ELECTRON COOLER R&D AT HELMHOLTZ-INSTITUT MAINZ

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Abstract

Helmholtz-Institut Mainz conducts research related to critical design aspects of relativistic magnetized electron coolers. This comprises on the one hand accelerator physics issues such as minimally invasive beam diagnostics and optimization of energy and particle recovery. On the other hand, the realization of power supplies at several different Megavolt potentials is an important problem that we hope to attack with a new concept, namely using turbo generators. A status report of the different research subjects is given.

INTRODUCTION

The HESR (High Energy Storage Ring) will be erected as a contribution of Forschungszentrum Jülich to the Facility of Antiproton and Ion Research (FAIR). Several planned experiments at HESR require cooling of the stored ions with a magnetized relativistic electron beam. Cooling of antiprotons for the antiProton ANnihilation at DArmstadt (PANDA-) experiment [1] would represent the most significant application during the first operational phase of FAIR, which is expected to begin at the end of this decade. Furthermore, it is discussed to use the HESR as an ion-storage ring in a double polarized collider facility, the Electron Nucleon Collider at FAIR (ENC@FAIR), a machine which could become operational in the 2020 decade [2]. ENC@FAIR is a project of considerable importance for the hadron physics community, which is strongly represented at the new Helmholtz Institute Mainz (HIM). ENC@FAIR with both its machine and experimental aspects is therefore a long-range project pursued by HIM. While several of the planned experiments at PANDA can be performed with stochastic cooling alone, the presence of relativistic magnetized cooling is mandatory for ENC@FAIR. First calculations of the cooling power needed to compensate for the beam heating effects in collider operation indicate that a current of several amperes would be needed [2]. Furthermore, it is evident that the desire for maximum center of mass energy of the collider favors operation at the highest proton momentum possible at HESR (BR=50 Tm), which corresponds to an e^-energy of 8 MeV. No device of comparable performance exists so far. The former Fermilab cooler parades the highest energy of all electrostatic cooling devices (4.5 MV) but it was not operating in a completely magnetized fashion [3] and it ran at currents well below 1 A since it could fulfill its task with very low cooling rates. Though a design based on an extrapolation of established technology was developed by a team at the university of Uppsala [4] it is by no means clear if such an approach is feasible.

The realization of the magnetized multi MeV cooler for HESR requires a very considerable investment. Several critical design issues are pending for which promising solutions should be provided before investment starts. We have identified several tasks where we hope to be able to contribute:

1. A first issue arises from the need of floating power supplies. The power needed for maintaining the longitudinal field in the acceleration stage and for operating the high current collector at the terminal will be of the order of 100 kW. The power will have to be distributed on many different potentials in the multi-MV range. Traditional concepts–such as transformers or shaft driven generator/pelletron combinations-could prove unsuitable for the increased demands.
2. Particle losses, especially from the collector, are even less tolerable if compared to sub-MV devices due to the high ionization rate associated with a loss process. We therefore investigate efficient loss-minimization concepts for high intensity beams.
3. Given the enormous beam power, it seems worthwhile to investigate new concepts of minimally invasive beam diagnostics.

TURBO GENERATORS

Cascaded transformers allow to transfer electrical power to many different potentials (stages). After rectification this power can be used to power the solenoids which create the longitudinal magnetic field in the acceleration column. Furthermore, small HV power supplies can provide the potential difference from stage to stage. The 2 MV cooler at COSY Jülich [5] will be one of the most sophisticated applications of the transformer principle. So far it is not clear if an extension towards higher voltages is technologically feasible. The group at Uppsala proposed to use a more conventional approach based on generators driven by insulating shafts and generation of HV by a pelletron, as it was the case in the Fermilab cooler. However, this mechanical system has to be distributed over many stages, which leads to a somewhat clumsy design that will become less attractive if one extends this approach from the initially proposed 4.5 MV to 8 MV. A new concept was proposed by BINP for the 2 MV cooler project at COSY in its initial stage. The suggestion was to use compressed gas which drives an expansion turbine, the mechanical energy of which is converted into electrical energy. This turbo generator may then sit on any desired potential. Each individual 60 kV transformer stage would therefore have been replaced by such

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a small turbo generator. Since several open technological questions-especially reliability issues-threatened the timely completion of the 2 MV cooler, the project was given up in favor of a cascade transformer. In order to take up this idea again for systems with an even higher voltage, an industrial solution is desirable, especially because of the improved perspective for predictable long term performance. Such small turbo generators have recently been developed by industry in order to connect small regenerative energy resources to the power grid [6]. At HIM we have ordered two 5 kW turbo generators for experiments based on the original BINP idea. Sufficient mean time between failures and maintenance intervals (of the order of many months) could be achievable. The 5 kW generator yields enough power for about 10 stages of the COSY-cooler type. V.V. Parkomchuk pointed out that in this case, it may be advantageous to create a module where the turbogenerator powers, for instance, a 500 kV transformer which in turn supports the stages [7]. The total voltage can then be achieved by stacking these modules (see Figure 1), e.g. 16 in the case of an 8 MV cooler. Presently, it seems preferable to use the insulating gas, SF_6, itself as a medium for the turbines. The gas dynamical aspects of using SF_6 in a turbine still have to be clarified. A specific compressor system for creating a power of ≈100 kW in the compressed gas stream can be developed by one of the several manufacturers of compressors for industrial gases. This compressor would sit outside the HV tank of the cooler. Development of a suitable prototype for testing the system behavior under high voltages seems worthwhile and will be pursued by HIM, probably in collaboration with the Budker institute.

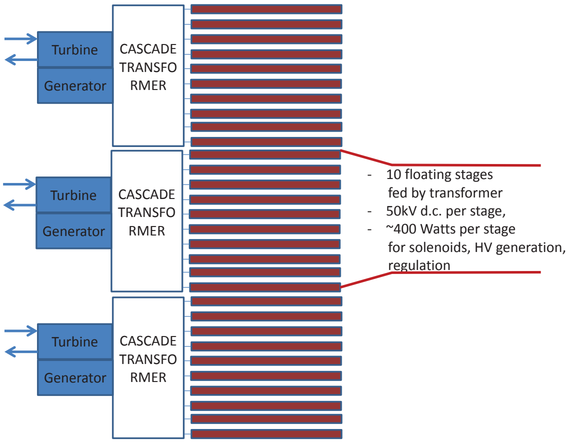

Figure 1: Example for stacking of three 500 kV cascade-transformers driven by 5kW turbogenerators.

COOLER TEST STAND

In MV coolers the greatly enhanced level of ionizing radiation (especially highly penetrating gamma radiation) associated with the loss of an electron will lead to a regime of operation where losses have to be strictly minimized. This will in particular concern collector efficiency and ionization of residual gas. Coolers in operation are not a good place to perform experiments in this direction since every day operation is a clear priority there. HIM has therefore used a laboratory site which was made available by the Institut für Kernphysik at Universität Mainz to build up a cooler test stand which is exclusively devoted to these issues. We took over some components which were intended for similar purposes at the University of Uppsala. These include an electron gun whose design is closely following the one from the Fermilab cooler. Furthermore, a linear solenoid channel for fields between 0.2 and 0.07 T was available, together with suitable power supplies. This hardware is operational since autumn 2012. The system is designed for a beam current of 1 A at 26 kV. Details of operational parameters and problems encountered so far can be found in [8].

Presently, an extension of the solenoid channel is being installed which allows to incooperate a Wien filter. The design of the filter is based on a similar one in the 2 MV COSY cooler. In the Wien filter the incoming beam experiences no force since electric and magnetic force compensate for each other. It can pass towards the collector where some of the electrons will be elastically backscattered towards the cathode. However, due to the opposite velocity with respect to the incoming beam, backscattered particles get strongly deflected in the Wien filter. This deflected stream of secondary particles can be stopped and measured by a suitable collecting plate. Though the filter does not increase the collector efficiency-which may be in the range of several 10^{-5}-this fraction of backscattered particles can be stopped at relatively small energies which are not extremely harmful for cooler operation. Particle recovery is therefore achieved with a minimum of ionizing radiation, which is the goal of such measures. We expect first measurements with this system in 2013.

MINIMALLY INVASIVE BEAM DIAGNOSTICS

Modulation of the beam is a well developed method in order to diagnose the beam in a virtually non-invasive fashion. Useful information can also be gained from scrapers of various forms, but both methods are probably not ideal for online operation where a multi Megawatt d.c. beam is running. As an alternative, we investigate Thomson scattering. In such an experiment a laserbeam propagates through the electron beam; in our experiment the laser and the electron beam will be perpendicular to each other. Some photons are then Thomson-scattered towards the forward (electron beam-) direction and experience a Dopplershift, which enables separation of the weak photon-signal from possible stray radiation of the very powerful incoming laser beam. The signal is proportional to the areal density of the electron beam along the propagation direction of the laser. The electron density distribution may be obtained by moving the laser over the electron beam. A 150 W laser operating at a wavelength of $1 \mu\mathrm{m}$ and at a repetition rate of 10^5 Hz with 20 ns bunch length is available for the experiment. The experimental set-up is shown in Figure 2. We will use a 100 keV photoelectron source which produces a current of 100 mA for the duration of a Laser pulse. Due to the duty factor of 2×10^{-3}, the average current is only $200\,\mu A$ which will enable sustained operation of the photo cathode and does not require energy recuperation of the 100 keV beam. The scattered electrons are detected under 45 degrees with respect to the beam direction with a photodetector covering a solid angle of 100 msr. For a laser power of 100 W and a beam diameter of 3 mm, the count rate would be 14 Hz. At MeV beam energies the count rate can in principle be increased by at least three orders of magnitude for the following reasons. First, the stronger Doppler shift allows to use CO_2 lasers with $10\,\mu\mathrm{m}$ wavelength resulting in a factor ten higher rate due to the increased number of incoming photons at a given power. Second, multi-kW CO_2 lasers are easily available commercially. Third, the stronger relativistic boost yields an effective increase of the solid angle.

For our proof of principle experiment, achieving a reasonable signal to noise ratio is essential. Concerning electron beam induced backgrounds, we already have some experience resulting from beam induced fluorescence (BIF) measurements [9]. In this measurement the beam profile of a $500\,\mu$A beam (duty factor 0.1, 10 ms pulse length) was measured while passing through nitrogen gas at 10^{-5} mbar partial pressure. A photomultiplier was used in single photon counting mode to detect the fluorescence photons. Though no optical filter was used, background conditions were dominated by thermally generated electrons from the photomultiplier cathode. This background will be eliminated in the Thomson experiment by cooling the photomultiplier. Therefore we believe that electron beam induced background could be controllable. Concerning laser induced background, it is advantageous that the primary radiation will have a photon energy below the threshold of the detector. Experiments during which we shone $\approx 1\mu\mathrm{m}$ radiation directly on a photomultiplier photocathode revealed that mW radiation levels were required to excite significant photocurrents. In conjunction with suitable filters, we therefore expect to also be able to control the laser induced background.

SUMMARY & OUTLOOK

The accelerator section at HIM has started cooler related research concerning three different aspects. First, a 5 kW turbo generator has been identified as a candidate system to power the solenoid channel in future high energy coolers. This replaces the traditional methods of transporting energy to multi MV potentials (rotating shafts, belts, chains) by using the internal energy of a compressed gas, preferably SF_6. Many technical issues have to be clarified before the chances of success for such an approach can be realistically estimated. A recently finished collaboration agreement with BINP creates the opportunity to start working together to resolve these questions. Second, a small test set-up allows for dedicated experiments, especially dealing with optimization of collector efficiency and vacuum conditions. A third research issue is minimally invasive beam diagnostics with Thomson scattering. A proof of principle experiment of this technique will already begin in 2013.

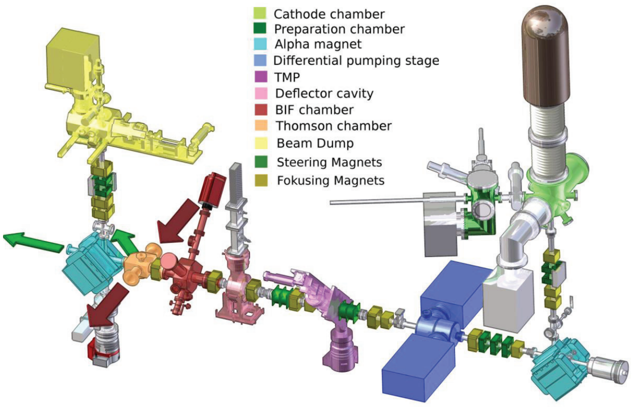

Figure 2: Test source (upper right side) with beam line and additional scattering chambers for BIF and Thomson diagnostics. Big red arrows indicate the direction of the Thomson-laser beam, green arrows the possible directions of photon detection. The electron beam is deflected by the alpha magnet into a beam dump located at the upper left.

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