ON THE WAY TO A RELATIVISTIC ELECTRON COOLER

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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 needed 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 at FAIR) project. Using the experience of the 2 MeV electron cooler at COSY, which has the highest energy of all coolers that were made based on the idea of magnetised cooling and transport of the electron beam up to now, a new concept for powering the solenoids at high voltage is proposed.

INTRODUCTION

The use of electron coolers in the range of electron beam energy lower 400 keV is well established and state of the art. For higher electron energies there exists up to now only one machine – the Recycler Electron Cooler (REC) of Fermilab with a terminal voltage of 4.4. MV [1]. The cooler was installed into the Recycler during the summer of 2005 and was operating until the end of 2011 when the Tevatron was shut off. The cooling opened the possibility for several times higher, record luminosities. The REC overcame not only the great challenge of operating 4.4 MV pelletron accelerator in the recirculation mode with up to 1A beams, but also resolved the hard issue of high quality beam transport through non-continuous magnetic focusing beamline [2]. The next unique high energy electron cooler -the 2 MV COSY electron cooler- was commissioned in 2013 at Juelich [3]. Development of high energy electron coolers is a technical challenge due to the engineering problems like high voltage generation, power transmission to the gun and collector in the accelerator "head" and the power transmission to the magnetic coils at the accel/decel tubes for magnetised electron beam transport. Today there is a need for further development. In the high energy storage ring HESR for antiprotons at the FAIR facility in Darmstadt a 4.5 MV electron cooler is planed [4]. The proposed concept of the polarised Electron-Nucleon Collider (ENC) integrates the 15 GeV/c HESR of the FAIR project for protons/deuterons and an additional 3.3 GeV electron ring [5]. A new 8.2 MV electron cooler is an essential part in this concept. In the NICA collider project of JINR Dubna a 2.5 MV electron cooler is foreseen with one electron beam per each ring of the collider [6]. There are some special features of high energy cooling. The cooling rate decreases with $\beta^{-4}\gamma^{-5}$ [7]. To obtain a maximum friction force the "waveiness" of the magnetic force line should be as small as possible to get a smaller contribution to the effective electron velocity [8]. To get a high cooling rate magnetised electron cooling is necessary. All low-energy (3-400 keV) electron coolers are based on magnetised cooling. The electron beam transport and alignment of electron and ion beam is done with continuous magnetic field. Strong magnetic field completely suppresses transverse temperature of electron beam, so that effectiveness of cooling is determined by a very low longitudinal temperature of electrons. Non-magnetised cooling relies on the fact that rms velocity spread of electrons is comparable or smaller than the one of ions which need to be cooled. For the REC (non-magnetised case) cooling times of about one hour was sufficient. The new coolers for COSY and the new future projects should provide a few orders of magnitude more powerful longitudinal and transverse cooling. This requires new technical solutions. The basic idea of the 2MeV COSY cooler and for the future HESR and NICA collider coolers is to use a high magnetic field along the orbit of the electron beam from the electron gun to the collector. Faster cooling times are essential for the future projects. The technical problems for electrostatic accelerator at 8-10 MV and needed electron beam currents up to 3 A is a great challenge. An alternative can be a low frequency linac with bunched electron beam. Today this system achieved electron peak currents of about 10 A [9].

In order to solve critical technical issues of a future relativistic electron cooler based on an electrostatic accelerator the Helmholtz-Institut Mainz promotes collaborations with other Institutes such as Forschungszentrum Juelich (FZJ), Budker Institute of Nuclear Physics Novosibirsk (BINP), Russia and Lehrstuhl fuer Technische Thermodynamik und Transportprozesse, University Bayreuth. One of the challenges in case of the electrostatic accelerator is the powering of HV-solenoids for the magnetised electron beam transport. The HV-solenoids are located on different electrical potentials inside a high voltage vessel, which is why they needed a floating power supply. A novel idea from Budker institute is to use small turbines for high voltage generation, for power of the magnetic coils in-side the high voltage vessel and for powering of

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gun and collector in the HV terminal. At the moment, two different concepts are being discussed. In the first design, many small HV-solenoids are powered by a cascade transformer, which is powered by turbo generators. In the second proposal, few big HV-solenoids are powered directly by turbo generators.

HIGH VOLTAGE ACCELERATOR-VESSEL

An important element of the electron cooler device is the high voltage vessel, whose principal design is illustrated in Figure 1.

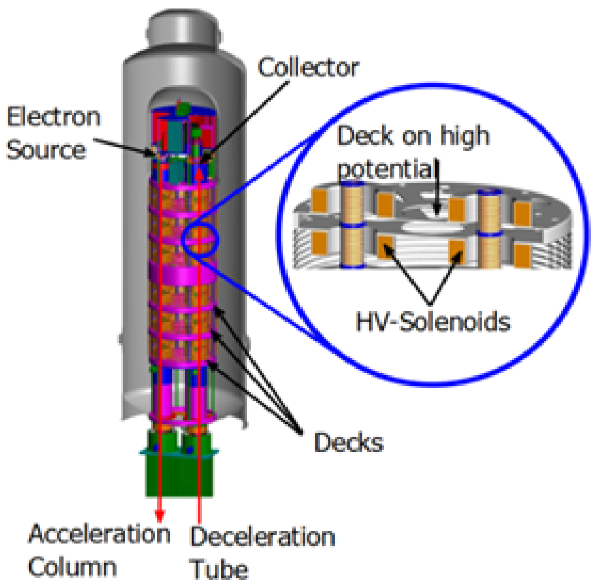

Figure 1: Principal design of the high voltage vessel [10].

The main components are the DC-thermionic electron source, the collector, the acceleration and deceleration tubes. The acceleration/deceleration voltage is provided by a high voltage column, which is built in a modular way and consists of decks. Every deck has a defined electrical potential. To guide the electrons from the gun to the interaction section, where the cooling process takes place, and back to the collector, a homogeneous magnetic field is necessary. It is generated with solenoids, the so-called HV-solenoids, which are mounted on the decks. This results in various requirements to the power supply for the HV-solenoids. Because the decks are on a fixed electrical potential, the power supply for the HV-solenoids must not be grounded. A high reliability of the powering system for the HV-solenoids is a must. In addition to the HV-solenoids, there are more devices on the HV deck, which also need powering, e.g. vacuum pumps.

POWERING OF THE HV-SOLENOIDS

Currently, two different concepts are being discussed, which were proposed by the BINP in a frame of a design study [11]. In both concepts, the power supply should be built in a modular way. While the 2MeV COSY cooler serves as a basis for the first concept, for the second concept the Swedish design, which had originally been planned by the Svedberg Laboratory, Uppsala University [9], was taken as a model.

Cascade Transformer

A well known and tested technology to power the HV-solenoids is a cascade transformer, which is already in use at the COSY cooler. to power the HV-solenoids and to generate a potential difference of 60kV between the individual decks.

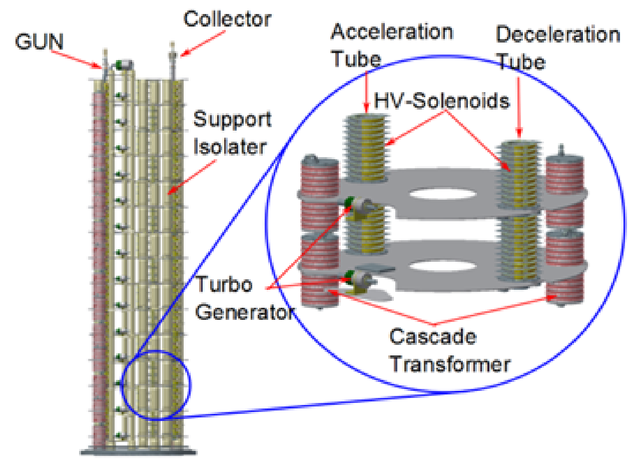

Figure 2: Powering the HV-solenoids with a cascade transformer. The left image shows the whole modular power supply, the right drawing shows two modules. The magnetic field is generated by several small HV-solenoids that are mounted along the acceleration/deceleration tube. The HV-solenoids are powered by a cascade transformer. A second cascade transformer generated the acceleration/deceleration voltage. Both cascade transformers are feeded by a turbo generator, an assembly of a turbine and a generator.

The turbine is powered by a gas under high pressure, consequently driving the generator. An advantage which is obtained with the use of turbo generators is that the expanded gas from the turbine can be used for cooling the HV-solenoids.

High-Voltage Column with Unit Elements

In this approach, the power supply should also be built in a modular way, but instead of a cascade transformer which distributes the power to many small decks (or HV-solenoids respectively), only one deck, a so-called Separation Box, per module should be used (Figure 3). Each Separation Box sits on a defined electrical potential. The potential difference between two Separation Boxes is 600kV, the distance is 0.7m. Every Separation Box contains all the electronics of a module. Furthermore, two HV-solenoids are mounted per Separation Box. In this design, the HV-solenoids are composed of four coils. To smooth the variations of the magnetic field, the coils are surrounded with iron. But also in this design, a floating power supply is necessary to feed the HV-solenoids. As in the first design proposal, turbo generators should be

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used. But in contrast to the first approach, the turbo generators feed the HV-solenoid and all the other electronics inside the Separation Box directly. For the generation of the acceleration/deceleration voltage a Cockcroft-Walton generator can be considered.

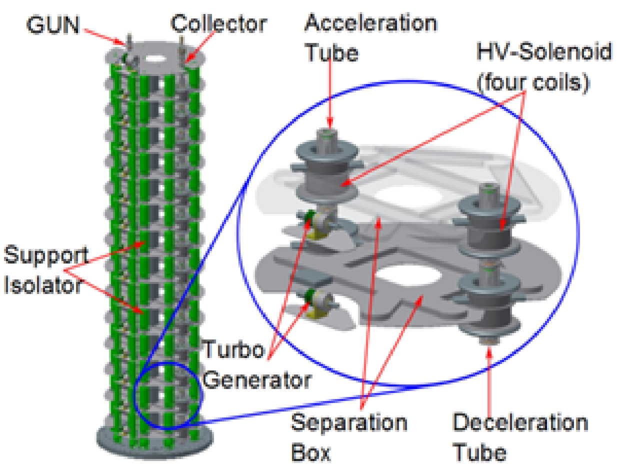

Figure 3: Direct powering of the HV-solenoids with a turbo generator. The left image shows a drawing of the entire module with electron gun and collector. On the right two modules, consisting of a Separation Box and two HV-solenoids are shown.

The second design approach allows easier construction and maintenance. Disadvantages are higher power consumption and the arrangement of the HV-solenoids that demands more attention to the beam optics due to small variations of the magnetic field along the beam axis.

GREEN ENERGY TURBINE

For both concepts, a suitable turbo generator is essential. A research for proper turbo generators has identified the GREEN ENERGY TURBINE (GET) (Figure 4) form the company DEPRAG [12] as a potential candidate, which works with dry air. Further properties of the GET are listed in the Table.

Table: Properties of the GET

Power	5 kW
Pressure (in)	4 bar
Pressure (out)	1 bar
Mass Flow	4 m3/min

A critical point in both concepts is the generation of the pressurised gas. As the high voltage vessel is filled with sulphur hexafluoride, the preferred gas is SF_6, since this reduces the problems e.g. in the case of leaks. Based on the data of the GET, the efficiency was roughly estimated to 12.5% for a compressor power (air) of 40kW. If we assume the same specification of the GET for SF_6 as driving gas, a compressor power of 28kW is required. This results in an efficiency of 18%, but that is probably an overestimation. However, a low efficiency means high operational cost. Alternatively an Organic Ranking Cycle (ORC) like process could be applied in the case of SF_6 [13].

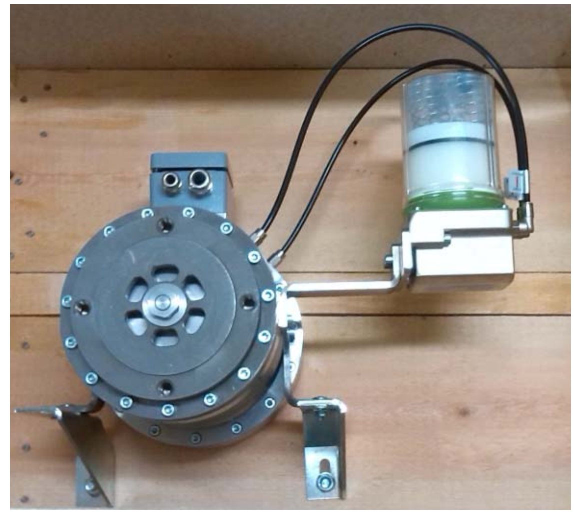

Figure 4: GET turbine with lubrication unit.

CONCLUSION

To investigate the pros and contras of the different approaches a test bench is necessary, where e.g. the reliability, temperature regime, efficiency of the turbine can be studied. Other problem to study is the magnetic field quality dependent on the magnetic coil design.

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