PROGRESS WITH THE 2 MEV ELECTRON COOLER FOR COSY-JUELICH/ HESR

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Abstract

The 2 MeV electron cooling system for COSY-Juelich was proposed to further boost the luminosity even in presence of strong heating effects of high-density internal targets. The project is funded since mid 2009. Manufacturing of the cooler components is in progress. The space required for the 2 MeV cooler was made available in the COSY ring during the summer 2010 shutdown. The design and construction of the cooler is accomplished in cooperation with the Budker Institute of Nuclear Physics in Novosibirsk, Russia. The 2 MeV cooler is also well suited in the start up phase of the High Energy Storage Ring (HESR) at FAIR in Darmstadt. It can be used for beam cooling at injection energy and is intended to test new features of the high energy electron cooler for HESR. Two new prototypes of the modular high voltage system were developed, one consisting of gas turbines the other based on inductance-coupled cascade generators. The technical layout of the 2 MeV electron cooler is described and the status of component manufacturing is reported.

INTRODUCTION

The new generation of particle accelerators operating in the energy range of 1-8 GeV/u for nuclear physics experiments requires very powerful beam cooling to obtain high luminosity. For example the investigation of meson resonances with PANDA detector requires an internal hydrogen target with effective thickness 4×10^{15} atoms per cm^2 and 10^{10} – 10^{11} antiprotons at 15 GeV circulating in the HESR. In this case the peak luminosities ranging from 2×10^{31} to 2×10^{32} $cm^{-2}s^{-1}$ are achievable. These experiments allow to observe meson resonances in proton-antiproton annihilations. Resolution of the experiments is limited by momentum spread in antiproton beam, which must be better than 10^{-4}.

The average momentum losses $\frac{dp}{pdt}$ on such a target (for 4 GeV antiprotons) will be about $4\cdot10^{-6}s^{-1}$ and the heating rate of momentum spread by fluctuation of ionization losses will be near $\frac{dp^2}{p^2dt} = 2\cdot10^{-9}s^{-1}$. To obtain momentum spread of 10^{-5} – 10^{-4} cooling time in the range $\tau_{cool} = 2(dp/p)^2/(dp^2/dt/p^2) = 0.1\div10s$ is needed. The 4 MeV electron cooler at the RECYCLER ring (FNAL) [1] achieves cooling time about 1 hour. The new cooler for COSY should provide a few orders of magnitude more powerful longitudinal and transverse cooling that requires new technical solutions. The basic idea of this cooler is to use high magnetic field along the orbit of the electron beam from the electron gun to the electron collector. In this case high enough electron beam density at low effective temperature can be achieved in the cooling section. For example the electron beam density of $2\cdot10^8$ cm^{-3} (6 mm beam diameter and 1.5 A of current) magnetized with longitudinal magnetic field of 2 kG will have $2.7\cdot10^6$ cm/s drift velocity in the beam reference frame. This velocity corresponds to a cooling time near 0.1 s for the low angular spread ($\Delta p_\perp / p = 10^{-5}$) beam.

BASIC DESIGN FEATURES

The basic parameters for the COSY cooler are listed in Table 1. The length restrictions are given by the space available in the COSY ring. The height is limited to 7 m by the building.

Table 1: Basic Parameters and Requirements.

COSY 2 MeV Electron Cooler	Parameter
Energy Range	0.025 ... 2 MeV
High Voltage Stability	$< 10^{-4}$
Electron Current	0.1 ... 3 A
Electron Beam Diameter	10 ... 30 mm
Length of Cooling Section	2.69 m
Toroid Radius	1.00 m
Magnetic Field (cooling section)	0.5 ... 2 kG
Vacuum at Cooler	10^{-9} ... 10^{-10} mbar
Available Overall Length	6.39 m
Maximum Height	5.7 m
COSY Beam Axis above Ground	1.8 m

In Fig. 1 the layout of the COSY 2 MeV cooler is shown. The cooler HV terminal is installed inside the pressure vessel filled with SF_6 gas. The main features of the cooler are:

1. The design of the cooling section solenoid is similar to the ones of CSR (IMP) and LEIR (CERN) coolers designed by BINP [2, 3]. However, for the 2 MeV cooler the requirement on the straightness of magnetic field lines is so high ($\Delta\theta < 10^{-5}$) that a system for control of magnetic field lines in vacuum becomes necessary.
2. For suppression of high energy electron beam losses at IMP and LEIR coolers electrostatic bending was used [4]. The shape of the 2 MeV transport lines, however, dictates a different approach. The collector (inside the HV terminal) will be complemented by a Wien filter to suppress return flux.

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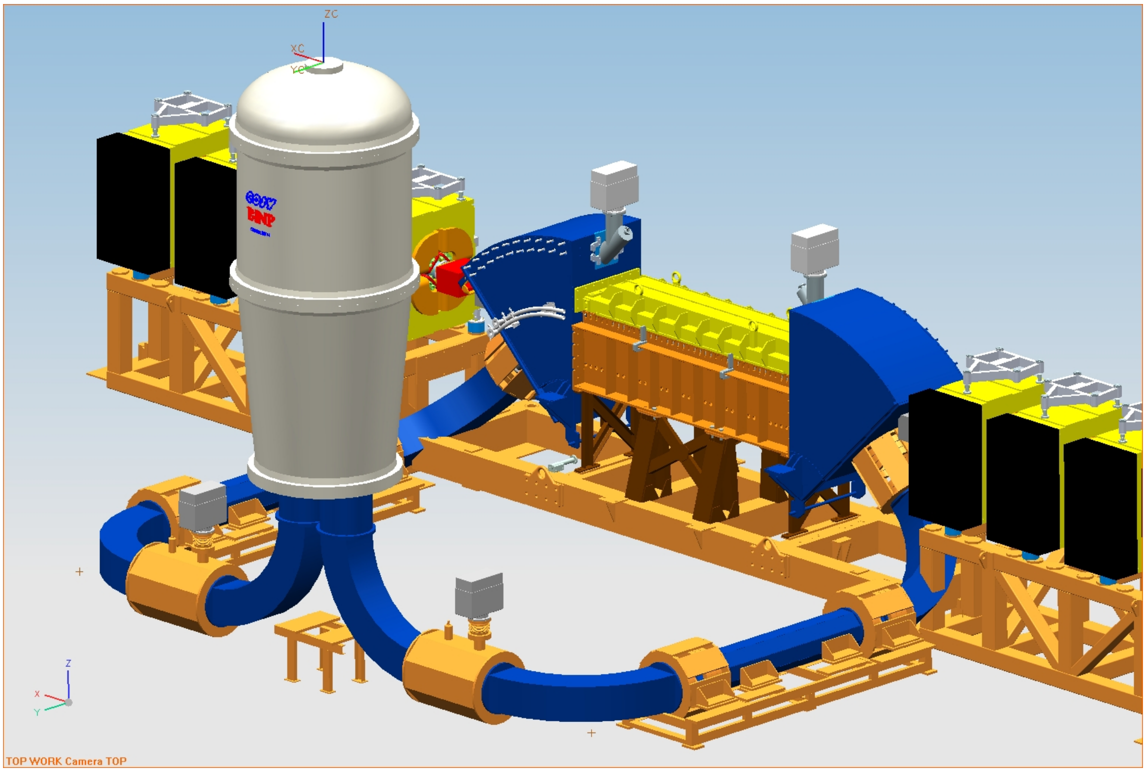

Figure 1: Layout of the 2 MeV electron cooler for COSY.

MAIN COMPONENTS

For the last few years the COSY-BINP collaboration was studying prototype elements for the magnetized cooler. The turbine electro generator driven by compressed gas feeding magnet coils along the HV column was tested. For the 2 MeV electron cooler a cascade transformer is proposed to power components at high potential. This approach benefits from the experience with ELV-8 industrial accelerator technology. It also provides necessary power for the collector. The operation range of the 2 MeV cooler is very broad from 24 keV to 2 MeV. In this case the electron optics of the accelerating tube should be very flexible. So, the continuous longitudinal magnetic field is preferable. The generation of such field demands the large number of independent solenoid coils located in each section. The solution based on a cascade transformer is expected to be more reliable because such a transformer does not contain any moving parts. For this reason the reliability of this design depends on electrical strength only. However, the cascade transformer design also has disadvantages. An issue inherent to all cascade solutions (e.g. cascade generator) is related to power transfer efficiency. The total power consumed by all sections is passed through the first one. That is why the power efficiency of the section should be extremely high in order to keep the power losses reasonable. Moreover, the required number of HV sections appears to be close to the upper limit for such systems. For 4 or 8 MeV electron cooler with lowest electron energy of about 500 keV it is possible to use smaller number of optic elements (e.g. Fermilab cooler [5] or Swedish project [6]). In this case the gas turbine has some advantages because it can be easily installed in any place of the accelerating column without complicated system of shafts. Absence of shafts and high operation frequency of the turbines (above typical mechanical resonance) makes the issues related to mechanical vibration less pronounced. This regime of the cooler operation can be easily checked with the 2 MeV COSY cooler. Turning off some power supplies of the coils in any section allows simulating the electron optics for the different regime of cooler operation, as the accelerating tube having smooth magnetic field or with some variation of it. For higher electron energies the concept of turbines will be further developed.

The power supply for the modular high voltage sections, high voltage terminal and collector consists of 34 high frequency (20 kHz) transformers with cascaded connection. The transformer column and a prototype of one section are shown in Fig. 2 and Fig. 3. The main problem of such a design is leakage of the magnetic field from the transformer that can however be resolved by adding compensative capacitors. The transformer column has a spark-gap system for safety in case of gas breakdown.

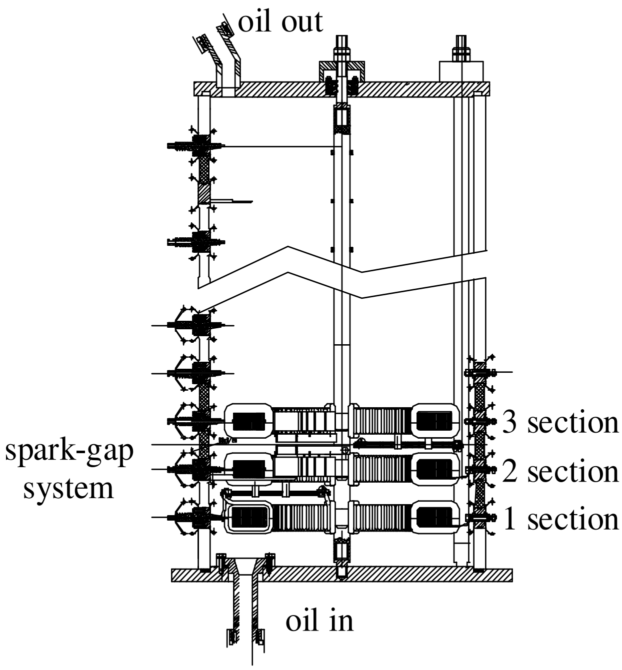

Figure 2: Transformer column.

The inner diameter of a transformer section is 20 cm, the outer diameter - 28 cm and the height 2 cm. The design value of energy-transfer power amounts to 40 kW. Oil is used as isolation and cooling medium.

Measurements of the transverse components of the magnetic field is intended to be carried out by a probe similar to the one described in [7]. The probe consists of a ferromagnetic rod and a mirror attached to it whose plane is perpendicular to the solenoidal field. This unit is installed into a gimbal that allows the magnetic body to align itself along the magnetic field lines. The sensor is mounted on a cart that can be moved along the solenoid axis. A laser beam directed along the axis of the vacuum chamber is reflected by the mirror to a position sensitive photo detector. A signal proportional to the displacement of the laser spot controls the current in corrector coils surrounding the vacuum chamber. These currents produce magnetic fields compensating the transverse components of the magnetic field. As a result the laser spot moves to the detector center and values of the transverse field components are determined from current values in compensating coils.

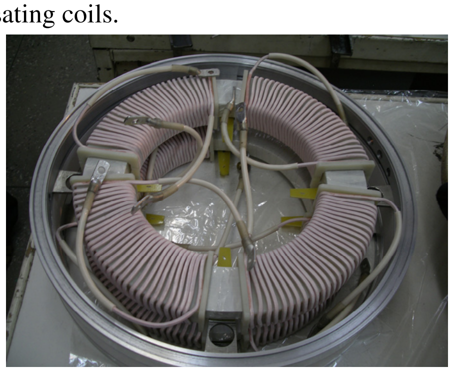

Figure 3: Prototype of the transformer section.

BEAM DIAGNOSTICS

For measurement of the electron beam position 10 pickups (5 in the beam line from gun to the cooling section and 5 from cooling section to collector) are foreseen. 2 pickups will be placed at the entrance and at the exit of the cooling section for measuring the proton as well as the electron beam position (Fig. 4). The last two ones have a special design due to the fact that the in situ magnetic field measurement needs space for the magnetic sensor which is mounted on the cart that can be moved along the solenoid axis. Each pickup consists of 4 sectors. To study the dynamics of electron cooling in a synchrotron only non-destructive instrumentation can be used. Beam diagnostics based on recombination is usually used to optimize electron cooling of protons (H^0-diagnostics). In the future HESR ring, however, this technique is not applicable due to antiprotons being accelerated. An Ionisation Profile Monitor delivers real time data in both transverse planes allowing detailed analysis of beam profile evolution in COSY. Attempts to use scintillation of residual gas to measure beam profiles were very promising. So ionisation and possibly scintillation profile monitors become vital for optimization of electron cooling of antiprotons. The IPM was designed at GSI keeping the requirements for the future FAIR machines in mind [8]. The ionisation products are guided to a position sensitive detector by transverse electric field. An arrangement consisting of an MCP stack (100x48 mm^2), a luminescent screen, and a 656×494 pixel CCD camera is used to detect ions in high resolution mode. The IPM actually contains two identical units to provide simultaneous measurements in both, horizontal and vertical, planes. The IPM is installed in COSY in the arc downstream of the cooler telescope. The data acquisition software was developed at FZJ with an emphasis on real-time display of beam profiles. The software also performs fitting and plots beam width and position vs. time. The beam current measured by the beam current transformer (BCT) is also displayed. A Scintillation Profile Monitor (SPM) is being developed at COSY as a robust and inexpensive alternative to the IPM. The disadvantage of much lower event rate compared to the IPM and thus the necessity to locally add nitrogen to the residual gas is compensated by the much simpler mechanical design of the SPM. The light emitted by the gas in the vacuum chamber is focused by a lens onto a multichannel photomultiplier (PMT) array (Hamamatsu 7260-type, 32 channels, 0.8·7 mm photocathode, 1 mm pitch). The readout is performed using a multichannel current digitizer, developed at iThemba LABS [9]. A method using Thomson scattering is proposed to measure the electron beam profile in the cooling section [10].

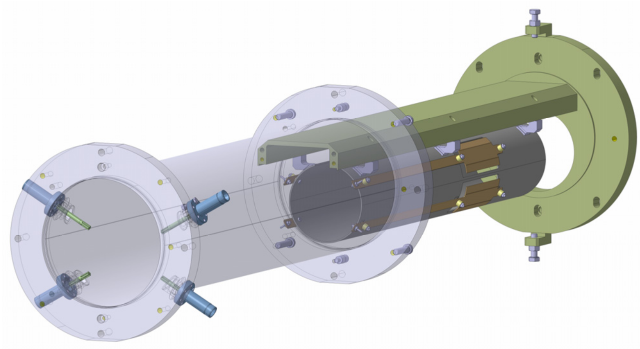

Figure 4: Prototype of the Beam Position Monitor in the cooling section.

Figure 5: High voltage vessel in BINP Novosibirsk.

SUMMARY

The 2 MeV electron cooler is under construction. The cooler components are being manufactured at BINP, Novosibirsk. The pressure vessel is now available at BINP (Fig.5). A second vessel is now under construction in Germany due to certification issues with the German TUV (Technical Inspection Agency). The HV system is modular. It is based on a resonant cascade transformer providing power to multiple HV sections at different electrical potential. A Wien filter is intended to improve collector efficiency. Since the straightness of magnetic field in the cooling section needs to be better than 10^{-5} a in-situ magnetic field measurement system is being built as well. The system will allow verification of magnetic field quality without disassembling the magnetic system or breaking vacuum. Diagnostic tools for optimisation of the electron cooling system are developed and tested. The production of the main components in the BINP workshop as magnet system, acceleration tubes, high voltage section and cascade transformer is on the way. Modifications to the COSY ring itself and its infrastructure to make space available for the cooler are in progress. Changing cabling and replacement and installing new cooling water pipes are finished.

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