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LEIR ELECTRON COOLER STATUS

G. Tranquille, A. Bubley[1)], V. Parkhomchuk[1)], V. Prieto, R. Sautier

CERN, Geneva, Switzerland

Abstract

The electron cooler for LEIR is the first of a new generation of coolers being commissioned for fast phase space cooling of ion beams in storage rings. It is a stateof- the-art cooler incorporating all the recent developments in electron cooling technology (adiabatic expansion, electrostatic bend, variable density electron beam…) and is designed to deliver up to 600 mA of electron current for the cooling and stacking of Pb54+ ions in the frame of the ions for LHC project. In this paper we present our experience with the commissioning of the new device as well as the first results of ion beam cooling with a high-intensity variable-density electron beam.

1) BINP, Novosibirsk, Russia

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V. Prieto, R. Sautier, G. Tranquille, CERN, Geneva, Switzerland
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INTRODUCTION

The LHC program foresees lead-lead collisions in the spring of 2008 with luminosity up to 10^{27} $cm^{-2}s^{-1}$. Following a series of tests in 1997 [1], the Low Energy Ion Ring (LEIR) has undergone a major upgrade in order to prepare these dense bunches of lead ions by the transformation of ion beam pulses from the LINAC3 into short high-brightness bunches using multi-turn injection, cooling and accumulation.

The electron cooler plays an essential role in producing the required beam brightness by rapidly cooling down the newly injected beam and then dragging it to the stack. The device was built in collaboration with the Budker Institute for Nuclear Physics (BINP) in Novosibirsk, Russia and was delivered to CERN at the end of 2004. Vacuum preparation and mechanical modifications for the definite installation in the LEIR ring were made in the first half of 2005, followed by a short period dedicated to the hardware commissioning of the cooler.

ELECTRON COOLER COMMISSIONING

Hardware commissioning of the electron cooler concentrated on ensuring the vacuum compatibility of the new device as well as exploring the performance limits. The main parameters of the cooler have been given in previous papers [2]. Two operational regimes can be used depending on the momentum of the ions to be cooled. If the small normalized emittances required cannot be reached at injection energy e.g. due to direct space charge detuning, operation of the cooler at the extraction energy will be necessary. In this scenario (unlikely for Pb ion operation, but a possible option for an eventual later upgrade to lighter ions), the LEIR magnetic cycle must contain an additional plateau at a suitable higher energy.

Vacuum Tests

The materials used for the cooler construction (316LN stainless steel vacuum chambers, CF flanges, hydroformed bellows, high-voltage feedthroughs) were specifically chosen to meet the stringent vacuum requirements of LEIR [3]. Upon reception from BINP, all the vacuum elements were sent for cleaning following CERN standard procedures. Specially designed NEG cartridges were installed at the gun exit and the collector entrance where the gas load is the highest. In addition, NEG cartridges were placed in the toroid chambers and the vacuum chamber of the drift tube where the ions are cooled by the electrons was NEG coated.

The bakeout of the cooler is necessary in order to obtain a static vacuum in the low 10^{-12} torr range. All vacuum elements are heated to temperatures between 100°C and 300°C over a period of a few days and the NEG elements (vacuum chamber coating and cartridges placed in the toroids and gun and collector entrances) are activated towards the end of cycle by heating to 700°C for 2 hours. During the bakeout the cathode of the electron gun is also outgassed and activated. Unfortunately after the first bakeout a leak was detected on one of the gun ceramics and the measured pressure was an order of magnitude greater than what is needed. After the installation of a differential pumping system around the gun, the pressure level decreased to a more acceptable level of $6x10^{-12}$ torr.

Magnetic Field Adjustment

The longitudinal guiding field is created by three sets of series-connected “pancake” coils: (i) the cooling section, (ii) the 40° and 50° toroids, and (iii) the gun and collector solenoids. The series connection of the gun and collector solenoids provides a stable beam size at entrance to the collector. This field value is kept relatively high (0.235 T) also because of the high-perveance gun which requires a strong confinement of the dense electron beam as it is accelerated to the desired energy. However, the vertical component of the magnetic field in the toroids induces a horizontal kick on the ion beam and therefore the maximum operational field in the toroids and the cooling section is 0.075 T. The ratio of the currents in the cooling section solenoid and the gun solenoid is used to control the electron beam size in the cooling zone. The magnetic field in the toroids provides the matching of fields in the gun region and the cooling section.

Independent of the gun requirements, a high magnetic field is welcome for improving the cooling process but the transverse component $B_\perp$ must be kept very small so that the ratio $B_\perp/B$ never exceeds 10^{-4} all along the electron trajectory in the drift solenoid. To achieve this field quality, careful tuning of the field correction coils and mechanical adjustment of the “pancake” structure of the drift solenoid were made before the final installation in LEIR (Figure 1).

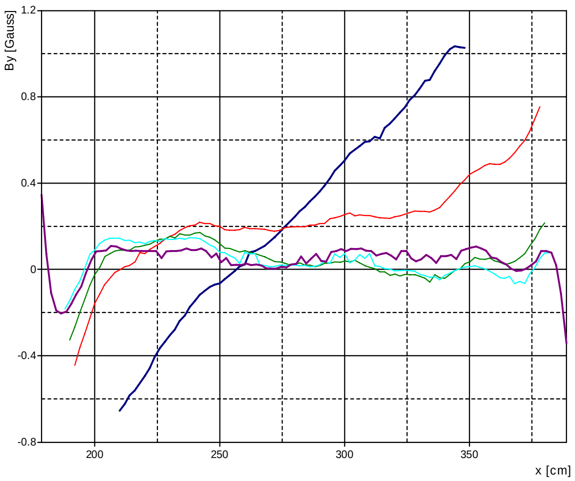

Figure 1: Adjustment of the cooler solenoid for the optimisation of the vertical field component of. Five iterations (blue trace to magenta trace) were needed to reduce B_y/B to 10^{-4} (for B = 1000 G).

Gun Characteristics

The high perveance gun provides an intense electron beam in order to decrease the cooling rate. However, in theory, increasing the electron density induces first an increase of the recombination rate (capture by the ion of an electron from the cooler), which is detrimental to the ion beam lifetime, and secondly increases the electron azimuthal drift velocity, thus increasing the cooling time. To combat the increase in electron-ion recombination, the electron gun has a “control electrode” used to vary the density distribution of the electron beam. The beam profile is adjusted in such a way that the density at the centre, where the cold stack sits, is smaller and thus the recombination rate is reduced. At larger radii, the density is large and allows efficient cooling of the injected beam executing large betatron oscillations.

Figure 2 shows the measured electron beam intensity as a function of the control to grid voltage ratio. As the control electrode voltage is increased, the electron beam distribution changes from a parabolic beam ($V_{cont} < 0.2\ V_{grid}$) to a completely hollow beam ($V_{cont} = V_{grid}$). The beam position was also measured for all the gun configurations investigated. This is done by the direct modulation of the electron intensity by a high frequency sine wave applied on the grid electrode.

ION BEAM COOLING STUDIES

The cooling of ion beams was studied in parallel with the commissioning of the LEIR ring [4]. Schottky diagnostics, ionisation profile monitors (IPM) and beam current transformers (BCT) were used to measure the phase-space cooling characteristics and to investigate the influence of the electron beam profile on the ion beam lifetime [5].

As many of the LEIR systems had to be commissioned at the same time it was difficult to obtain long cycles dedicated to electron cooling studies. Almost all our measurements were performed on the standard magnetic cycle lasting 2.4 or 3.6 seconds during which 2 or 3 Linac pulses are cooled and stacked at 4.2 MeV/u, then accelerated to 72 MeV/u before being extracted to the PS ring. The results presented in this section are therefore not direct measurements of the cooling time constant but more an indication of the capabilities of the new cooler. Systematic measurements of the cooling time will be made during the next commissioning period planned at the end of the year.

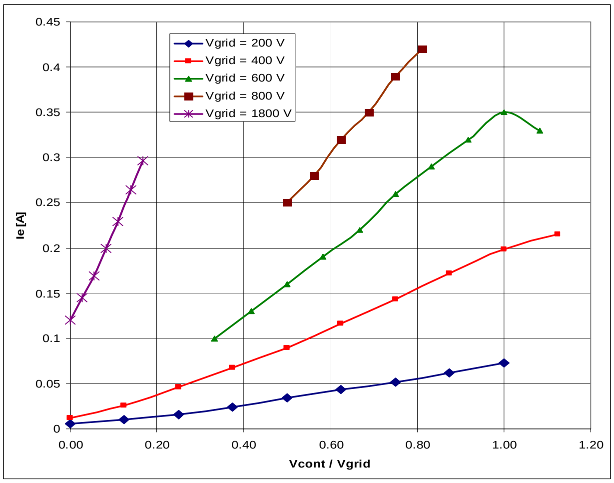

Figure 2: Electron beam current as a function of V_{cont}/V_{grid} for E_e = 2.5 keV.

Lifetime and Accumulation

In previous tests [1] the maximum accumulated intensity was a factor 2 lower than that required for the nominal LHC ion beam ($1.2\text{x}10^9$ ions). This was in part attributed to a short lifetime due to the recombination of ions with the cooling electrons and also to the limited electron current that could be obtained for effective cooling with the old electron gun. In our measurements intensities well above $1.2\text{x}10^9$ ions could easily be accumulated with an injection repetition rate of 1.6 Hz and an electron current of 110 mA. If the repetition rate is increased, the maximum number of stacked ions decreases proportionally for the same electron current.

The lifetime of the circulating beam was also compared for a parabolic and a hollow electron beam distribution (Figure 3). From the plot we see that the beam distribution does not significantly influence the lifetime indicating that recombination may not be after all the main cause of the short lifetime measured in the 1997 tests. Other processes related to the vacuum conditions or the injection scheme could be more dominant.

Longitudinal and Transverse Cooling

The combined longitudinal and transverse multi-turn injection scheme used in LEIR means that the electron cooler has to cool the newly injected beam in all three planes and then drag it to the stack position with a momentum offset. This cycle is repeated a number of times after which the electron energy is stepped up to position the beam at the right frequency for acceleration to the ejection energy. In order to perform these manipulations all the high voltage power supplies are controlled by function generators. The electron beam energy, intensity and profile can therefore be programmed not only between magnetic cycles but also during the cycle.

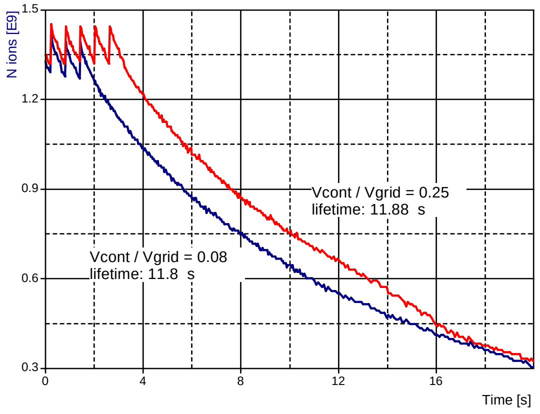

Figure 3: Beam lifetime for a parabolic (blue) and hollow (red) electron beam distribution.

Figure 4 shows the evolution of the longitudinal Schottky distribution during the injection/stacking process. The initial momentum spread (typically 4x10^{-3}) is rapidly reduced to less than 10^{-4} by electron cooling and then is dragged to the stack momentum, 2‰ lower than the nominal momentum. After the second injection the electron energy is ramped up such that the stack and the new beam are cooled at the nominal momentum at which the beam will be bunched and accelerated.

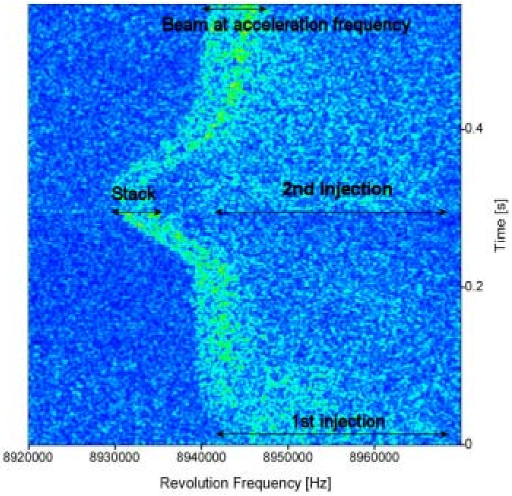

Figure 4: Longitudinal Schottky evolution showing the cooling and stacking of two injections of Pb ions.

During this time the transverse beam dimensions are also electron cooled in order to maximise the space available for any subsequent injections. Figure 5 shows the horizontal beam size measured by the IPM during the whole LEIR cycle. As the cooling progresses the beam emittance is reduced by more than a factor of 30. After acceleration to the extraction energy the measured emittance was typically 0.4 µm, well within the 0.7 µm needed for the LHC beam. Some measurements on the transverse cooling as a function of parameters such as beam size, "hollowness" and intensity were made, but the emphasis was on the optimisation the cooling process with respect to the injection scheme

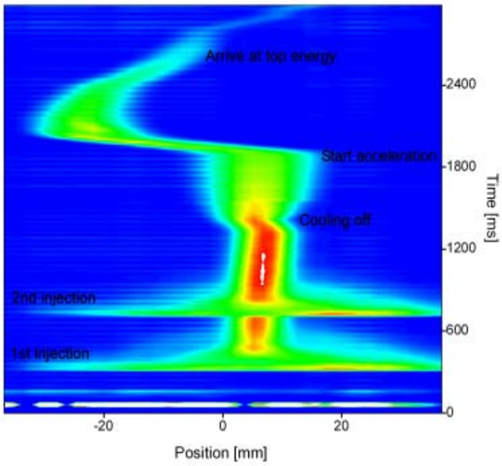

Figure 5: Horizontal cooling observed on the ionisation profile monitor.

CONCLUSIONS

The new electron cooler for LEIR has been successfully integrated in the LEIR environment and commissioned. It has been used routinely for the LEIR ring commissioning with O^{4+} and Pb^{54+} ions where its role has been central in obtaining the Pb ion beam characteristics required for the first LHC ion run planned for 2008. Clear indications of the usefulness of high-intensity electron beams with variable density distributions for effective beam cooling have been observed, but a more systematic study of the influence of the different variables on the cooling performance still needs to be done.

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