ELECTRON COOLER FOR NICA COLLIDER

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Abstract

The electron cooling system at electron energy up to 2.5 Mev for the NICA collider is under design at JINR. The electron cooler is developed according to the available world practice of similar systems manufacturing. The main peculiarity of the electron cooler for the NICA collider is using of two cooling electron beams (one electron beam per each ring of the collider) that never has been done before. The acceleration and deceleration of the electron beams is produced by common high-voltage generator. The conceptual design of the electron cooling system has been developed. The cooler consist of three tanks. Two of them contain acceleration/deceleration tubes and are immersed in the copper ("warm") solenoids. The third one contains HV generator, which design is based on voltage multiplying scheme.

CONCEPTUAL DESIGN OF THE COOLER

The electron cooler (Fig. 1) consists of three tanks filled with SF6 gas under pressure of 8 at. The tanks 1 and 3 contain acceleration tube and electron gun for one of the electron beam and deceleration tube and electron collector for another one. The tank 2 houses the HV generator.

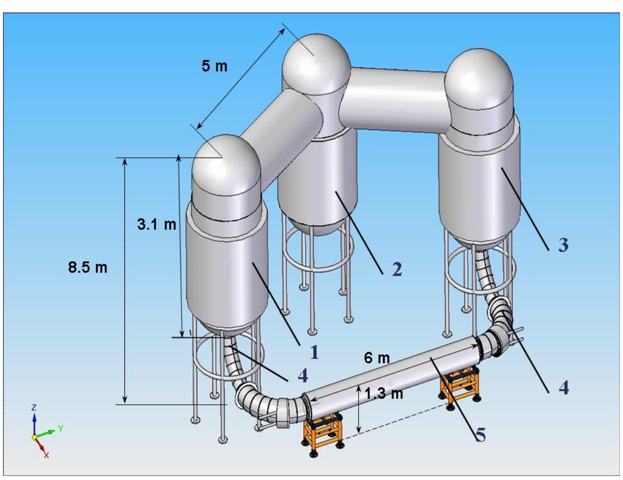

Fig.1. General view of the electron cooler. 1, 3 – tanks with electron gun and acceleration tube and deceleration tube + collector for electron beam of opposite direction, 2 – tank with HV generator, 4 – beam transportation solenoids, 5- electron cooling section.

The magnetic field is formed by a set of straight and toroidal solenoids. The solenoids forming the magnetic field in the region of acceleration/deceleration tubes are placed outside of the tanks that resolve the problem of HV insulation.

Table 1. Cooler parameters

Electron energy, MeV	0.5 ÷ 2.5
Electron beam current , A	0.1 ÷ 1,0
Beam diameter, cm	1,0
solenoid magnetic field, T	0.1 ÷ 0.2
HV PS current, mA	1
Collector PS, kW	2×2
HV PS stability, ΔU/U	1×10^{-4}
SF_6 gas pressure, at	5 ÷ 8

ELECTRON BEAM GENERATION AND ENERGY RECUPERATION

Both acceleration and deceleration systems consist of three main subsystems (Fig. 2): acceleration vacuum tube with electron gun or collector mounted on the upper end of the tube, high pressure tank, solenoid forming longitudinal magnetic field. Acceleration vacuum tube with electron gun or collector mounted on the upper end of the tube. Electron gun design (Fig.3) has three main elements: cathode with the Pierce electrode, control (steering) electrode, anode connected with first (upper) flange of acceleration tube. Electron collector (Fig.3) consists of three elements as well: collector anode connected with upper flange of deceleration tube, suppressor ("repeller") electrode, electron collecting vessel. The last one is cooled by water circulating at high potential. The design and construction of collector cooling system is in progress.

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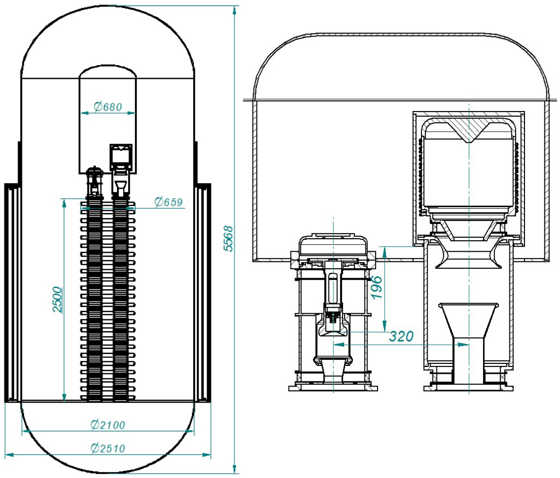

Fig.2. Acceleration and deceleration systems of two beams of opposite directions

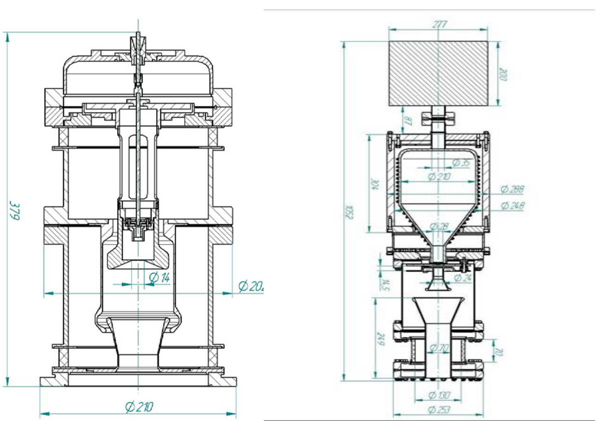

Fig.3. Electron gun and electron collector design

MAGNETIC AND ELECTRIC FIELDS SIMULATION

The magnetic field in gun and collector area is formed by means of ferromagnetic shields (Fig. 4), that helps to provide sufficiently homogenous magnetic filed in electron gun and good shield of the collector. The numerical simulation of magnetic field at the cathode and collector region been performed (Fig.5) and the optimal configuration of the magnetic screen has been found. The cathode of electron gun is located be 0.3 m lower of the shield plane.

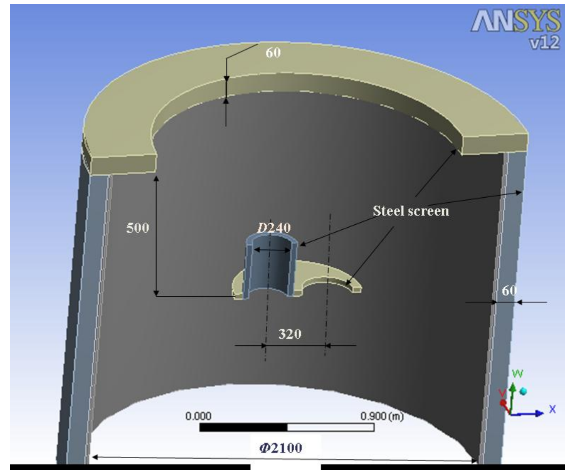

Fig.4.Optimal magnetic screen configuration

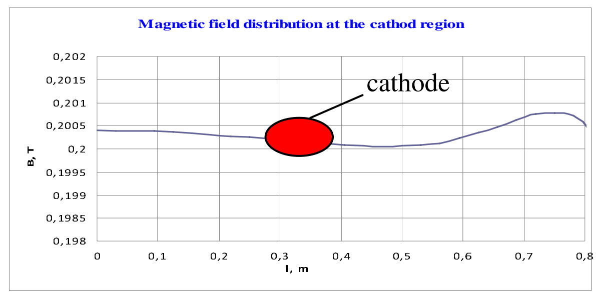

Fig.5.Magnetic field distribution at the cathode region for configuration presented in Fig.4

The cathode diameter is chosen of 13 mm that is standard size for commercially available impregnative cathodes. The electron beam diameter is cooling section one can easily vary with appropriate choice of magnetic fields ratio in acceleration section and cooling one.

Electric field distributions along the solenoid axis and electron transverse temperatures versus axial coordinate are shown on Figs. 6 and 7.

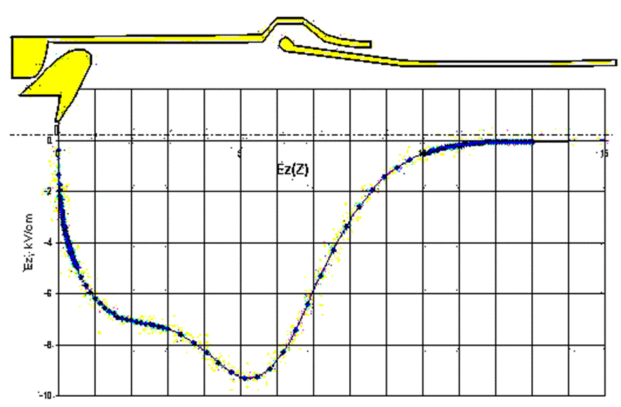

Fig.6. Electric field distribution at the solenoid axis: Ucath = -60 kV, UControl = -41 kV Uanod =0 kV, I = 1A, µP=0.38

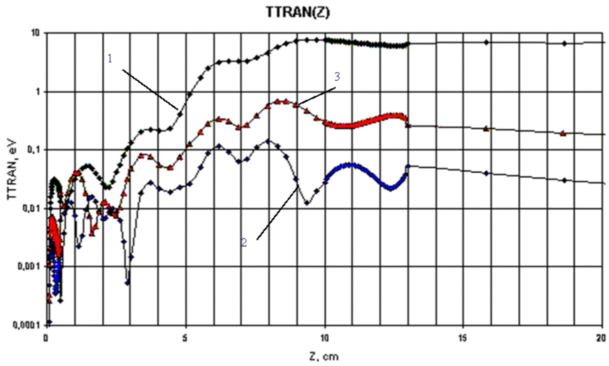

Fig.7. Distribution of electron transverse temperatures TTRAN (Z) along the trajectory of electrons emitted from the cathode on radius R = 0,65 cm; B = 1 (1), 2 (2), 1.5 (3) kG

To enhance the collector efficiency a permanent magnet with opposite field direction is applied. As result magnetic field lines form a magnetic trap reflected electrons are trapped in the collector with a great efficiency. Electron motion in the collector is calculated with the SAM code and results are shown in Fig. 8. The carried out numerical simulation of electron motion in collector with permanent magnet of opposite field direction have shown high efficiency of secondary electron trapping.

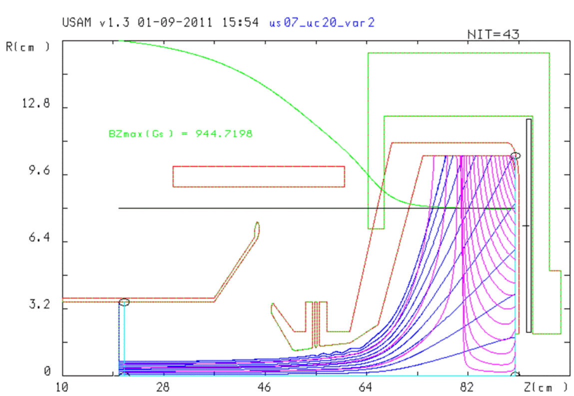

Fig.8. Magnetic field lines in the collector (permanent magnet of opposite field direction is placed on the rear wall of the collector). I = 1A, $U_{cath\text{-}coll}$= 2 kV, μP=11.26

HIGH VOLTAGE GENERATOR

High voltage (HV) generator (Fig.9) is based on the principle of the cascade scheme. The chosen scheme has three diode columns and twelve multiplying levels. At the working frequency of 20 kHz the total number of diodes (type 2Ц106Г by Russian standard) is equal to 2500, the total number of capacitors (type C2-29B-2 by Russian standard) is equal to 8316. The HV of U = 2.0 MV is controlled with three-phase autotransformer (AT) of the voltage of 380 V at 50 Hz. The controller transmits the feed-back signal to the three-phase rectifier (V). Smoothed by means of the filter the control signal comes to the inverter (F) that transforms it into 2 kHz meander. This voltage through resonance throttle (DR) comes to high voltage transformer (HT) with two symmetrical high voltage windings and further to the entrance of the symmetrical cascade generator (CG). It has maximum output voltage of 2.0 MV. For high voltage fluctuations suppression one should add at the exit of CG (Fig. 9) the low-power high voltage triode (T), which operates as a variable resistance controlled by the feedback signal from precise voltage divider (DU) via the feedback chain FB2 at ground level and FB3 at high potential. Operating voltage of triode T has to be higher than 10 kV, operating current – more than 1 mA. For example, if the stray capacity of high-voltage "output" to the ground potential is of 0.1 nF (to be defined later more exactly) voltage "loss" is of 500 V and voltage restoration time is of 0.1 ms, the triode current has to be at lest of 0.5 mA.

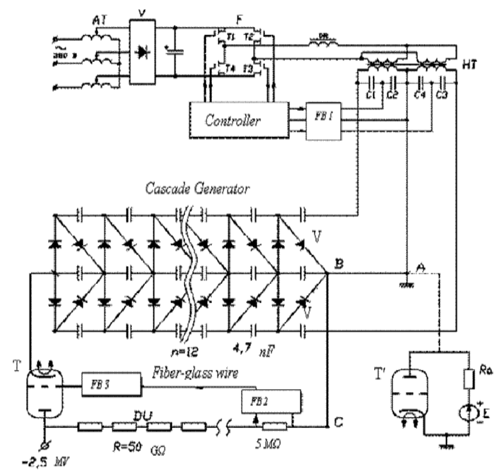

Fig.9. The HV generator electric scheme

The base element of the cascade of capacitors is ceramic capacitor with the following characteristics:

C = 1 nF; U = 40 kV; ø = 40 mm; l = 42 (65) mm.

The cascade of capacitors consists of 48 series sections. Each section consists of 33 parallel capacitors mechanically fixed between two metal disks of 5÷8 mm thickness and ø ≈ 320 mm that work as intermediate electric shields (Fig. 10). Sections are connected into CG stages: seven sections in series form one stage (280 kV, 4.7 nF).

There are 12 voltage multiplying stages (12x280 = 3360 kV) in each of three CG cascades. The cascade of capacitors is connected into mechanically firm design by means of a plastic tube, which is located in the center hole of metallic shields. The cascades are located inside the tanks and are connected each other by two diode groups (V). The third group ("V") doesn't contain diodes and plays the role of mechanical support only.

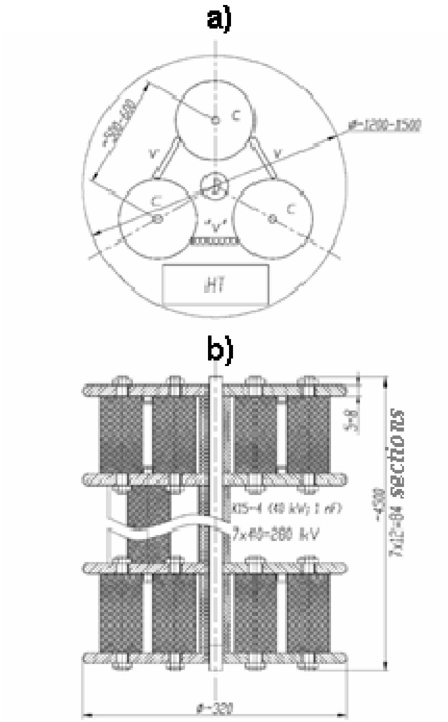

Fig. 10. Design of main elements of power supply of 2.0 MV (a) and cascade of capacitors (b)

Diode groups (V*)* are designed with the columns of avalanche diodes which may work at SF_6 gas pressure. Operating voltage is of 150 kV, the current is of 400 mA at 500 Hz frequency. Voltage divider (VD) is used for high voltage measurement and stabilization by means of feedback to triode via controller. It is made of 2500 precise in resistors in series (20 MΩ; ±0,25%; 2 W) with temperature coefficient of 10^{-6} °C^{-1} = $\pm 25 \cdot 10^{-6}$ °C^{-1}. Divider is placed in the main tank axis, where the potential is distributed almost uniformly along the axis by cascade of capacitors. The dimensions of the tank for the generator accommodation are of 6000×1200 mm.

CONCLUDING REMARKS

The scheme of the HV e-cooler has been chosen and construction of 250 kV prototype is in progress. Simulation of magnetic field formation in acceleration columns, electron beam formation and recuperation has been done. Design of the magnetic system, the electron gun and collector has been done. Design of magnetic system the system of power transmission to high potential is in progress.