100MS INJECTION INTO LEIR

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Abstract

Results of machine developments for 100ms spaced injections from Linac3 into LEIR are presented.

INTRODUCTION

The LIU project aims to increase the number of ions [1] injected into the LHC, and one of the limitations to be overcome is to increase the number of ions available from the pre-injector, Linac3, as well as to accumulate and accelerate this higher intensity in LEIR. One of the methods to increase the number of Pb54+ ions available from Linac3, is to decrease the spacing between the 200us long pulses, and if the same length of LEIR injection plateau is kept, the number of pulses that can be transferred from Linac3 to LEIR increases from 7 to 13. Additionally, it could be conceived to inject a smaller number of injections in a much shorter time, and reduce the LEIR cycle from 3.6 to 2.4s. In order to decrease the injection spacing to 100ms, the following was demonstrated to be possible with the presently installed equipment:

- the Linac3 ECR source already operates at 100ms spaced pulses,

- most of Linac3 was designed to run at 10Hz,

- the injection system of LEIR was designed for 10Hz operation,

- the electron cooling beam current could be doubled from the operational value of 220mA.

Within the LIU project, the following actions were made to allow remaining equipment to run at 100ms spaced pulses.

- pulsed quadrupole and corrector dipole power converters were upgraded to 10Hz,

- these pulsed magnets had thermal interlocks added,

- Ventilation was improved on the RF racks to give additional cooling.

All of these measures were anyway limited to proving up to 13 pulses in a 3.6s cycle, as well as allowing for continuous 5Hz operation. In this regard, the consolidation of the ventilation system of Linac3 is also needed to allow continuous operation at these higher repetition rates.

The results presented in the following sections are based on two MD sessions.

Table 1: Parameters used for comparison of intensity at 100 and 200ms space injections

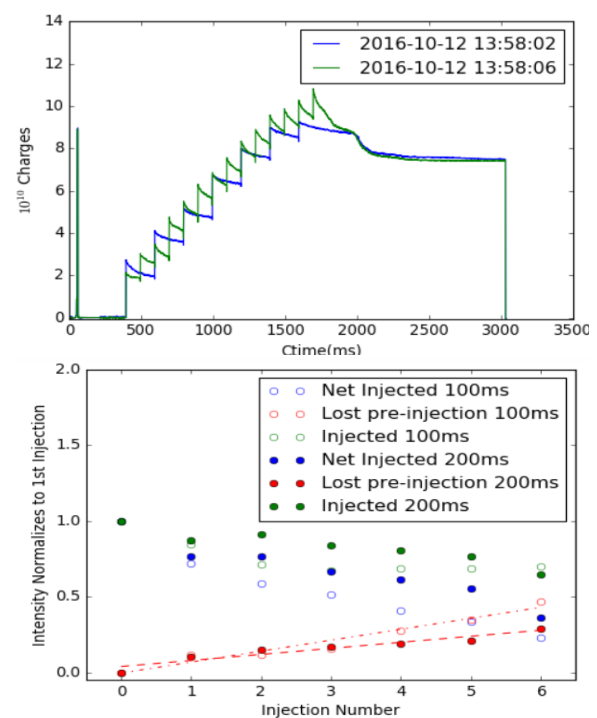|	NOMINAL 200ms	AMD 100
Spacing (ms)	200	100
# Injections	7	14
Electron cooler (mA)	220 Non-uniform beam (too high current)?	510
Accum Intensity (Charges Total)	9.5E10	12.0E10
Extracted Intensity (Charges Total)	8.0E10	8.0E10

Figure 1: Top: Beam intensity stored in the ring for 14x 100ms injection (green) and 7x 200ms injections (blue); Bottom: Comparison of the first 7 injections into LEIR when spaced by 100ms (open circles) and 200ms (closed circles). Linear fits are shown to the intensity lost pre-injection.

INTENSITY

On 12/10/2017, the optimized cycle being used for operation (*USER=NOMINAL*) was cloned and the injection rate decreased to 100ms along with the number of injections being increased to 14. The electron cooler was increased in beam intensity and optimization of the injection and stacking process was done (including injection line trajectories, orbit

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during accumulation, electron beam energy etc.), details are given in Table 1.

The intensity during a LEIR cycle is shown in Figure 1 (left) where it can be seen that slightly more beam is accumulated with the 100ms injections, but this is limited due to two loss mechanisms:

- fast loss of the beam stacked in the ring when the injection bump is opened,

- loss of the accumulated beam between injections.

The fast loss was measured using the fast Beam Current Transformer (BCT) and comparing the reduction in signal in the 100 μs before the injection beam starts. Comparison of the magnitude of the beam lost, to the intensity injected on the first injection is shown in Figure 1 (right) where it can be seen that for 100ms spaced injections, the amount of stacked beam lost is increasing more rapidly with injection number, reaching approximately 50% of the intensity of the first injection intensity, by injection number 8.

The slow loss of accumulated beam in between the injections is also more pronounced when the beam is injected with 100ms spacing (Figure 1 (left)). This loss is composed of two components, one of the order of milliseconds, and the second the order of seconds. writing this as:

$$I = I_{fast}e^{\frac{-t}{t_{fast}}} + I_{slow}e^{\frac{-t}{t_{slow}}} \qquad (1)$$

and at and intensity of 8E10 charges circulating, the (fast,slow) decay times are (20ms,4500ms) for 200ms and (20ms,2000ms) for 100ms spaced injections, the slow decay time is 2.5 times shorter for the higher injection rate.

This can be initially compared to the ion loss rate for Pb54+ ions that was measured at LEAR in 1996 [2] and the total beam decay rate (for both electron cooling losses and vacuum losses) was calculated to be 7seconds.

TRANSVERSE COOLING RATE

The transverse cooling of the circulating beam can be measured with the Ionization Profile Monitor [3]. The projected beam profile can be measured every 1ms to which a gaussian fit is made to calculate an rms beam size. A fit of the decay of the beam size is then made, i.e.:

$$\sigma = \sigma_0\, e^{\frac{-t}{t_{cool}}} \qquad (2)$$

where the time window 11 ms after each injection are not included in the fit due to the often seen large beam size oscillations measured after the injection process.

Measurements of the beam profile as a function of time in the cycles were made with the parameters is 2, and the resulting cooling times are reported in Figure 2 (right). Contrary to the data in table 1 in this case for 100ms spaced injections the electron cooling current was 430mA. In Figure 2 (right) the lines shown are not fits, but only guides for the eye.

The following conclusions are drawn from this result:

Table 2: Parameters used for comparison of transverse beam cooling rates at 100 and 200ms space injections

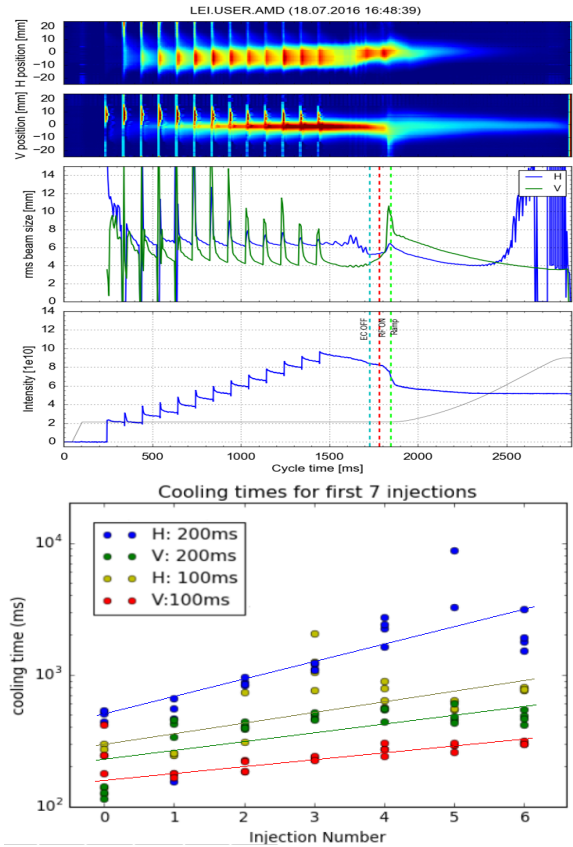|	NOMINAL 200ms	AMD 100ms
Spacing (ms)	200	100
# Injections	7	13
Electron cooler (mA)	220	430
Accum Intensity (Charges Total)	9.5E10	9.5E10
Extracted Intensity (Charges Total)	8.0E10	5.0E10

Figure 2: Top: Plots of the beam profile measured with the Ionization Profile Monitor; Bottom : Transverse cooling times for the circulating beam following 100 and 200ms spaced injections, first 7 injections shown.

- the cooling times increase as a function of injection number, but the effect on the measurement of the already stacked and cooling beam is not known

- the vertical cooling time is measured to be 2 - 3 times faster than the horizontal plane (however, this may be affected by the losses in the vertical plane),

- the increased electron cooling current improves the cooling time by a factor 1.5 - 2.

FUTURE MEASUREMENTS

In 2017 only xenon will be available in LEIR, and the performance of the beam is expected to be significantly different and it is not foreseen to spend effort understanding limitations of the xenon beam as the required intensity for physics is low. However studies will be possible to understand some of the processes, these are listed below:

- Preliminary testing of 150ms cycling of the Linac3 source,

- measurement of xenon cooling times from IPM after its repair,

- measurement of the effect of injection bump on circulating beam,

- inclusion of dispersion into the analysis of cooling rate for the horizontal IPM,

- benchmarking of cooling simulations, including parametric studies.

REFERENCES

[1] LHC Injectors Upgrade: Technical Design Report - Volume 2: Ions, Eds J. Coupard et al, LIU-PM-RPT-0025, https://edms.cern.ch/document/1626950/

[2] J. Bosser, Review of Recent Work on Electron Cooling at LEAR, CERN-PS/96-13(AR), 1 April 1996.

[3] C. Bal, V. Prieto, R. Sautier, G. Tranquille, First Results from the LEIR Ionisation Profile Monitors, Proc DIPAC 2007, Venice, Italy, TUPB24, https://accelconf.web.cern.ch/accelconf/d07/papers/tupb24.pdf