2 MEV ELECTRON COOLER FOR COSY AND HESR – FIRST RESULTS

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Abstract

The 2 MeV electron cooler was installed in the COSY ring in 2013. The new system enables electron cooling in the whole energy range of COSY. The electron beam is guided by a longitudinal magnetic field all the way from the electron gun to the collector. This well-proven optics scheme was chosen because of the wide electron energy range of 0.025-2 MeV. The electrostatic accelerator consists of 33 individual sections of identical design. The electrical power to each section is provided by a cascade transformer. Electron beam commissioning and first studies using proton and deuteron beams were carried out. Electron cooling of proton beam up to 1670 MeV kinetic energy was demonstrated. The maximum electron beam energy achieved so far amounted to 1.25 MeV. A voltage up to 1.6 MV was demonstrated. The cooler was operated with an electron current up to 0.5 A. The paper provides insights into the recent progress in high energy electron cooling at COSY and perspectives for the HESR ring at FAIR.

INTRODUCTION

The 2 MeV cooler at COSY is the first device utilizing the idea of magnetized cooling in this energy range, being an important step towards relativistic electron cooling required for the HESR at FAIR [1]. Furthermore, it has been shown, that the 2 MeV cooler, if installed in the HESR, can be used without changes for the heavy ion operation modes [2,3].

The construction of the 2 MeV electron cooler for COSY began at the Budker Institute of Nuclear Physics (BINP) in 2009 and ended 2012. In spring 2013 the cooler was installed in the COSY ring. First beam cooling results were obtained in October 2013 by the joint BINP-COSY team. Further beam cooling experiments followed during a two-week period of dedicated beam time beginning of 2014. At that time a first attempt to use electron and stochastic cooling in the same machine cycle was made. Furthermore, electron cooling of proton/deuteron beam into a barrier bucket was demonstrated. The design of the cooler and its main parameters are described in [4,5].

EXPERIMENTAL RESULTS

Table 1 summarizes the electron and proton beam parameters during the recent cooling experiments. The experimental results presented below are for a dc proton beam unless otherwise noted. Beam width and bunch length are rms values.

Table 1: Beam Parameters used for Cooling

Proton energy, MeV	Electron energy, keV	Max. electron current, mA
200	109	500
353	192	500
580	316	300
1670	908	340

Cooling at 200 MeV

At this energy the magnetic field in the cooling section was set to 480 G. Figure 1 shows the result of transverse cooling of a dc proton beam using 200 mA electron beam at 109 keV. The number of protons in the ring was intentionally lowered to $1 \cdot 10^8$ to exclude intensity effects and to minimize the particle loss rate.

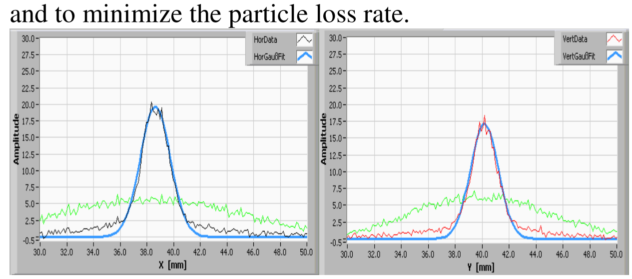

Figure 1: Horizontal and vertical profiles of the electron cooled proton beam. Profiles of an uncooled beam are shown in green, cooled beam profiles in black and red, the corresponding Gaussian fits in blue. Beam widths σ_{hor} = 1.2 mm and σ_{vert} = 1.15 mm were measured.

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The Ionization Profile Monitor (IPM) was used to acquire beam profile data in real time [6]. Figures 2 and 3 show transverse and longitudinal cooling in the same machine cycle. The cycle duration was set to 514 s. At t = 30 s in the cycle (flat top) the electron current was ramped up to 200 mA causing the beam to shrink transversally and longitudinally. At this energy cooling was also accompanied by significant beam losses.

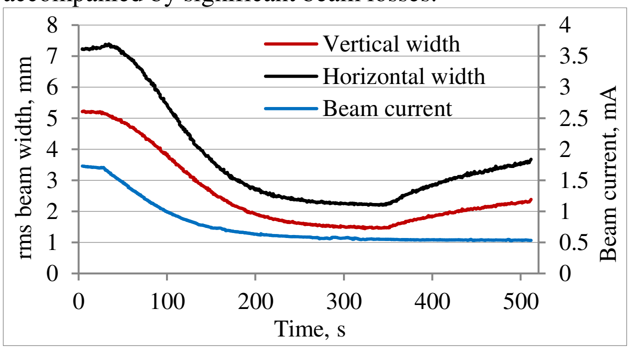

Figure 2: Evolution of horizontal and vertical beam width and beam current. The 200 mA electron beam was turned on at t = 30 s and turned off at t = 350 s.

In the middle of the machine cycle about $4 \cdot 10^9$ particles remained in the ring. After the e-beam was turned off at t = 350 s, the proton beam size as well as the width of the longitudinal spectra increased again due to intra-beam scattering. In contrast to the initial cooling the beam can be cooled again (not shown in Figures 2 and 3) without losses. A standard COSY beam position monitor was used to measure the Schottky spectra [7].

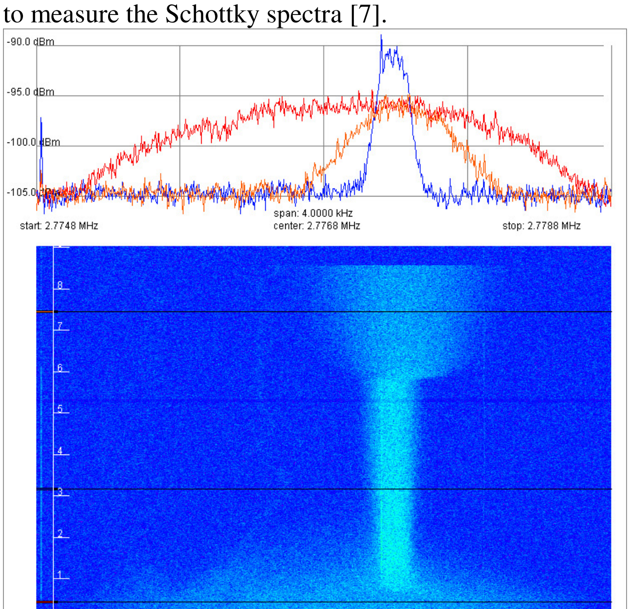

Figure 3: Evolution of the longitudinal Schottky spectra. The 200 mA electron beam was turned on at t = 30 s and turned off at t = 350 s. The upper plot shows the spectra of the uncooled (red) and cooled (blue) beam and a spectrum after the e-current was turned off (orange). Black lines represent the corresponding time markers in the spectrogram (lower plot). Time scale in minutes is shown on the left edge of the spectrogram.

Figure 4 shows the effect of electron cooling of bunched beam on bunch length. After finishing acceleration the RF amplitude was reduced to about 100 V.
Cooling with 200 mA resulted in equilibrium bunch length of 27 ns.

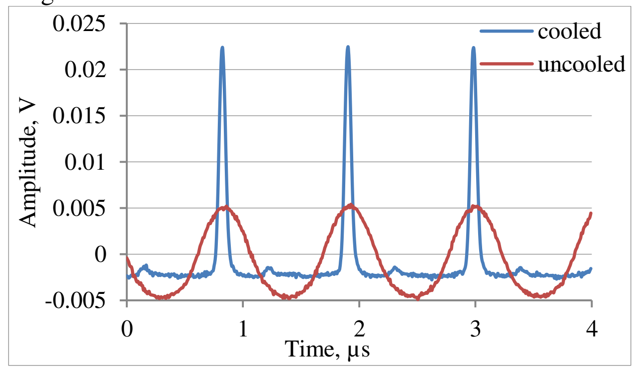

Figure 4: Proton bunch shortening during electron cooling with 200 mA. Shown are the bunch shapes for the cooled and uncooled proton beam as reported by the bunch phase monitor [8].

Cooling at 1670 MeV

At 1670 MeV the magnetic field in the cooling section was set to 1.3 kG.

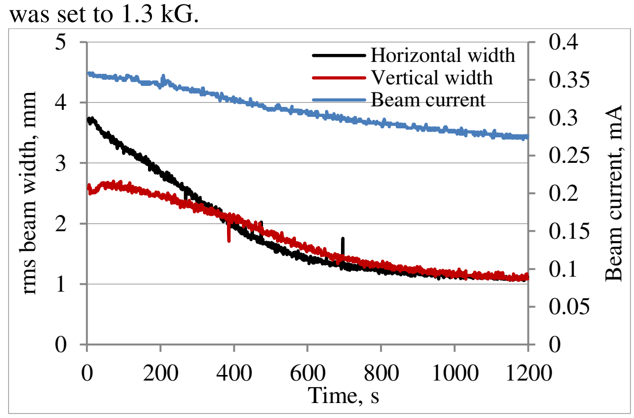

Figure 5: Evolution of the beam width and proton beam current during electron cooling with 320 mA.

In addition to Figure 5 showing the effect of electron cooling on transverse beam size, the effect of precooling using the stochastic cooling system is shown in Fig. 6.

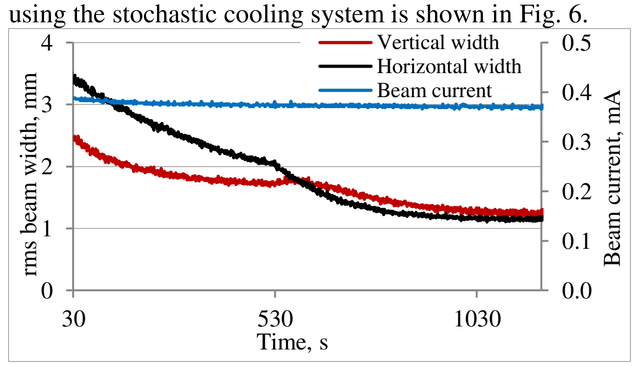

Figure 6: Evolution of the beam width and beam current during transverse stochastic (first half of the machine cycle) and electron cooling with 320 mA (second half).

Hoizontal and vertical stochastic cooling was active in the first half of the machine cycle leading to a significant reduction of the transverse beam size without significant beam loss. The longitudinal behavior of the beam in the same machine cycle is shown in Fig. 7. One can see that the beam becomes wider due to the absence of longitudinal cooling in the beginning. Fast cooling of the beam core and somewhat slower cooling of the tails of the distribution has been observed after electron cooling was turned on at t = 2 min.

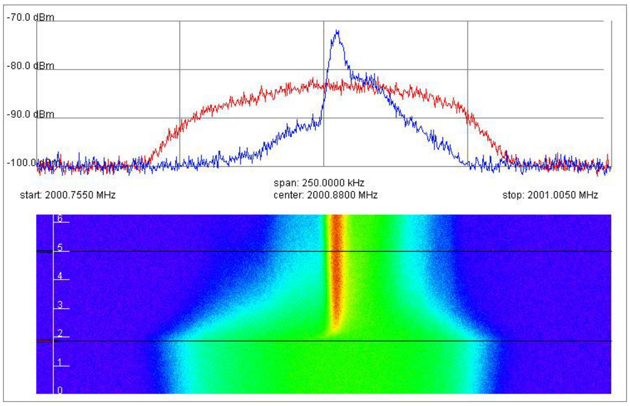

Figure 7: Longitudinal electron cooling of proton beam at 1670 MeV. A pickup of the stochastic cooling system was used to measure the Schottky spectra [9]. Only a part of the machine cycle is shown. Transverse stochastic cooling was active until t = 2 min, after that electron cooling was turned on. In the upper plot the red curve corresponds to the longitudinally uncooled beam while the blue one shows the spectrum of the cooled beam.

Figure 8 shows the reduction of bunch length as a result of electron cooling. A bunch length of about 8 ns was demonstrated.

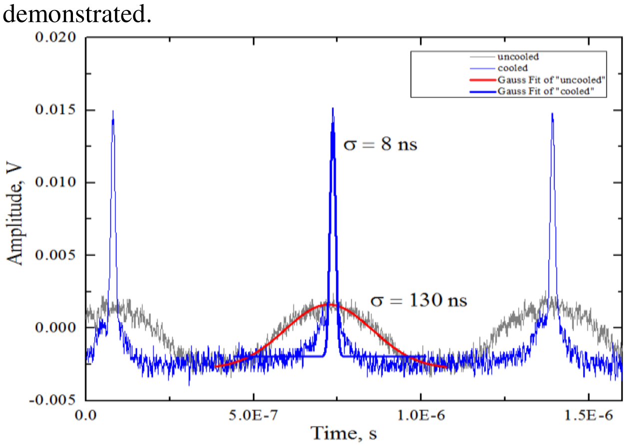

Figure 8: Electron cooling of bunched proton beam at 1670 MeV. Shown are the bunch shapes for the cooled and uncooled proton beam as reported by the bunch phase monitor.

CONCLUSION

The 2 MeV electron cooler is being put into operation at COSY. A first series of experiments were carried out by the joint BINP-COSY team. Electron cooling of a proton beam up to 1670 MeV corresponding to 908 keV electron energy was demonstrated. The maximum electron beam energy achieved so far was 1.25 MeV. A high voltage up to 1.6 MV was obtained. Cooling of a deuteron beam at low energy was successful. Cooling into a barrier bucket as well as simultaneous electron and stochastic cooling was successfully demonstrated. The first impression is that the overall cooling time becomes shorter; the two systems however, need to be carefully matched. The emphasis of the recent experiments was put on the cooler hardware. The interaction of the cooler with the machine, in particular the cooling rates will be studied in detail during the upcoming dedicated beam time. The data obtained so far suggests a more favourable scaling of the cooling time with energy as compared to the $\beta^4\gamma^5$ scaling [1]. At low energy a significant beam loss was observed during the cooling process, similar to the losses typically observed using the 100 kV cooler [10]. At higher energies the losses are much less pronounced. The loss mechanism has to be investigated in more detail. The current straightness of the magnetic field in the cooling section of about $2{\cdot}10^{-4}$ can be improved by about one order of magnitude. This work is scheduled for the upcoming maintenance period in summer 2014. This is expected to improve the cooling performance at high energies. The recently developed software includes an automated correction of uncompensated transverse kicks, the electron beam experiences when passing the bent sections of the transport line. This is the first step towards a model based operation of the cooler.

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