

PROJECT OF ELECTRON COOLER FOR NICA COLLIDER

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Abstract

Electron cooling system (ECS) of the NICA collider is designed to form the required parameters of the ion beam at energy of the experiment in the range of 1 - 4.5 GeV/amu that requires energy cooling electrons from 0.5 to 2.5 MeV. To achieve the required energy of the electrons all elements of ECS are placed in tanks filled with sulfur hexafluoride (SF₆) under pressure of 6 atm. For testing items ECS elements the test bench "Recuperator" is used. This paper presents the results of testing the prototype elements of the ECS and the first results of technical design of ECS.

ELECTRON COOLING SYSTEM OF THE NICA COLLIDER

High voltage elements must be placed in three tanks due to the requirements to ECS parameters (Fig. 1). ECS NICA collider has two independent electron beams. Therefore tanks 1 and 3 (Fig. 1, 2) contain a devices for generating and formation of electron beams, the acceleration of the electrons, and after passing through the cooling section, deceleration of the electrons and their energy recuperation. Tank 2 (Fig. 2) contains a high-voltage generator voltage up to 2.5 MW. Inside tanks 1 and 3 are placed solenoids of the superconducting magnetic system (the field up to 2 kGs) for transporting electron beams, so the material for these tanks could be a magnetic steel that allows using the tanks walls as magnetic shield for magnetic flux "return". All three tanks are filled with the insulating gas SF₆ («sulfur hexafluoride») under pressure of 6 atm.

Electrons of the two beams are accelerated by electrostatic voltage in a longitudinal magnetic field and when get the necessary energy transported in a longitudinal magnetic field into the cooling section (Fig. 3). In this part of the trajectory electrons and ions circulating in the collider ring, are merged.

Table 1: Parameters of ECS for NICA.

Parameter	Value
Electron energy, MeV	0,5 - 2,5
Electron beam current, A	0,1 - 1
Electron beam diameter, mm	10 - 20
Magnetic field of SC solenoids, T	0,1 - 0,2
Relative current losses at recuperation	3×10^{-4}
Elegas (FS ₆) pressure, bar	6

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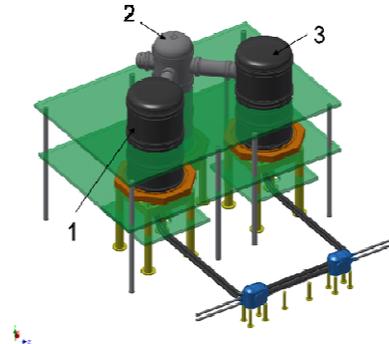


Figure 1: Scheme 1,3 - acceleration tanks, 2 - tank of the high-voltage generator.

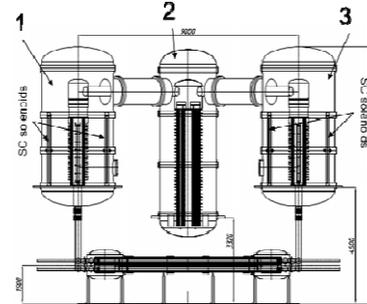


Figure 2: Tanks 1,3 - acceleration tanks, 2 - tank of the high-voltage generator.

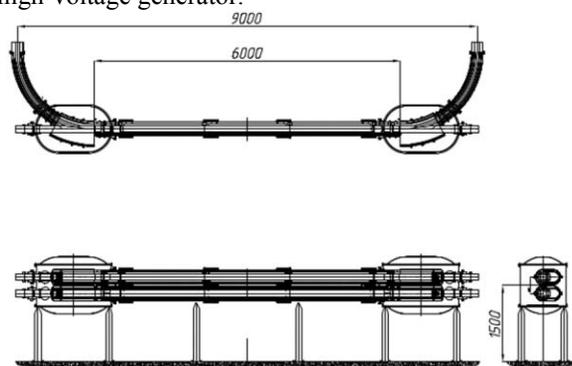


Figure 3: Transportation and cooling sections.

TEST BENCH "RECUPERATOR" AND PROTOTYPING ECS

Test bench "Recuperator" (Fig. 4, 5 and Table 2) is a model of the electron cooling system. It has linear vacuum chamber of a length of about 4 m and a diameter of 10 to 30 cm, immersed in a longitudinal magnetic field

from 0.3 to 0.6 kGs. The electron beam is generated by an electron gun of variable perveances. Electrons pass drift section (model of the cooling section) and enters the electron collector whose potential is of 1-2 kV (Fig. 4) higher than the potential of the gun cathode (electron energy recuperation mode).

The cooling water system for the collector cooling was designed, assembled and tested. It consists of a water tank, two radiators and the pump driving water inside the system. Water circulates through collector, the connecting hoses and two radiators (connected in series), where it is cooled. Test had shown efficiency of the system sufficient for cooling the collector at the power of the recuperating beam up to 0.5 kW.

Table 2: Main Parameters of the Test Bench "Recuperator".

Parameter	Value
Electron energy, keV	up to 4
Beam current, mA	up to 400
Cathode diameter, mm	10
Residual gas pressure, Torr	2×10^{-3}
Magnetic field, Gs	up to 400

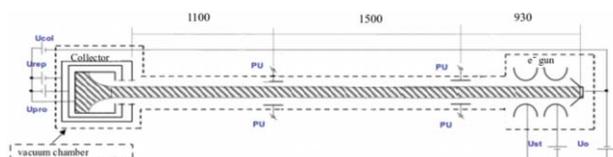


Figure 4: Scheme of test bench "Recuperator".



Figure 5: Test bench "Recuperator".

DESIGN PROJECT OF THE NICA ECS

The first concept NICA ECS has been developed jointly by JINR and All-Russian Electrotechnical Institute (VEI, Moscow) on the basis of the voltage generator of the Dynamitron type. Its maximum DC voltage is of 2.5 MV and current of 1 mA (sufficient in recuperation regime).

In each of the **two acceleration tanks** of high-voltage accelerator – recuperator are placed two accelerating structures of the seven high-voltage sections each one of a total length of 2.14 m. They are placed vertically (Fig. 1, 2). In the upper part of the accelerating structure on the

magnetic screen which maintained by four columns of the sections of insulators are mounted electron gun and a water-cooled collector, both covered by electrostatic screen.

The main peculiarity of ECS design is application of **superconducting solenoids (SC)** placed inside acceleration tanks under pressure of 6 atm. Such solution allows to reduce significantly the tank diameter and magnetic steel. The value of the saturation field for the material of the tank walls is chosen of 1.5 T. The diameter of SC solenoid cryostat is of 2370 mm that gives the tanks' wall thickness is of 67mm. The tank height is of 2.8 m and the weight of each accelerator tank is of 40 t.

Tank of the high-voltage generator has an internal diameter of 2.3 m and height of 7.3 m. In the tank are placed three assembly of capacitors in the form of vertical columns which are positioned around the supporting tube of a dielectric material and rest on the lower mounting platform inside the tank. Columns of capacitors are surrounded by metallic guard rings, which are having outer diameter of 1200 mm. Two transformers and two electric motors of capacity of 5 kW equipped with reducers are placed at the bottom of the tank. Electric motors are intended to drive two generators located on the upper platform of the tank under high potential and connected with motors mechanically by shafts of a dielectric material (glass-reinforced plastic) and rotating inside the tubes serving as support for capacitor columns. Auxiliary equipment powering electron gun and collector, vacuum pumps and other devices are also located on the upper platform of the generator tank within the high voltage accelerators tanks. Power/voltage transmission lines connecting the high-voltage generator tank with accelerator tanks by two high voltage feed-through which inner tubes are used as electrostatic screen for low voltage supplying electric power to guns and collectors.

Two beam transfer lines are equipped with SC solenoids as well, which have straight and toroidal sections (Fig.3). The last ones have curvature radius of 1.5m. The solenoids transport electrons from the acceleration tube exit through cooling section and to the entrance of deceleration tube. Each SC solenoid is placed inside own cryostat. The total length of each transfer line is of 12m.

Cooling section located in the Collider tunnel has length of 6 m. It consists of two vacuum cryostats of dimensions of 1500x900x1200 (h) mm which contain SC magnetic coils and magnetic shields, correctors for steering electron beams and pick-up stations for positioning both electron and ion beams.

ELECTRON BEAM RECUPERATION EXPERIMENT

To reduce losses in the recuperation process has been put forward the idea of using a contrary magnetic field on the back wall of the collector. In our tests, to generate the magnetic field has been proposed to use permanent magnets. Calculations and simulations of magnetic fields

in the collector for the NICA was done. Simulation was made for two versions: without (Fig. 6a) and with magnets (Fig. 6b). In simulation, primary electron energy 60 keV, collector voltage was -58 kV, beam current was 1 A, magnetic field was 1 kGs and magnets had field of 100 Gs.

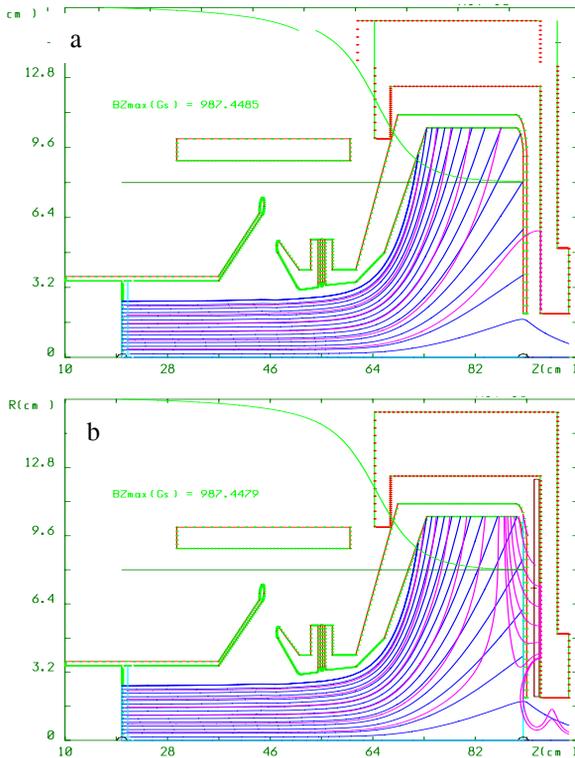


Figure 6: Distribution of magnetic field and primary electron trajectories in collector without(a) and with(b) permanent magnets.

Results were obtained with weak test magnets and experiments have shown that the magnets decrease the collector losses (Fig. 7, 8). It means that experiments with more powerful magnets are needed. Full current was bigger at maximum electron energy (what we can obtain) but losses were bigger too (Fig. 7, 8). Maximum current was obtained 330 mA at electron energy of 3.5 keV, collector potential relatively to cathode was of 1.22 kV and losses were $3.6 \cdot 10^{-4}$.

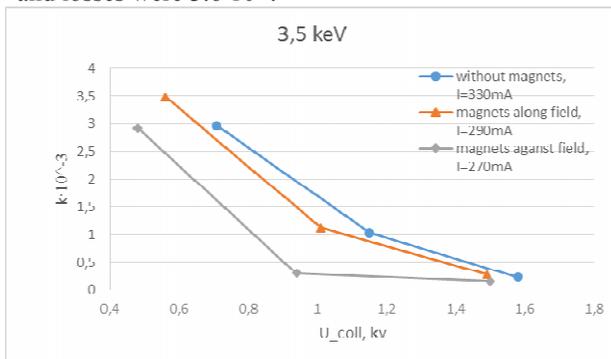


Figure 7: Losses versus collector voltage at different magnets' position.

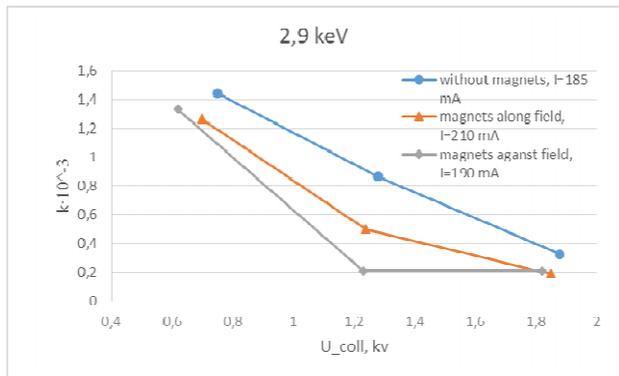


Figure 8: Losses versus collector voltage at different magnets' position.

CONCLUSION

Project Status:

- technical design ECS for NICA Collider is in a progress;
- test experiment on electron recuperation at the test bench “Recuperator” is in active stage of research;
- conceptual project of HV generator is completed by group of All-Russian Electrotechnical Institute (Moscow) ;
- preliminary agreement is achieved on fabrication of high pressure tanks - with Geliymash company (Moscow) and on
- procurement of equipment for SF6 gas system of ECS– with DILO company (Germany).

Commissioning of startup version of NICA is planned for 2019.

In nearest future we plan to develop at the test bench “Recuperator”:

- the electron gun with the adiabatic optics and dispenser cathode of diameter of 50mm;
- the electron collector of high recuperation efficiency;
- a stable DC electron beam with a current up to 1 Amp at high recuperation efficiency.

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