PROJECT OF ELECTRON COOLER FOR NICA

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Abstract

The problems of development of high energy electron coolers are discussed on the basis of the existing experience. Necessities of electron cooling application to NICA collider are considered and the project parameters of the electron cooler at NICA collider are presented.

Electron cooler of the NICA Collider is under design and development of its elements at JINR. It will provide the formation of an intense ion beam and maintain it in the electron energy range of 0.5–2.5 MeV. To achieve the required energy of the electrons all the elements of the Cooler are placed in the tanks filled with sulfur hexafluoride (SF_6) gas under pressure of 6 atm. For testing the Cooler elements the test bench «Recuperator» is used and upgraded. The results of testing of the prototypes of the Cooler elements and the present stage of the technical design of the Cooler are described in this paper.

INTRODUCTION

The first question to be answered is: "Why do need HV E-Cooler for the NICA collider?" This Collider will have to operate at the energy of heavy ions like $^{197}Au^{79+}$ in the range of 1÷4.5 GeV/u. To reach the project luminosity one needs to form short and high intense ion bunches and maintain their parameters during a long time, of the order of 1 hour at least. In NICA project two energy ranges of the Collider and two its regimes are considered.

A) Space charge (SC) dominated regime:
E_{ion} = 1–3 GeV/u. Electron cooling is mandatory here when acceptance is filled with ions up to the Laslett tune shift $\Delta Q = \Delta Q_{max} = 0.05$. Then beam intensity and Collider luminosity are limited (see details in [1]):

$$L \le L_{max} = (0.01\text{–}1)\times 10^{27}\ \text{cm}^{-2}\cdot\text{s}^{-1}.$$

B) Intrabeam scattering (IBS) dominated regime:
E_{ion} = 3–4.5 GeV/u. With energy increase SC effect becomes small, luminosity can be increased up to

$$L = 1\times 10^{27}\ \text{cm}^{-2}\cdot\text{s}^{-1}$$

and is maintained constant. However, to keep bunch parameters one has now to suppress IBS. It can be done by application of stochastic and electron cooling. At the energy above 3 GeV/u luminosity is artificially limited by max event rate acceptable for detector MPD. In this energy range electron and stochastic cooling are supposed to be used in the NICA Collider simultaneously providing a long life time of the Collider luminosity.

Nowadays electron coolers are demanded in the energy range up to tens MeV. There are several well advanced projects. In general one can divide then in two groups: high voltage (HV) and high energy (HE) electron coolers. The first ones use conventional DC HV schemes. These coolers can be used, practically, up to 10–15 MeV electron energy. Such projects are under development at COSY (FZJ), NICA (JINR), HESR (FAIR), HIAF (Lanzhou). The second group — HE electron coolers are developed on basis of several different novel approaches, like coherent e-cooling, optical e-cooling, and some others. Most feasible of them looks option of "energy recovering linac" (ERL) [2] that is under development at RHIC BES (BNL) and MEIC (JLab) projects.

THE EXPERIENCE WE HAVE

Presently we have only two examples of HV electron cooler. One is well known electron cooler at Recycler storage ring at Fermilab that was designed and constructed by the team led by S. Nagaitsev [3]. The cooler had electron energy up to 4.3 MeV at working electron current of 0.1–0.5 A (max electron current 1.6 A). The cooler design was based on the Pelletron scheme — a version of electrostatic accelerator. It had unmagnetized electron beam. Presently the machine is dismantled.

The second electron cooler was designed by original scheme and constructed by the team of V. Parkhomchuk at Budker INP [4, 5]. The cooler has maximum design electron energy of 2 MeV at the Electron beam current of 3.0 A. HV generator is made by the cascade transformer scheme, electron beam is magnetized. The "COSY cooler" is under commissioning presently [4], [5].

These two machines characterize the level of technical development in this field today.

THE CONCEPTS OF A HV E-COOLER FOR AN ION COLLIDER

The First Consideration

The NICA electron cooler is the very first experience of design and construction of such cooling system with two cooling electron beams. Therefore some consideration of a general character has been done.

An evident scheme based on two independent cooling electron beams has been proposed in the NICA project (see below). More sophisticated scheme — one (common) electron beam to cool two ion beams was

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proposed for NICA Collider by Budker INP team. The solution is technically good, however the electron beam is a feed back between two ion beams: an instability in one ion beam excites electron beam that brings the instability signal to another ion beam, i.e. we have "the three beams' instability"! Finally the scheme with common electron beam has been rejected.

Two Concepts of the HV Electron Cooler with Two Electron Beams

Two schemes of HV electron cooler for the NICA Collider were proposed. Both schemes had to meet the specifications formulated in the NICA project (Table 1).

Table 1: Main Parameters of the NICA Electron Cooler

DC magnetized electron beam	
Electron energy, MeV	0.5–2.5
Electron beam current, Amp	0.1–1.0
Solenoid magnetic field, T	0.1–0.2
Electron transverse temperature in PRF, eV	1.0–5.0
Electron longitudinal temperature in PRF, meV	5.0
Electron energy spread in Lab. system, $\Delta E/E$	1e-5

The first scheme proposed and being developed by JINR group has three tanks filled with SF_6 gas at the pressure of 6 atm and connected each other with coaxial feeder (Fig. 1). The leftmost and rightmost tanks contain by two accelerating/decelerating tubes for two electron beams of the opposite direction for cooling the ions circulating in the upper Collider ring and the lower one, correspondingly. The tubes are equipped with electron guns and collectors (Fig. 3). The middle tank contains the HV generator and terminal with the power supplies for the electron guns and the collectors.

Advantage of this scheme is a short solenoid system and a reliable scheme of the voltage multiplier applied for HV generation. The disadvantage is probable problems at tuning of the cooler regimes when electron beams are ON.

The second scheme proposed by Budker INP group is based on the design of the "COSY cooler". It is actually two "COSY cooler" with independent solenoid systems and power supplies (Fig. 2). The advantage of such approach is evident: the existing machine that demonstrated its reliability in the first tests. As disadvantages one can specify are the long solenoid system (approximately twice longer than in the NICA scheme) and problematic design for SC solenoids inside the tanks (see the next section): the COSY design is not applicable et al. in this case.

SC Solenoids

The solenoids in both concepts are supposed to be superconducting, because warm solenoids in such device consume a lot of electric power due to the large length. In the project the feasibility of the application of HTSC tape is considered as well. The tape with dimensions of 12×0.5 mm^2 is commercially available presently. Conceptual design of the NICA cooler has shown the possibility of formation of the magnetic field of the sufficient homogeneity using a conic solenoid (Fig. 3).

Such design allows one to save significantly the tape amount. An important issue is the critical magnetic field for the HTSC tape at 77 K (LN_2) that is about 1.0 T. This constraint required to reduce the maximum magnetic field on the HTSC winding of the conic solenoid.

The HV Generator

Several types of the HV generators were considered: Pelletron (van der Graaf), cascade transformer, dynamitron scheme, voltage multiplier ("Cockroft – Walton"), turbine driven generator [6]. Preliminary analysis of all the options (Table 2) forced us to choose the voltage multiplier option. Such HV power supply is developed presently by the group from All-Russian Institute for Electrotechnique (Moscow) in collaboration with JINR.

Table 2: Typical Parameters of HV Generators

Generator type	**Max. voltage, MV**	**Max. current, mA**	**Reliability**
Pelletron	13.0	0.1 (per chain)	Longstanding experience (Nat. Electrostatic Corp., Madison,USA)
Cascade transformer	2.0	1.0 (?)	BINP, commissioning stage
Dynamitron	25.0	?	World experience
Voltage multiplier	5.0	2.0	ARIE, Moscow, RF ("old" experience)
Turbine driven generator	?	?	BINP & Mainz Univ. R & D (very promising)

MODELING OF THE COOLER ELEMENTS

The element of the NICA electron cooler designed by the NICA group are tested at the test bench "Recuperator" (Fig. 4). It was constructed and used in the end of the 1980th — beginning of the 1990th for test of the electron

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collector and electron gun for the electron cooler of LEAR. The test bench is a good training ground for young researchers. The Electron Cooling Group of Dzhelepov Lab. of Nucl. Problems of JINR is developing new schemes of the electron collector and electron gun for the HV electron cooler of the NICA Collider and the methods for testing parameters of these devices.

CONCLUDING REMARKS

HV electron cooler for an ion collider *has to be equipped with* two independent beams of magnetized electrons (preferably), which are generated by an electron gun with a "hollow" electron beam and the sectioned "Pierce electrode". It allows one to avoid/reduce recombination of the ions to be cooled with the cooling electrons and provide electron beam positioning using the beam current modulation and PU electrodes in the beam transfer line.

The electron cooler solenoids are to be superconducting. Application of HTSC winding looks realistic presently and is very promising.

Application of the HV generator of the voltage multiplier type is considered as most practical for the moment.

The three tanks' scheme seems adequate to the parameters of the HV electron cooler for the NICA collider.

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