LEIR: TOWARDS THE NOMINAL LEAD ION BEAM

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Abstract

The Low Energy Ion Ring (LEIR) is a central piece for LHC ion operation at CERN, transforming long Linac3 pulses into high density bunches needed for LHC. The first phase of LEIR commissioning successfully attained its goal of providing the so-called "early ion beam" (one bunch of 2.25 10^8 Lead ions) needed for the first LHC ion runs with reduced luminosity. Studies in view of generating the beam needed for nominal ion operation (2 bunches of 4.5 10^8 ions in LEIR) were carried out in parallel with the setting-up of the early beam in the accelerators further downstream in the LHC injector chain. The main characteristics of the machine using a new state of the art electron cooler are discussed together with the latest results.

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 (built by BINP-Novosibirsk), 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]. During the LEIR commissioning [6-9], the beam for this early scheme has been produced and transported to the PS injection region. The goal of the first LEIR operation run during last fall was to send the early beam to the PS to commission it[10], and to explore the way to the nominal beam in LEIR.

THE "EARLY SCHEME"

In LEIR, the simple "early scheme" consists in accumulating 2.2 10^8 lead ions(54+), bunching this beam on h=1, accelerating it from 4.2 to 72 MeV/n and sending it to the PS (Figure 1).The main results of this run are:

- The Ion Source performance was significantly improved such that LEIR received regularly, from the Linac3, an intensity of 22 eμA or more.
- Only one shot was needed to produce the early beam. The beam was cooled, accelerated on a cycle of 2.4 s and extracted toward the PS without particular difficulties.

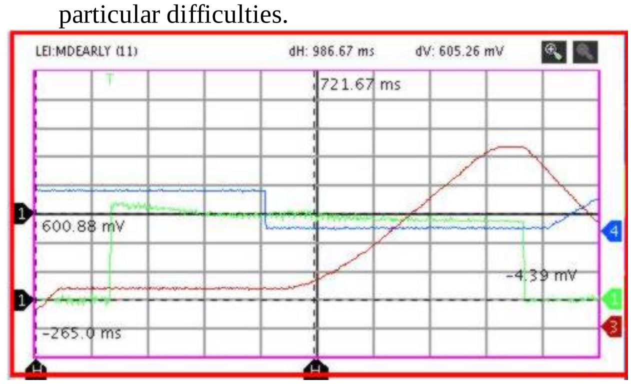

Figure 1: The "early ion beam" in LEIR (200ms/div). The red trace is the main bending field, the green trace is the beam current (8 10^7 ions/div), the blue trace is the electron cooling cathode voltage which is reduced just before the ramp.

- The injection efficiency was strongly influenced by shot to shot trajectory fluctuations in the injection line. This has been caused by stray fields generated by pulsed magnets (PS ring and ejection line). Magnetic shielding will be implemented to cure the problem during the present machine shut down.
- The new fully digital RF system was for the first time used in operation (see below). It performs very well and reliably apart from a fault related to commissioning the system.
- The normalised transverse emittances measured along the transfer line to the PS by the 3 profiles method (3 secondary emission grids distant by about 60 degrees phase advance) were found to be about 0.3 μm. The longitudinal emittance is ε_l<0.02 eVs/n. All these measurements are well within specifications.
- The availability of the beam for the PS commissioning was about 78%. The stops were mainly due to 3 faults; delay of the start-up by a vacuum leak in the electron cooler; a general stop of the power network at CERN; an error introduced in the RF digital system while commissioning a voltage loop in parallel to sending beam to the PS.

THE "NOMINAL SCHEME"

In LEIR, the so-called nominal scheme" consists in accumulating 9 10^8 lead ions (54+), bunching this beam on h=2, accelerating and sending it toward the PS. The main issues are: i) to accumulate in less than 1.6 s the number of particles needed by applying 4 or 5 successive sequences of multi-turn injection and cooling, ii) to maintain a sufficiently low pressure, good vacuum quality and, in turn, a low beam loss rate during operation[11-12], iii) to cool the beam to very small normalised emittances ($\varepsilon_{h,v}$<0.7 µm, ε_l<0.1eVs) leading to a strong space charge and Intra-Beam Scattering (IBS) regimes at the beginning of acceleration. The results (Figure 2) obtained and the remaining questions are:

- Careful adjustments of the injection and cooling settings allowed reducing the cooling time to 300ms. Thus five injections could be accumulated. The nominal intensity has been available at the end of the accumulation. Due to losses during the ramp, about 80% of the nominal intensity could be ejected and transferred towards the PS.

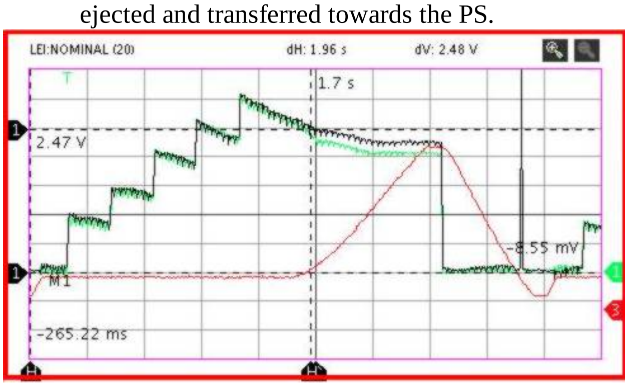

Figure 2 : The "nominal beam" in LEIR(400ms/div). The red trace is the main bending field, the green and black traces are the beam current with 5 injections (1.9 10^8 ions/div). Note the increased losses rate after each injection. About 9 10^8 ions are present before acceleration and more than 7 10^8 remain at extraction.

- The increased Linac3 current to above 22 eµA most of the time allows to accumulate the number of lead ions needed. A further increase of the Linac 3 current, bringing it closer to the design value (50 eµA) will help obtaining the "nominal beam".
- The upgrade of the vacuum system allowed increasing the beam lifetime beyond 10 s. No significant improvement was observed with scrubbing. A slightly hollow beam of the electron cooler improved the lifetime to some extent. Nevertheless up to 1.7 10^9 ions has been accumulated by continuous injection sequences in less than 6 s. The beginning of acceleration where space charge effects are strong is still a concern as frequently large losses appear. A better understanding of the strong transverse oscillations observed in this part of the cycle is needed.
- The two bunches were extracted and sent to the PS without too many problems. Unfortunately, we were not able to measure the emittances in the transfer line due to problems with the secondary emission monitors in the ejection line.

MULTITURN INJECTION

The long pulse (200µs i.e. 70 revolutions in LEIR) from the Linac3 is injected with stacking in the horizontal, vertical (by an inclined electrostatic septum), and longitudinal (by energy ramping) phase spaces, with about 50% injection efficiency (Figure 3). A possible improvement is a further increase of the injection efficiency to reduce the vacuum deterioration around the electrostatic septum.

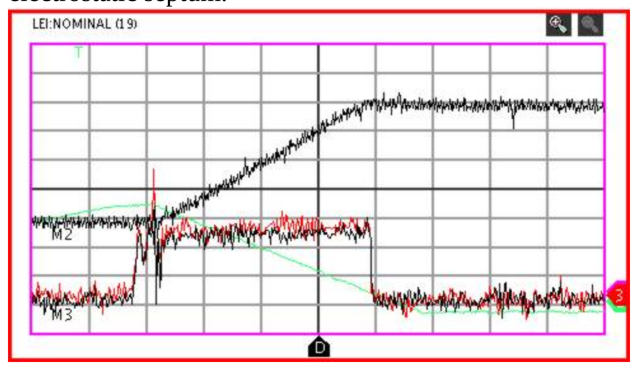

Figure 3: A typical multiturn injection in LEIR (50µs/div). The green trace is the current of one of the 4 orbit bumpers, the red and black close traces are the injection current (10 µA/div) and the black ramping trace is the accumulated current (270 µA/div).

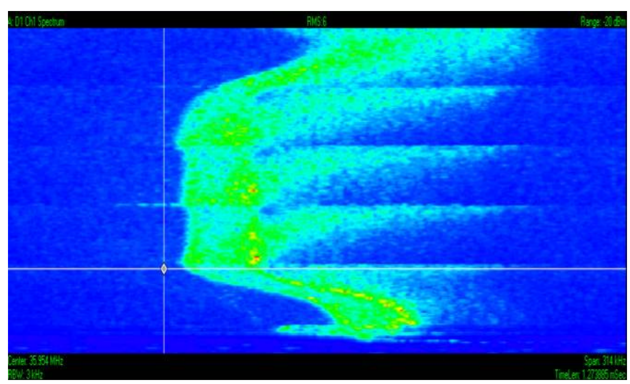

Figure 4: Spectrogram of the momentum cooling during stacking on the injection front porch. The vertical and horizontal axis denote time (1.6 s total from top to bottom); and momentum spread (1% full scale) respectively. There are 5 injections-cooling stacking sequences every 300ms

ELECTRON COOLING

The new state of the art electron cooling device [9] has been run with a current of 200 mA, an adiabatic expansion (about a factor 2.6) to adjust the electron beam to the ion beam dimension. A slightly hollow electron beam distribution turned to be the best compromise between a fast cooling (in 0.3 s) and minimal recombination rate between the circulating ions and the electrons of electron beam (Figure 4).

ALL DIGITAL LOW LEVEL RF

LEIR is the first CERN circular machine equipped with an all-digital low-level RF (LLRF) system [14]. This is a modular system composed of custom VME motherboards and daughter cards which use floating-point Digital Signal Processors and Field Programmable Gate Arrays. Input signals (cavity gap returns, transversal and longitudinal pick-ups, PS RF reference) are digitally down converted to base band and their in phase and quadrature components are used for the beam control loops. Digital up-conversion allows cavity control and RF train generation. A width-modulated clock phase-synchronizes all the synthesizers and receivers located on the daughter cards with a revolution tag

The LLRF system captures and accelerates the beam at harmonic h = 1 or h = 2, and synchronize the bunch(es) in frequency and phase with the PS machine prior to extraction. Frequency program, steering, beam phase, radial and synchronization loops are implemented in full Pulse-to-Pulse Modulation fashion; all beam control parameters are user-controllable. Extensive online diagnostics is also available; Figure 5 shows the cavity-to-beam phase φ and the magnetic field measured by the system as a function of the time within a cycle.

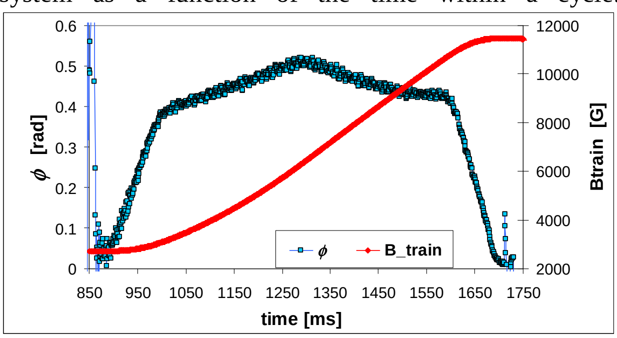

Figure 5: Cavity-to-beam phase φ and magnetic field measured by the LLRF system as a function of cycle time.

The non-tunable, large-bandwidth (0.35–5 MHz) cavities are based on the Finemet® high-permeability magnetic alloy [15]. The LLRF system short-circuits a cavity when no voltage is applied to it. This reduces the effective impedance seen by the coasting beam. During the 2006 LEIR run, the LLRF system has controlled cavity voltage and phase in a feed-forward fashion, over the required 60 dB dynamic range. During the 2007 run a dual harmonic cavity servo-loop will flatten the bunch(es) to reduce the transverse space charge tune shift. It will also minimise the cavity impedance at frequencies $h\ f_{rev}$ and $2{\cdot}h\ f_{rev}$, where f_{rev} is the revolution frequency and h the main harmonic.

CONCLUSION

The “early beam” has been produced in LEIR. In addition, the “nominal beam” is in good progress as 80% of the desired intensity was extracted towards the PS. Further studies will focus on: i) losses at high intensity, ii) to improve the intensity reproducibility and iii) make the operation easier by improving the beam measurements software.

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