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LEIR COMMISSIONING

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The Low Energy Ion Ring (LEIR) is a central piece of the injector chain for LHC ion operation, transforming long Linac 3 pulses into high density bunches needed for LHC. LEIR commissioning is scheduled to be completed at the time of the conference. A review of LEIR commissioning highlighting expected and unexpected problems and actions to tackle them will be given.

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The Low Energy Ion Ring (LEIR) is a central piece of the injector chain for LHC ion operation, transforming long Linac 3 pulses into high density bunches needed for LHC. LEIR commissioning is scheduled to be completed at the time of the conference. A review of LEIR commissioning highlighting expected and unexpected problems and actions to tackle them will be given.

INTRODUCTION

The LHC [1,2], presently in construction at CERN will, in addition to proton operation, provide Pb ion collisions. The ion accelerator chain existing before the LHC era was by far not sufficient to provide the ion beams needed. The most fundamental upgrade of this ion accelerator chain [3-5] was the addition of the Low Energy Ion Ring. The role of this small accumulator ring, equipped with a new state-of-the-art electron cooler (contracted by BINP), is to convert several (200 μs) long Linac pulses into short high brilliance bunches needed for LHC ion operation.

Since nominal LHC ion operation is very demanding for both the LHC and the injector chain, first LHC ion operation will take place with a lower luminosity and less bunches using the so-called "early scheme" [3-5]. The aim of the LEIR commissioning described in this paper is to provide the beam for this early scheme and to transport it to the PS injection region. LEIR commissioning followed a schedule with alternating commissioning and installation phases.

The first phase of the LEIR ring commissioning until December 2005 (and injection line commissioning as well) has been carried out with O^{4+} ions instead of the nominal Pb^{54+} beam. The reason is that, extrapolating from observations with O^{8+} and O^{6+} beams in LEAR, a longer vacuum life-time (lower cross section for charge exchange processes with the rest gas) had been expected and that the beam rigidity is very close to the one of Pb^{54+}.

LEIR COMMISSIONING HIGHLIGHTS

General Comments and Overview

Commissioning of the Linac 3 to LEIR transfer line has taken place in spring 2005. This phase has been dominated by "teething problems" and debugging of the control system [6,7], and already some difficulties with the optics of the injection line [8]. The beam finally reached the LEIR injection region for the first time at the beginning of July.

During the summer 2005, LEIR commissioning was kept on hold, as scheduled, for completion of the LEIR ring installations.

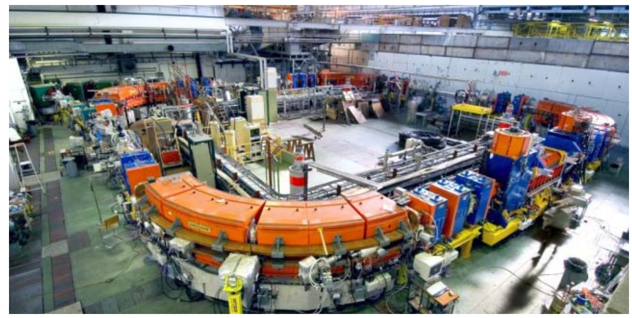

Figure 1: Almost completely installed LEIR Ring (a few days after first circulating beam).

At the beginning of October 2005, the installations were sufficiently advanced (see Fig. 1) to start LEIR ring commissioning with O^{4+} ions. During the first phase with fast progress many milestones were met: first circulating beam, almost nominal injection efficiencies after setting up the elaborate multiturn injection, first bunching, orbit measurements and corrections, lattice investigations [9], compensation of the strong lattice perturbations by the electron cooler, first acceleration tests. However, setting-up of and investigations on electron cooling were hampered by an unexpected short life-time of the O^{4+} beam, late installations and, at the very end, lack of time.

The shutdown in January 2006 has been used for hardware upgrades.

Ring commissioning resumed in the middle of February with Pb^{54+} ions. At the very beginning, progress was slowed down by difficulties to tune the injection efficiency with Pb^{54+} ions, again due to problems with injection matching. After improving the injection line setting and setting-up of the transverse damper, clear signs of cooling could be observed on 3rd March without particular difficulties [10]

Finally LEIR commissioning was completed almost on schedule on 12th May. It has been proved that LEIR can provide the beam needed for the first LHC ion runs.

Expected and Unexpected Difficulties

Various difficulties expected and encountered are reported in a chronological order:

- Controls debugging [6,7]: The ambitious decision to deploy many LHC developments already for LEIR implied a significant effort for controls debugging. Thanks to the dedication and the work of controls experts and the commissioning team, a working (although not yet perfect) control system is available. In addition, validations of solutions developed for the LHC [7] have been carried out.

- Understanding of the Linac 3 to LEIR transfer line: Extrapolating from experience with the old transfer line during the LEIR ion accumulation tests between 1995 and 1997, injection line commissioning had been expected to be smooth. However, during commissioning, significant discrepancies between expectations and observations were found. The work (measurements and updated models of the line) to understand the injection line optics is described in ref. [8].
- First injections: Since circulating beam is necessary for proper diagnostics in the LEIR ring, first injections and circulating beam had been expected to be a critical milestones. Surprisingly, a circulating beam was established quickly and without any particular difficulties.
- Position pick-up damage: An unexpected problem, discovered during the first phase of LEIR ring commissioning, is that currents induced by the ramp (C-shaped magnet and a vacuum chamber not isolated w.r.t. ground potential) damage the outer conductor of cables connecting pick-ups installed inside the bending magnets with their head amplifiers. This problem has been cured temporarily in autumn 2005 by reducing the ramp to a maximum magnetic field of half the nominal one. A definite cure implemented during the January 2006 shutdown [11] was to insulate the head amplifier box from the magnet yoke in order increase the resistance of the longer current loop and, hence, to reduce the current.
- Short beam life-time and, as a consequence, difficult interpretation of cooling investigations in autumn 2005: Almost perfect exponential decay, which could often be observed, can be explained by charge exchange interactions of the circulating ions with rest gas and a relatively high pressure in one section. One notes that the expected gain in life-time by using O^{4+} ions was not that significant. Possible reasons for the high pressures are difficulties with recuperated bellows and the fact that parts (found after opening the machine, see Fig. 2) of an ionization profile monitor have been hit by the beam. In addition to these losses with an almost exponential decay of the intensity, fast losses have been observed and were probably caused by instabilities. From Schottky signals, transverse "activity" could be observed in good correlation with these losses. In consequence, results of investigations on electron cooling were difficult to interpret, since no significant increase of density was observed. The problem has been cured by hardware upgrades (Au coated strips to intercept ions before they hit the monitor) and proper setting-up of the transverse damper.
- A degradation of the "dynamic vacuum" with beam, due to additional outgassing caused by ions hitting the chamber in the machine, has been a serious limitation during a proof of principle experiment carried out in 1997 [12]. Therefore, a collimation system [13] aiming at intercepting most ions with Au coated absorber blocks, having a low beam loss induced outgassing yield, has been installed. The "early LHC ion beam" could be obtained without any particular difficulties and even with movable absorber blocks far from the beam.

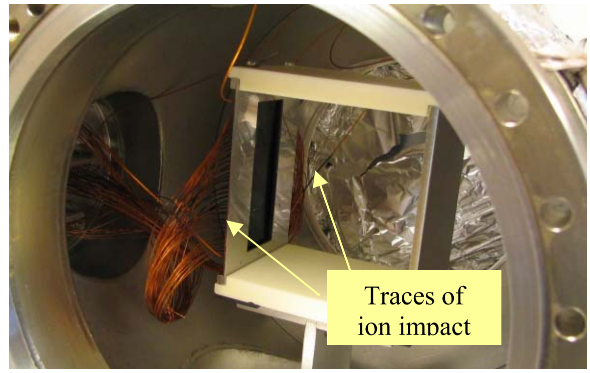

Figure 2: Vertical Ionization Profile Monitor after opening the machine.

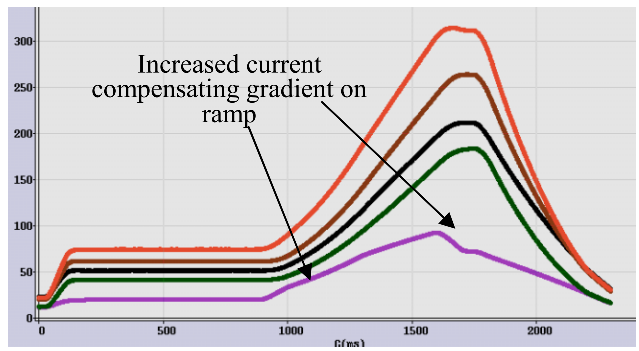

Figure 3: Quadrupole currents versus time with corrections to compensate gradients due to acceleration.

- Optics perturbations due to gradients seen by the beam during the ramp inside the bending magnets: During the ramp, a net current flows along the vacuum chamber inside the C-shaped bending magnets and excites quadrupolar fields. Corrections of the resulting very strong lattice perturbations have been implemented in the magnetic cycle generation software. Fig. 3 shows the measured quadrupole currents versus time after implementing this correction. The change of current w.r.t. an evolution following the normal ramp is visible during acceleration. Adjustment of only one parameter describing the conversion of ramp rate to gradient has been sufficient to obtain excellent acceleration efficiencies, even with faster acceleration than planned initially.

LEIR Status

The beam needed from LEIR for the first LHC ion runs has been produced. The evolution of the beam current along a 2.4 s cycle in shown in Fig. 4. Since during LEIR commissioning the current delivered by the Linac was still lower than expected (~17 µA instead of 50 µA), two shots have been accumulated on a longer accumulation plateau in order to obtain the intensities (2.3 10^8 Pb^{54+} ions) needed. Consequently, the ramp had to be shortened from the planned length of 1 s to 0.8 s. The time evolutions of the longitudinal density, measured via Schottky diagnostics, is shown in Fig. 5. The ejected beam has been observed with three secondary emission profile monitors (harp) in the ejection line. The normalized RMS emittances were found to be ~0.26 µm (nominal 0.7 µm). The horizontal mismatch w.r.t. theoretical model is negligible, whereas the vertical mismatch needs correction (so-called geometrical mismatch of ~70%, which would yield a blow-up of the RMS emittance of about 15% due to filamentation in the receiving PS).

No systematic investigations on the beam needed for nominal LHC ion operation have been made since this was not the aim of LEIR commissioning and due to lack of time. However, almost twice the intensity needed for nominal LHC operation could be accumulated by applying a special mode with very long accumulation plateaus. The accumulation rates were by far too slow for nominal LHC operation and will be increased by increasing the current delivered by the Linac and an increase of the injection repetition rate. Promising beam life-times up to 14 s (including losses due to recombination in the electron cooler and interactions with the rest gas) could be measured at this occasion.

CONCLUSIONS AND OUTLOOK

Thanks to the work of many people from several departments involved in the I-LHC and LEIR projects, LEIR installations and commissioning have been completed (almost) on time.

The beam needed from LEIR for the first LHC ion runs has been obtained by accumulation of two Linac 3 shots (compensating the low intensity from the Linac) on a special short 2.4s cycle with a longer accumulation plateau and faster acceleration. Beam parameters were found well within specifications. In addition, LEIR commissioning allowed validation of control system developments for the LHC.

LEIR is stopped at present, but will be restarted in autumn 2006 in order to provide the beam needed for commissioning the PS, the next accelerator in the chain, with the beam needed for the first LHC ion runs. The aim is to transfer this forthcoming LEIR restart and operation as much as possible from the local LEIR control room, used for commissioning, into the new CERN Control Centre (CCC). Commissioning of the early LHC ion beam in the SPS, the last accelerator of the LHC injector chain is scheduled for 2007 in order to be ready for a first LHC ion run in 2008.

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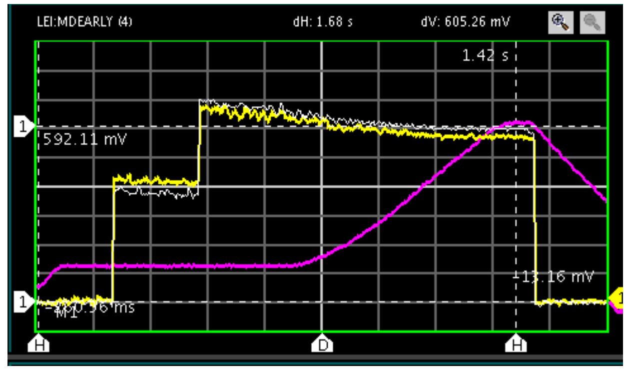

Fig. 4: Time evolution of the beam current (yellow) and the magnetic cycle (purple).

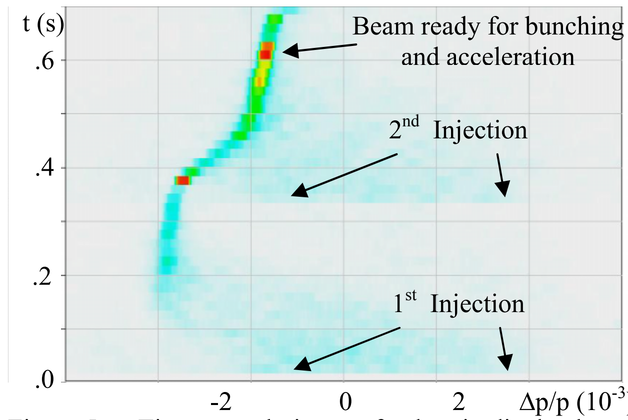

Figure 5: Time evolution of longitudinal beam distribution measured via Schottky diagnostics.

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