ELECTRON COOLING AT GSI AND FAIR - STATUS AND LATEST ACTIVITIES

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Abstract

The status, function and operation parameters of the existing and future electron coolers at GSI and FAIR are presented. We report on the progress of the ongoing recommissioning of the former CRYRING storage ring with its electron cooler at GSI. First systematic results on the cooling of a 400 MeV proton beam during the last ESR beamtime are discussed. Motivated by the demands of the experiments on high stability, precise monitoring and even absolute determination of the velocity of the electrons i.e. the velocity of the electron- cooled ion beams, high precision measurements on the electron cooler voltage at the ESR were carried out towards the refurbishment of the main high-voltage supply of the cooler. Similar concepts are underway for the CRYRING cooler high-voltage system.

INTRODUCTION

Following machines with electron coolers are available at GSI (Table 1) or foreseen within the FAIR project:

- SIS18 (18 Tm, electron cooling), in operation [1]: accumulation of stable ions.
- ESR (10 Tm, stochastic and electron cooling, internal target), in operation [1]: accumulation, storage, deceleration, experiments with stable ions / rare isotope beams (RIB).
- CRYRING (1.44 Tm, electron cooling), under installation and commissioning: storage, deceleration, experiments with stable ions/RIB (also antiprotons as a future option).

Table 1: Basic Operation Parameters of the Electron Coolers at GSI. Typical values are in brackets.

Parameter	SIS18	ESR	CRYRING
main HV power supply (kV)	≤ 35	≤ 320	≤ 20
e^- energy/HV (kV)	[≤ 7]	[2-220]	[≤ 8]
e^- current (A)	[0-1.5]	[0-1]	[0-0.15]
gun perveance (μperv)	2.9	2	1.68
cathode diameter (inch)	1	2	0.16
adiab. exp. factor	1-8	1	10-100
guiding B field (T)		[0.02-0.1]	
in gun	≤ 0.4 [0.18]		≤ 4 [3]
in cool. section	≤ 0.15 [0.06]		≤ 0.3 [0.03]
cool. section length/eff. (m)	3.4/2.8	2.5/1.8	1.1/
ring circumference (m)	216	108	54
vacuum (mbar)	10^{-11}	10^{-12}-10^{-11}	10^{-12}-10^{-11}

CRYRING AND ITS ELECTRON COOLER

Initially, CRYRING was the designated storage ring for FLAIR [2]. It was moved into a cave behind the ESR [3] to benefit from an earlier realisation of a working machine for ions. Activities concentrate around this CRYRING@ESR project as it also serves as a test bench for FAIR developments (control system, beam diagnostics, vacuum etc.).

CRYING@ESR is dedicated to low-energy experiments with highly-charged heavy ions like collision spectroscopy at the electron cooler, a transverse electron target and a laser spectroscopy setup [4]. The electron cooler is the most important device for preparation of (decelerated) stored beams and most experiments. In particular, for electron-ion recombination studies: (i) The adiabatic magnetic expansion by a factor 100 offers a transversally very cold electron beam with $k_BT_\perp = 1.5 - 3.5$ meV [5, 6] (compared to $k_BT_\perp \approx$ 200 meV in the ESR). The expected longitudinal electron beam temperature $k_BT_\parallel = 0.05 - 0.20$ meV is as usual determined by the longitudinal-longitudinal relaxation. (ii) The electron beam energy has to be ramped in a small range around the nominal electron energy which is matched to the ion velocity. Fast and precise ramping of the cooler voltage will be realised by a special HV amplifier in the range ± 2 kV installed on the HV platform [4].

In 2015 considerable efforts were made to rebuild the CRYRING machine and provide the associated infrastructure (Fig. 1). In parallel, the cooler had to undergo repairs because of damage to the gun toroid vacuum chamber, which occured after the transport from Sweden (complete disman-

Figure 1: CRYRING in the cave behind the ESR.

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tling of the cooler gun side was necessary for welding purposes). Refurbishments were also made to cabling, cooling water circuits and to the vacuum system by adding gauges and some new heating jackets. After successful leak test the cooler was moved to its final position inside the cave (Fig. 2). Many tasks still remain, like cabling of the magnets, cabling of the HV system and the isolation transformer that powers the components on the HV platform, preparation of control software and the installation of a cryogenic He transfer line for easy handling and fast refilling of the superconducting gun solenoid.

Figure 2: CRYRING cooler in the cave.

According to the current time table, vacuum pumping and commissioning of the ring without beam starts at the end of 2015. First-turn commissioning of the ring with light ions from an internal ion source [4] will take place in 2016. First standalone operation of the cooler with electron beam is scheduled for early 2016.

RECENT ESR COOLER OPERATION

During the beam time in 2014 several machine development experiments were carried out. The feasibility of a possible future use of the ESR in a chain of decelerators for antiprotons at FAIR has been investigated. Both stochastic and electron cooling systems at the ESR were used to cool a proton beam at 400 MeV. For 10^8 protons with an initial rms momentum spread of $4 \cdot 10^{-4}$ the longitudinal damping

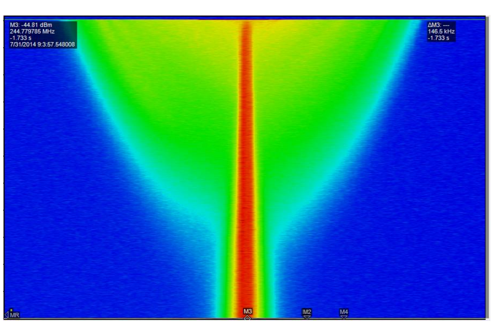

Figure 3: Longitudinal electron cooling of a 400 MeV proton beam with an electron beam current of 0.25 A in the ESR. Frequency spectrum measured with the resonant Shottky pickup [7] at 245 MHz (125th harmonic), span=200 kHz, total recording time = 650 s. The momentum spread was reduced from $4 \cdot 10^{-4}$ down to $3 \cdot 10^{-5}$ in 7 min.

time was about 8 s for stochastic cooling with the notch filter method. As expected, for electron cooling, the damping time was much longer i.e. 600 s for protons at the edge of the initial momentum distribution with 0.25 A electron current (Fig. 3). On the other hand, the final rms momentum spread reached with electron cooling was $2 - 3 \cdot 10^{-5}$ compared to $1 - 2 \cdot 10^{-4}$ with stochastic cooling.

At high beam phase space density, Schottky signal suppresion due to collective effects is expected [8]. This effect was demonstrated during strong electron cooling of a high-intensity proton beam at 400 MeV (Fig. 4). For stochastic cooling with the notch filter, the longitudinal damping time for 10^9 protons was about 15 s, whereas Schottky signal suppression was not observed.

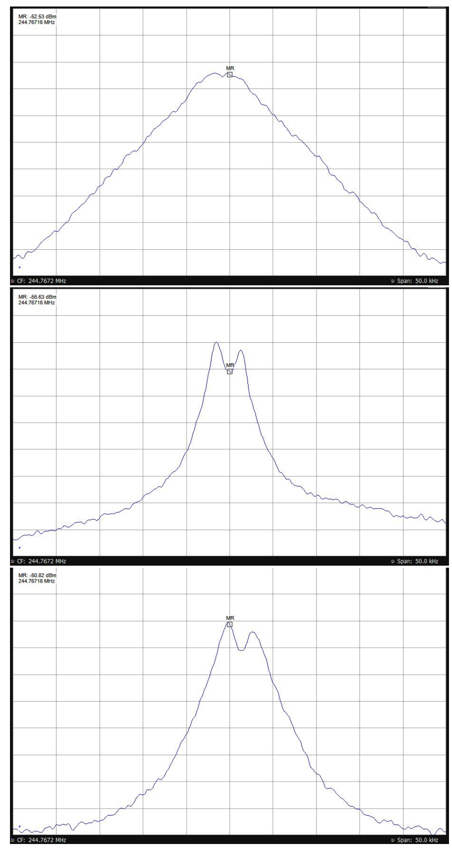

Figure 4: Schottky signal suppression (double peak structure, reduction of total integrated noise power) appearing in the momentum distribution of a beam of $1.3 \cdot 10^9$ protons with increasing electron cooler current; top: 100 mA, middle: 250 mA, bottom: 500 mA. Frequency spectra from the resonant Schottky pickup at 245 MHz, span=50 kHz.

HV MEASUREMENTS AT THE ESR COOLER

The versatile operation of the ESR cooler relies on the high stability of the velocity of the electron-cooled ion beams, realised by an adjustable, highly-stable (within ±1 V) accelerating voltage for the electron beam within an operation range of 2-220 kV. This is achieved with the main DC HV power supply of the cooler, which is a -320 kV device in a pressurized vessel filled with SF_6 gas.

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Experiments, like the laser spectroscopy of Bi ions and the precise energy matching to the HITRAP decelerating linac [9] demand absolute determination and the continuous precise monitoring of the applied HV accelerating the electron beam.

Before the last beam time in 2014, the HV power supply was serviced at the manufacturer site for correction of minor voltage instability and renewal of the SF_6 system. It was then transported to the german National Metrology Institute Physikalisch-Technische Bundesanstalt (PTB) for HV calibration. Unfortunately, the device was seriously damaged during transport, had to be refurbished again at the manufacturer site and was delivered back to GSI. To avoid more damage by transport an alternative concept was applied: a portable highly-precise HV divider callibrated against the PTB standards was used for real-time monitoring of the output of the HV power supply of the cooler.

A $^{209}Bi^{82+}$ beam at 390 MeV/u was used in a laser spectroscopy experiment of the hyperfine transition of hydrogen-like bismuth [10]. This was achieved by monitoring the applied voltage to the cooler with a calibrated HV divider. To meet the demands of the experiment, the PTB provided a high precision voltage normal. This voltage divider HVDC2.1 (Fig. 5 - top) featured a relative accuracy of $1.3 \cdot 10^{-5}$ in the Bi experiment performed at 214 kV cooler voltage [10, 11]. This increased the measurement accuracy compared to former beam times when the relative accuracy was below 10^{-4} [12] . Thus, it was found that the output voltage of the HV power supply showed significant variations over time: ±20 V (or even more) at 200 kV. This was independently confirmed in the longitudinal Schottky spectra of the ion beam (Fig. 6). With the high-precision HV divider the variations could be recorded online and were taken into account in the data during offline analysis.

The large variations of the output voltage resulted from damage to HV diodes and HV resistors in the output divider inside the HV power supply. The power supply had to be repaired again by the manufacturer on the GSI site (to avoid transportation risks). Since then, it has recovered its value of relative stability and operates as specified.

OUTLOOK

In the near future, it is foreseen to have a dedicated HV divider for experiments. This divider has aleady been tested and calibrated against the national standards of the PTB (Fig.5 - bottom).

In consideration of a prolonged operation of the ESR until 2030 a replacement for the main HV power supply (manufactured in 1988) will be needed.

Similar concepts are foreseen for the low-energy range (<20 kV), both at the ESR and the CRYRING coolers: a calibrated precise (≤ 1ppm) HV divider up to 20 kV based on the established PTB/KATRIN technology [4, 13, 14] will be implemented in their high voltage systems.

Figure 5: The Faraday room of the electron cooler. Top: The -320 kV power supply is shown on the left and the HV platform on the right. The HVDC2.1 200 kV (2 GΩ) DC HV divider (property of the PTB) is installed (in orange). Bottom: The Ohmlabs HVS 250 kV (250 MΩ) DC HV divider (property of the TU Darmstadt) specified for 10^{-4} precision is installed. The isolating transformer (in grey) powering the HV platform is seen in the back.

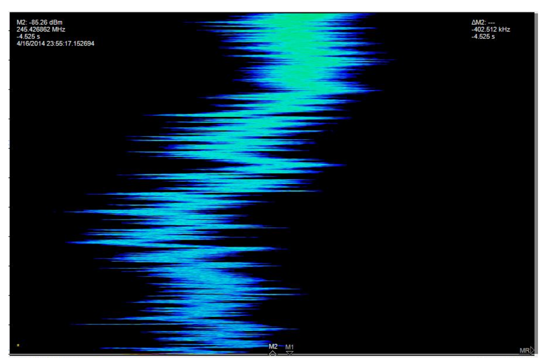

Figure 6: The instability of the electron cooler voltage observed in the longitudinal spectrum of the beam in the ESR. Frequency variation of ± 5 kHz around 245 MHz (span =20 kHz) corresponding to $\Delta V/V = \pm 10^{-4}$ i.e. ± 20 V at 200 kV for the cooler voltage. Total recording time= 90 min.

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