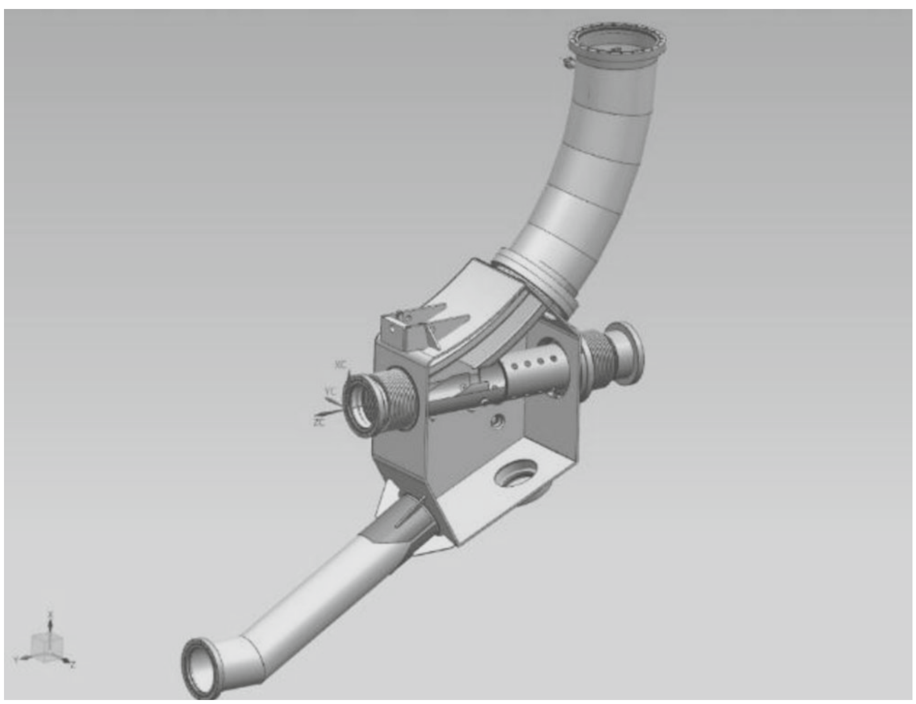


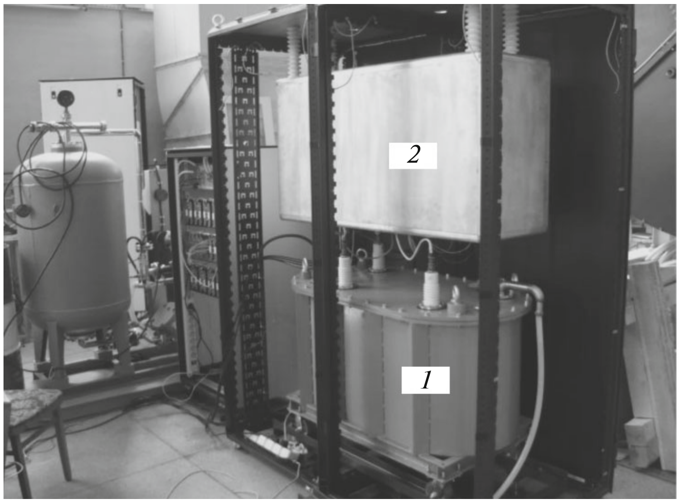
Fig. 4. Section of a part of the vacuum chamber (toroid chamber).

vent such accidents. These correctors form a field that compensates the beam deflection from the orbit.

One corrector design produces such a magnetic-field configuration that all beam shifts occur inside the magnetic system of the setup, while the beam at the inlet and the outlet of the booster ring has almost zero deflection. Figure 3 presents the results of calculations of the trajectory of gold ions at the injection energy (at the maximum shift). The starting point of calculations was at the center of the cooling solenoid. It can be seen that the ion beam exiting the setup has almost zero shift with respect to the vacuum chamber axis.

3. VACUUM SYSTEM

The vacuum chamber of the setup is functionally similar to the ones used at LEIR [3] and COSY, but its design was altered somewhat based on the accumulated experience. Pick-up electrodes in close proximity to the gun and the collector and getter pumps with external activation were added. The setup is thus fitted with three pairs of pumps: two Penning-type ones (connected to the chambers of toroids), two titanium sublimation pumps (inside the chambers of toroids), and two getter ones in the gun and the collector chambers.



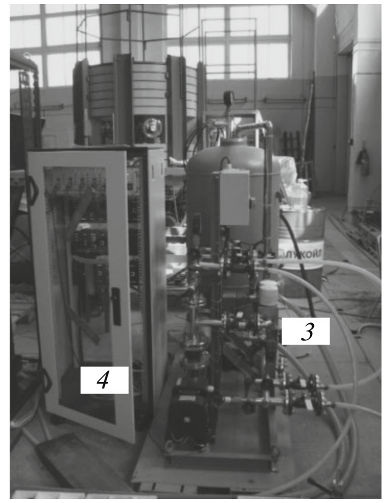


Fig. 5. High-voltage power source. Power transformer *1* in the oil tank, high-voltage terminal *2*, oil pumping system *3*, and BSS rack *4* are indicated.

The electron gun is an almost perfect copy of the one used in the COSY cooler. Just as the previous version, the new gun is fitted with a four-segment control electrode that provides an opportunity to shape an electron beam with a variable profile [4]. The only difference is in the shape of the upper section, where the pump port was removed and the diameter was changed. The electron collector is a compilation of two designs used at LEIR and COSY. The upper section, which receives the incident electron flux, is made conical in order to increase the current deposition area. The collector is cooled with transformer oil pumped by a dedicated oil-pump unit.

4. HIGH-VOLTAGE POWER SYSTEM

The power transformer core was fabricated and assembled from anisotropic electrotechnical strip type 3408 with a thickness of 0.3 mm in the UNICORE process.

Since transformer cooling is advisable and the secondary windings are under the primary rectifier potential and should withstand voltages up to 60 kV, the transformer is held in a tank with the transformer oil flow.

The high-voltage terminal is located directly above the oil tank with the transformer and is housed in a screened box. Electronic power supply and control units (Eurocard) for the gun are mounted within the terminal. The entire assembly is covered with a grounded hood. For convenience in operation and adjustment, the hood and the high-voltage terminal are made movable and may be rolled to the side along guides.

CONCLUSIONS

The key components of the electron cooling system are at a late stage of completion. Therefore, the chances that it will be commissioned by the end of 2015 are high.

ACKNOWLEDGMENTS

The studies on electron sources and cathodes for electron-beam production were supported by the Russian Science Foundation, project no. 14-50-00080.

REFERENCES

1. V. V. Parkhomchuk and A. N. Skrinskii, Phys. Usp. **43**, 433 (2000).
2. A. Bubley, V. Parkhomchuk, V. Reva, et al., "Commissioning of the LEIR electron cooler with Pb^{+54} ions," in *Proceedings of 20th Russian Accelerator Conference RuPAC'2006, Novosibirsk, Russia, September 10–14, 2006.*
3. V. Bocharov, A. Bubley, Yu. Boimelstein, V. Veremeenko, V. Voskoboinikov, A. Goncharov, V. Grishanov, A. Dranichnikov, Yu. Evtushenko, N. Zapiatkin, M. Zakhvatkin, A. Ivanov, V. Kokoulin, V. Kolmogorov, M. Kondaurov, et al., "Electron cooler commissioning," Nucl. Instrum. Methods Phys. Res. A **532**, 144–149 (2004).
4. A. Bubley, A. Goncharov, A. Ivanov, E. Konstantinov, S. Konstantinov, A. Kryuchkov, V. Panasyuk, V. Parkhomchuk, V. Reva, B. Skarbo, B. Smirnov, B. Sukhina, M. Tiunov, M. Zakhvatkin, and X. Yang, "The electron gun with variable beam profile for optimization of electron cooling," in *Proceeding of 8th European Conference on Particle Accelerator EPAC'2002, Paris, France, June 3–7, 2002,* pp. 1356–1358.

Translated by D. Safin