CONCEPTUAL PROJECT RELATIVISTIC ELECTRON COOLER FOR FAIR/HESR

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Abstract

A 4-8 MeV relativistic electron cooling system for the HESR storage ring, which is part of the future GSI facility FAIR, is proposed to further boost the luminosity even with strong heating effects of high-density internal targets. In addition the upgrade to 8 MeV of the relativistic electron cooler is essential for the future Electron Nucleon Collider (ENC and FAIR) project. The basic feature of the design is the power for magnet field coils at accelerating and decelerating column is generated by turbines (one option under investigation in this research group) operated on SF_6 gas under pressure.

HIGH ENERGY ELECTRON COOLERS

The first the high energy test bench for study intensive electron beam for using at cooling systems was constructed at BINP [1,2]. Main result (1MeV, 1A) has opened the prospects of design of high voltage cooler with high electron current. Later few physicists co-authors of [1], continued scientific activity at USA. S.Nagaitsev's team realized 4.4 MeV, 0.1 A electron cooler for RECYCLER [3]. From 2005 to 2011, the world's only relativistic electron cooling system was used to cool the antiprotons for accumulation and preparation of bunches before injection into the collider ring. Next high voltage cooler was installed at COSY synchrotron at 2013 [4]. The basic idea of that cooler is to use strong longitudinal magnetic field along the whole orbit of the electron beam from the electron gun to the electron collector. At this case we have chance to have high enough electron beam density at cooling section with low effective temperature. The main task for that cooler is suppression of scattering of a proton beam interacting with high-dense inner gas target. The same requirements are needed for HESR cooler for antiproton beams, but for the electron energy being up to 8 MeV.

COSY COOLER EXPEARIANCE

The COSY 2MeV cooler was used for the first experiments with cooling proton beam from 100keV to 908 keV at beginning 2014. Cooling rate on low energy demonstrated strong influence of the proton beam intensity. Cooling of a high intensity proton beam meets the high rate losses proton bean and only small fraction of the beam can be cooled. With increasing beams energy this phenomenon became weaker and the proton beam cooled practically without losses. Fig. 1 shows cooling processes as were measured at COSY cooler.

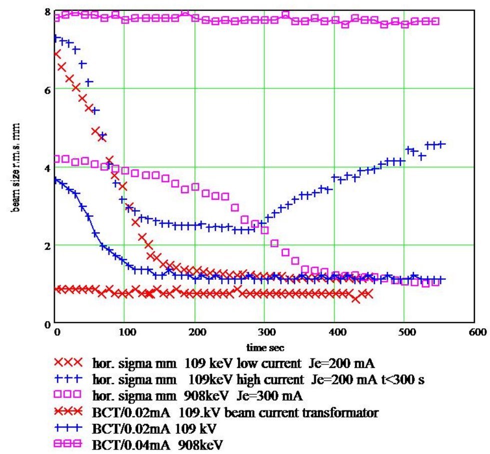

Figure 1: The beam size and proton beam intensity versus time for cooling experiments at different energies COSY.

The cooling at low energy of 109 keV shows the very high sensitivity for proton beam intensity. When the initial intensity proton beam was high, proton beam had high losses at initial moment of cooling. Only after the decay of the initial proton beam from 0.08 mA to 0.02 mA the decay of beam intensity was stopped. And after switch off electron cooling in 300 s, we can see grows proton beam size by intra beam scattering. For cooling low intensity proton beam 0.016 mA we can see only cooling proton beam size from 7 mm to 1 mm without any losses. For cooling at the high energy this phenomenon was suppressed. After acceleration proton beam to 1670 MeV, the proton beam current 0.33 mA cooled down without additional losses. The cooling time is near 300 s for 1670 MeV beam energy, and for 109 MeV cooling time is near 100 s. The formal equation predict $\gamma^5\beta^4$ scale for cooling time but in practice instead of 460 times the experiments show just 3 times. Reason is at decreasing emitance (4 mm instead of 7 mm) and more higher magnetic field at cooling section (1300 Gauss instead of 500 Gauss) for higher energy (and higher electron beam density).

HIGH VOLTAGE PROBLEMS

Corona Current

Figure 2 shows corona current versus voltage on high voltage terminal of the COSY cooler.

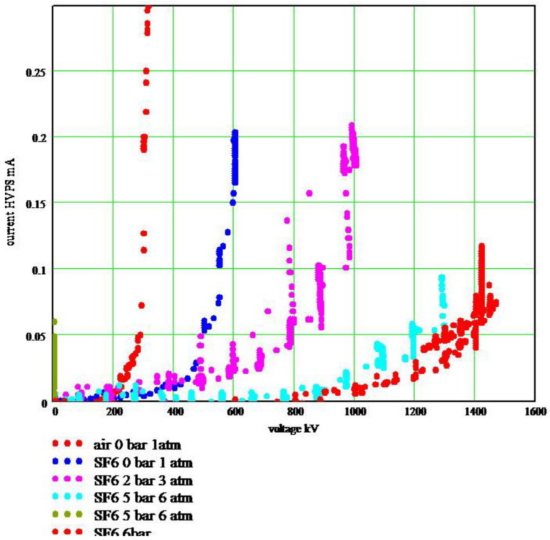

Figure 2: Corona current versus voltage.

The stable operation of the cooler requires a low level of corona current. The corona current noise generated oscillations at a high voltage feedback stabilization system. The fitting of corona current versus voltage and pressure of SF6 gas can be written when corona current excides 50 uA:

$$U(kV) = 450 * (p(atm))^{0.6}.$$

This equation means that for p= 7 bar or 8 atm maximum voltage for COSY cooler is 1560 kV. It corresponds to electric field on high voltage terminal 8.1 MV/m. For conceptual design of the 8 MV HESR cooler (fig. 3) electric filed on cylindrical part with diameter 2.5 m will be 7.3 MV/m which is slightly less the in COSY cooler.

Protection of the Cathode

The operation of the cooler with intensive electron current accompanies the crash of recuperation mode from time to time. At moment of crash the cathode surface bombarded with a high intensive the secondary ion flux. The special trigger system switch off the electron beam at this case to make this mode crash as short as possible. For 8 MV it cooler it looks reasonable to protect the cathode with using special bend of electron beam orbit just after the electron gun inside high voltage terminal. For COSY cooler positive influence switch on the Wein filter near collector was detected. In this case secondary electrons from collector generating bombarding ions deflected that improved the stability of operation.

High Voltage Vessel

Preliminary layout of the 8 MV cooler is shown in fig.3. Disadvantage of COSY cooler design was clear at time of commissioning. The access to acceleration tubes is complicated and time consuming. The coils along acceleration column occupied 4cm/6cm = 66% space. At new cooler we discuss same sort of design with modules where coils will occupied less space.

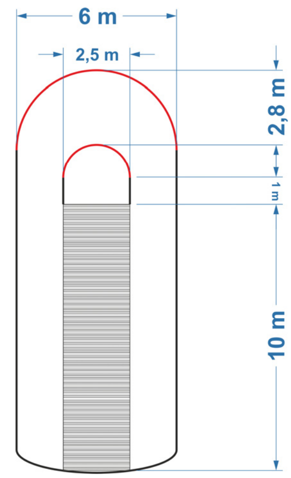

Figure 3: Conceptual design of the voltage vessel for 8 MV cooler.

Inside the vessel should be pressed to 6 bar SF6 gas for electrical isolations and to suppress corona current. The weight of SF6 in this vessel amount about 14 ton. At high voltage terminal we install local water cooling system for cooling the electron beam collector. For cooling power inside collector of 5 kV * 3 A = 15 kW we think to use heater exchange were SF6 gas will cool water at local cooling system. The hot SF6 gas will cool outside and return at the high voltage vessel with using external ventilators for circulation gas and special large diameter tube for communication SF6 flux. Basic design of the electronic for control and measuring will used radio connection, so called Zigbee protocol for the electronic boxes distributed along column and having different potential.

Magnet System for the Accelerate and Deaccelerate Tubes

Figure 4 show draft of magnet section around acceleration tube. It is compromise for free access to acceleration tube and modulation magnet field along beam axis $\Delta B / B = 10^{-3}$. Parameters of magnet system: external radius 27 cm, thickness of coil 4 cm, step 14 sm, weight of single coil 35 kg, power at single coil 300 W, power for all coil and both tube 3 kW. The power will be distributed along tube with cascade transformer at both directions from turbine 2.5 kW up and 2.5 kW down relative to local ground plate for turbine generator. At ground potential will be install the pickup electrodes and system of correction the magnet line direction. This 2D x and y dipole correctors can correct magnet lines so that beam orbit will pass pickups at centre of tube. For correct 1mm offset 500 Gauss on length 70 cm we need on length 16 cm to have transverse magnet field 4 Gauss.

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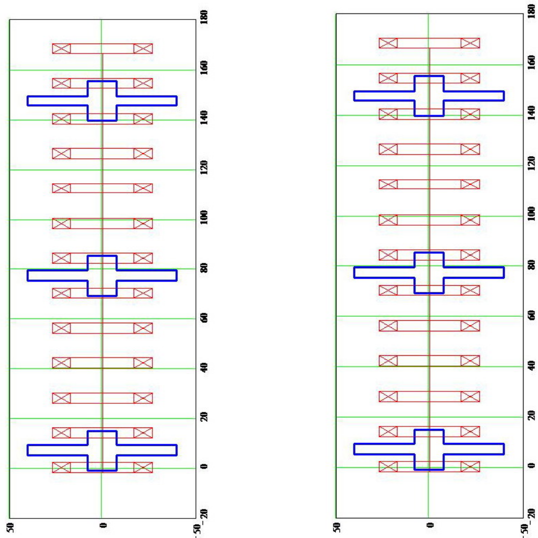

Figure 4: Conceptual design magnet system for 8 MV cooler.

But for cooling coils of magnet system may be will need special SF6 high pressed gas SF6 for pumping throw hollow conductor using at production of coils.

As example we can take cooper hollow conductor with dimensions 7*7 mm^2 and hole channel for cooling with diameter 4 mm. The current at each wire will be 70 A and current density 1.9 A/mm^2. The voltage on all 3 sections at serious will be 4.5 V. The each coil consist from 3 cooper wires with length 40 and thickness of this cooper coil 7*2*3=42mm. For this case cooling parameters shown at table 1.

It solution looks technically reasonable but will need additional calculation and testing.

Table 1. Cooling Parameters

parameter	SF6
Input pressure	12 bar
Output pressure	6 bar
Specific heat J/g Cp	0.66
Density g/ml	0.060 (12-6 bar)
Viscosity m^2/c	7×10^{-6}
Velocity at tube U m/s	5.2
Reinoldsa number Re	6.4×10^4
Flux of fluid Q l/s	0.09
Flux of mass ρQ g/s	5
Power for fluid Δp*Q W	54
Output temperature ΔT ^{0}C	28

CONCLUSION

The high voltage electron coolers became required for acceleration rings development at NICA (JINR) Dubna, HESR (FAIR) Darmstadt for study nuclear physics with relativistic ions beams of 1-16 GeV/n energy. The potential of the electron cooling and technical problems of design of such device is not yet clear. The cooler for COSY demonstrated possibility to solve the problems but next step is needed to design a test bench for study critical points of new technology.

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