LEIR INJECTION EFFICIENCY STUDIES AS A FUNCTION OF THE BEAM ENERGY DISTRIBUTION FROM LINAC3

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Abstract

High intensities in the CERN Low Energy Ion Ring (LEIR) are achieved employing multi-turn injections from the pre-accelerator LINAC3 combined with simultaneous stacking in momentum and transverse phase spaces. Up to seven consecutive 200 μs long, 200 ms spaced pulses are injected from LINAC3 into LEIR by stacking each of them into the six-dimensional phase-space over 70 turns. An inclined septum magnet allows appropriate filling of the transverse phase-space plane, while longitudinal stacking requires momentum variation achieved by a shift of mean momentum over time provided by phase shifting a combination of 2 RF cavities at the exit of LINAC3. The achievable maximum accumulated intensity depends strongly on the longitudinal beam quality of the injected beam. The longitudinal Schottky signal is used to measure the received energy distribution of the circulating beam which is then correlated with the obtained injection efficiency. This paper presents the experimental studies to understand and further improve the injection reliability and the longitudinal stacking.

INTRODUCTION

Figure 1 shows an overview of the layout of LEIR - the CERN low energy ion ring, its transfer lines, and its injector LINAC3. The ion beams are extracted from the source, injected into LINAC3 and accelerated to the kinetic energy of 4.2 MeV/u at the exit of LINAC3 with a linearly varying momentum of 4 ‰ along the 200 μs pulse. The LINAC3 repetition rate is 5 Hz. The transport from LINAC3 to LEIR consists of a 180° loop, a bi-directional transfer line ETL, which sees the injected beam and also the beam ejected towards the PS accelerator, and finally the last part of the LINAC3-to-LEIR transfer line called EI. The 200 μs long pulse is injected into LEIR over 70 turns by 6D phase-space painting. The LEIR ring optics has 10 m dispersion at the injection point while the transfer line has zero dispersion. The collapsing injection bump is designed such as to compensate the energy ramp of the incoming beam pulse so that the particles are injected at constant betatron amplitude. The electrostatic septum is tilted by 30 degrees to increase the degrees of freedom for phase-space painting. Details can be found in [1].

The LEIR injected and accumulated intensity are subject to shot-to-shot variations as well as drifts over several days. Varying stray fields of the close-by PS accelerator due to differences in super cycle compositions are at the origin of this as well as possible changes in parameters of LINAC3. In 2017 a joint LINAC3-LEIR test series was carried out to understand the correlation between the LINAC3 parameters
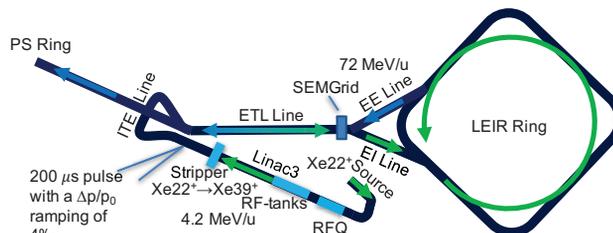
Figure 1: An overview of the PS ion injectors.

and the LEIR injected pulse characteristics with the goal of improving the long-term reproducibility. Parameter scans with the LINAC3 ramping and debunching cavities as well as with the tank 3 cavity were carried out.

Stripper foil degradation leads to a modified momentum distribution at the exit of LINAC3 and hence a reduced injection efficiency if the LEIR injection parameters are not adjusted accordingly. The slow degradation takes place over the course of several days. Figure 2 shows the impact on the injected intensity in such a case for ^{129}Xe^{39+} ions in 2017 [2].
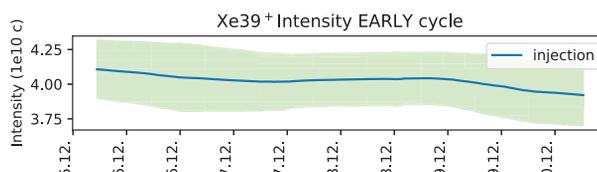
Figure 2: Due to degradation of the stripper foil the injection intensity (in the EI BCT) in LEIR decreases over time (here five days). The shaded area indicates the extent of shot-to-shot variations.

TEST CONFIGURATIONS AND RESULTS

The observables during the LINAC3-LEIR tests were the momentum distribution measured with the longitudinal Schottky pick-up, the beam intensity measured with a beam current transformer (BCT) in LEIR and the transverse beam profiles measured with a secondary emission monitor (SEM grid) in the ETL line. The momentum distribution was reconstructed from the Schottky signal using the method discussed in [3]. A compromise between short integration time to resolve short-term effects and frequency/momentum resolution had to be found. Around 25 measurements were averaged to minimize the impact of short time fluctuations.

04 Hadron Accelerators

A24 Accelerators and Storage Rings, Other

Ramping-debunching Cavity Versus Relative Momentum Offset

The LINAC3 ramping (RC) and debunching (DB) cavities provide the required momentum distribution along the 200 μs pulse for the multi-turn injection into LEIR. The cavity settings were adjusted to produce a narrow momentum distribution, where the phases of both cavities were kept constant to not ramp the mean momentum along the pulse. The phases were then scanned, and the corresponding spectrum was acquired at each step with the Schottky monitor and the SEM grids. The LEIR and transfer line momentum acceptance was measured in this way, and the momentum delivered by LINAC3 could be calibrated. The change per degree of phase corresponds to a change of $\Delta p/p_0$ of -0.073±0.001 and the $\Delta p/p_0$ acceptance is as predicted ±3.8‰. Figure 3 shows the results. The momentum offset $\Delta p/p_0$ evolves lin-
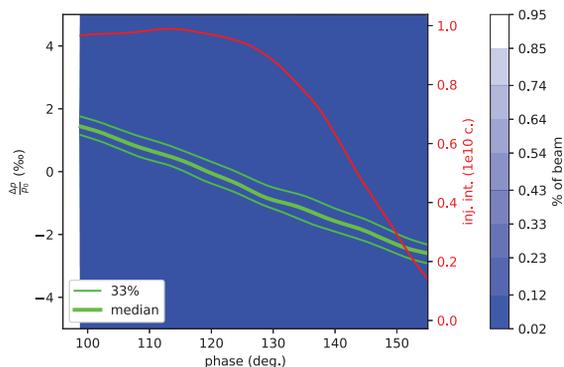
Figure 3: Contour plot of the momentum spectrum of an injected pulse and the spectra of pulses with constant energy (RC-DB phase).

early with the phase, while the momentum spread remains unchanged until the injected intensity (red curve) is significantly reduced. The beam intensity is constant until the phase value of 130° and decreases rapidly afterwards as the momentum acceptance is reached. Figure 4 shows the momentum distribution obtained for the total 200 μs pulse with ramped momentum (gray filled curve). For illustration, the distributions obtained at one fixed phase value of the ramping cavity (and debunching cavity) are superimposed. Vertical SEM grid measurements also revealed an increasing beam size (contrary to the horizontal plane), slightly raising along the pulse, and decreasing beam position with increasing phases, which will be addressed in additional studies.

RF Amplitude

Another set of studies was aimed at understanding the influence of the DB and tank 3 amplitude on the LEIR injection performance. The RC-DB phase was set to a constant value to obtain a narrow momentum distribution. Figure 5 summarizes the results for varying the DB amplitude. As expected, the momentum offset $\Delta p/p_0$ depends on the amplitude, but
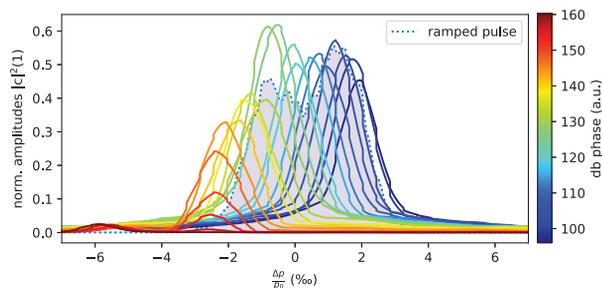
Figure 4: Momentum distribution as a function of the RC-DB phase. The operational pulse with ramped momentum is shown in gray.

in this case, also the momentum spread of the incoming beam is modified as a function of the DB amplitude.
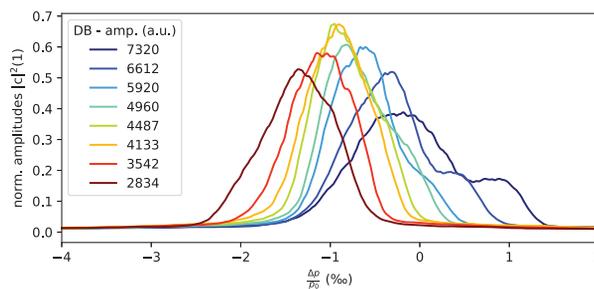
Figure 5: Momentum distribution as a function of the debunching cavity amplitude at constant phase.

The influence of the RF tank 3 amplitude on the injected beam parameters was of particular interest as it was observed during the 2017 $^{129}Xe^{39+}$ run that it could compensate for stripper foil degradation. For a wide range of tank 3 amplitudes, however, neither momentum offset nor momentum spread change in the Schottky spectrum while the injected intensity is very sensitive to this parameter, see Fig. 6.
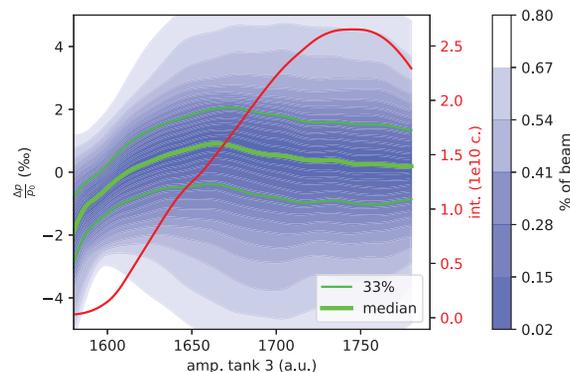
Figure 6: Momentum distribution in LEIR at injection as a function of the RF tank 3 amplitude. The red line shows the measured intensity in the LEIR ring.

Dispersion Measurement

A SEM grid at the end of the ETL line was used to measure the dispersion. The pulse structure and its fluctuations could also be studied. All pulses showed a beam size variation of 6% in the horizontal and 3% in the vertical plane. Assuming the optics remains unchanged along the time scale of the measurements, the transverse size variations could be attributed to the variations of the momentum spread with dispersion at the grid location in both planes. More studies in 2018 will address this in detail. Correlating the change of the horizontal mean position of the beam, while observing a constant transverse beam size along the pulses, with the measured momentum, yields a dispersion of 1.33±0.03 m at the location of SEM grid ETL.MSFHV30. The results are presented in Fig. 7. According to the optics model state the horizontal dispersion should be $D_x = 1.00$ m.
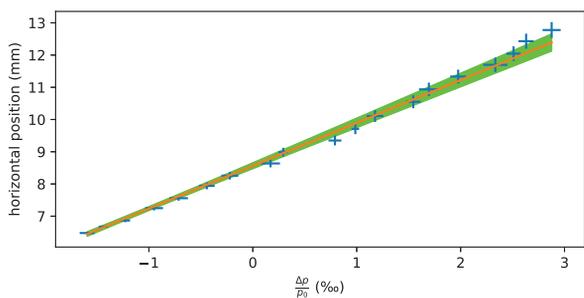
Figure 7: The position at the location of ETL.MSFHV30 as a function of the momentum off set. The fit yields a dispersion of 1.33±0.03 m.

The Stripper Foil

The LINAC3 stripper foils are thin carbon plates, which strip off electrons from the ions passing through. It is located after the RF tanks before the RF-DB cavities in LINAC3 as depicted in Fig. 1. The foils degrade slowly over several days making the tracking of momentum changes of the exiting ions challenging. Moreover, each foil provides a slightly different momentum distribution. The shot-to-shot intensity variation of the $^{129}Xe^{39+}$ beam is more stable than for the $^{208}Pb^{54+}$ beam that was used in previous runs. Therefore longterm momentum drifts could be disentangled from possible source fluctuations and pinned down to foil degradation as shown in Fig. 2. A study of twelve hours showed, however, no evident indications of drift in momentum offset or spread in the Schottky spectrum of the $^{129}Xe^{39+}$ beam. More studies are needed to find adequate methods to extract the variations of the momentum distribution online with sufficient precision to use this as input in LEIR injection parameter correction algorithms.

Influence of PS Stray Fields

The stray field of the PS magnets influences the beam transport from LINAC3 to LEIR. The analysis of the periodicity of the intensity fluctuations in the transfer line and LEIR with the available BCT data revealed that the intensity before injection into LEIR does not show the signature of the periodicity of the PS cycles, however, the injected intensity in LEIR does. It points to the fact, that the impact of the stray fields disturbs the pulse trajectory within the acceptance of the transfer line, whereas the particles are lost shortly before or at injection. The SEM grid data shows shot-to-shot variations of up to 3 mm in the horizontal and 0.5 mm in the vertical plane at the grid locations. Preliminary measurements with a single grid indicate that the focusing properties of the line are modified due to stray fields. A detailed study in 2018, with all three new SEM grids, will be carried out.

PLANS FOR 2018

In 2018 the accelerator complex will be operated with $^{208}Pb^{54+}$ ions. As from previous experience, stable beam delivery from LINAC3 is very challenging. In fact, the lead oven is a source of fluctuations by itself and has to be taken into account. On the other hand, new diagnostics will help to study the various phenomena. Nine new BPMs will be available in the injection line as well as three SEM grids that deliver time-resolved signals. In the LEIR ring, a new orbit system will be available, allowing for turn-by-turn and first turn acquisition.

CONCLUSIONS

A calibration of the LINAC3 RF phases of ramping and debunching cavity versus delivered momentum was performed yielding a $\Delta p/p_0$ change of -0.073±0.001 per phase degree and a $\Delta p/p_0$ acceptance of ±-3.8‰ in the transfer line and LEIR. The influence of various LINAC3 parameters on the momentum distribution and injection efficiency was studied. More tests will be necessary to establish a full understanding of the origins of the variations in LEIR injection efficiency. The impact of the PS stray fields and the question of emittance stability from LINAC3 will also have to be addressed.

ACKNOWLEDGEMENTS

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