RESULTS ON LEAD ION ACCUMULATION IN LEAR FOR THE LHC

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Abstract

In order to prepare dense bunches of lead ions for the LHC, it is foreseen to accumulate the 4.2 MeV/u linac beam in a storage ring using electron cooling. A series of experiments has been successfully concluded in the low energy ring, LEAR, to test the techniques involved. In this paper, the influence of the residual gas on the beam lifetime, the combined stacking in longitudinal and transverse phase space, the dependence of the injection efficiency on the optical settings of the storage ring, and the study of the high intensity effects including beam induced degradation by the vacuum are reported. The results obtained are discussed and will be taken into account to modify the LEAR machine for the LHC era.

1 INTRODUCTION

To fulfil the desired luminosity for the lead ions in the LHC[1], it has been proposed[2] to use a low energy accumulation ring to increase the number of ions per bunch. The final goal is to accumulate 1.2 10^9 lead ions per cycle of 3.6 s. A combined longitudinal and transverse multiturn injection[3] permits the increase of the number of ions injected. This freshly injected beam is strongly cooled by an electron cooling device leaving space for a new injection.

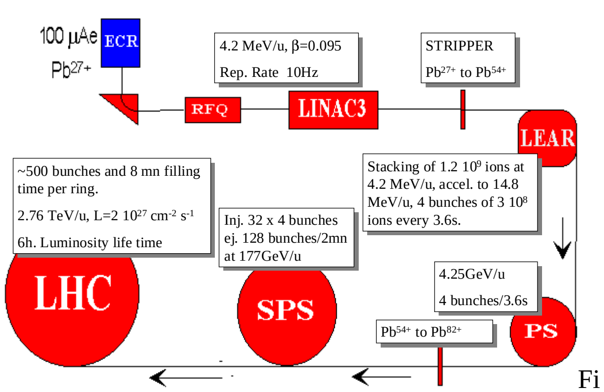

Figure 1: Plan for using LEAR as an ion accumulator for LHC

After having accumulated the required number of ions, the beam is accelerated and transferred to the PS, SPS and finally to LHC (Fig.1). This process is repeated as many times as needed to fill the whole LHC bunch set. In 1997, the LEAR[4] machine has been modified to test the combined injection, the multi-injection and the cooling (Fig.2). After having tested different lattices[4], two of them have been retained for the 1997 tests:

- the normal LEAR lattice (MACH1) with four superperiods (β_h≈1.7 m, β_v≈6.5 m, D=3.5 m at the centre of each straight section).
- a modified lattice (MACH97) where the LEAR straight section SS1 is adapted for the combined injection (β_h≈3 m, D=10 m) and the straight section SS2, where the cooler is installed, is better matched for the electron cooling ($\beta_{h,v}$≈5 m, D=0 m).

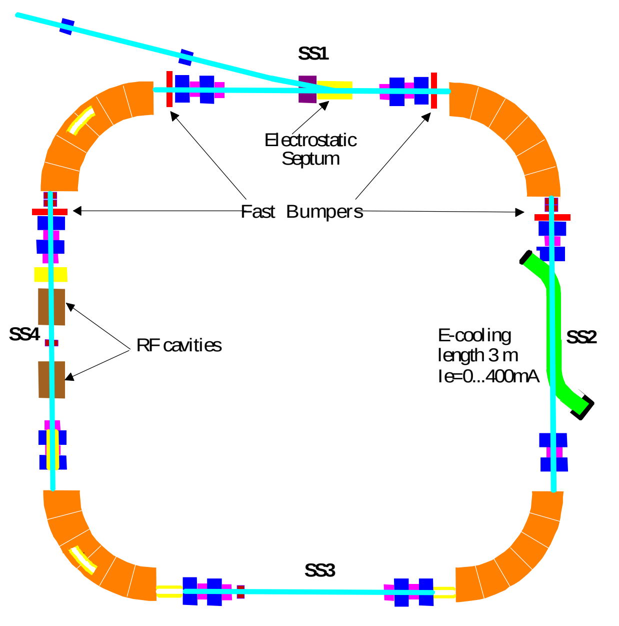

Figure 2: The modified LEAR in 1997. The electrostatic septum has been moved to the centre of straight section 1 for the combined multiturn injection. The electron cooling has been lengthened to 3 m and installed in straight section 2. Four bumpers have been added.

2 THE COMBINED MULTITURN INJECTION

To increase the number of ions injected per linac batch, a multiturn injection is needed. As momentum cooling is more efficient than transverse cooling and there is enough longitudinal acceptance in LEAR, an injection procedure has been proposed[3] where the momentum of the incoming beam changes during the transverse multiturn process. This momentum change is obtained by ramping both the accelerating voltage of the last tank of the linac and the phase of the debuncher. The dispersion and its derivative at the end of the LEAR injection line are set to zero. Efficient injection is obtained if the ratio $D/\sqrt{\beta}$, (D, β [m] being the dispersion and the horizontal Twiss parameter of the machine at the injection point) is large and of the order of 6 $m^{1/2}$. During the injection process, in the case of MACH97, the orbit bump is decreased from 40 mm to zero while the momentum is increased by 4 ‰ in 200 µs. In the transverse plane, the closed orbit for the injected beam is then fixed during the whole process (Fig. 3 and 4). Analysis[5] shows that about 35 equivalent turns can be injected into a transverse emittance of 50 π mm mrad and a momentum spread of 4 ‰ . Compared to a pure transverse multiturn injection three times more ions can be injected and in addition within a much smaller horizontal emittance (at least a factor 3). During the 1997 tests, up to 1.5 10^8 (1.1 10^8) Pb^{54+} ions have been injected per multiturn injection using MACH97 (MACH1) which is about 28 (22) efficient turns.

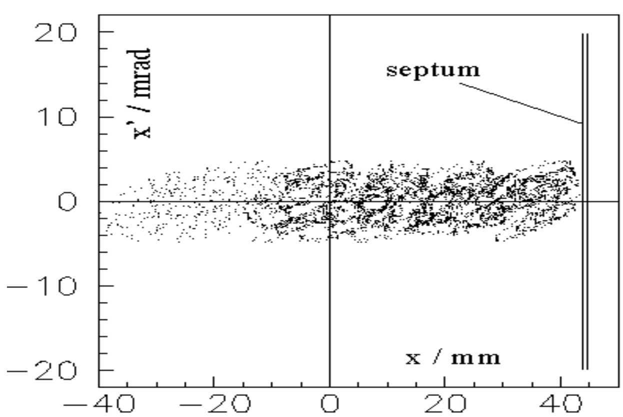

Figure 3: Scheme of combined multiturn injection. The darker part represents the injected particles. The left cloud of points represents the stacked particles.

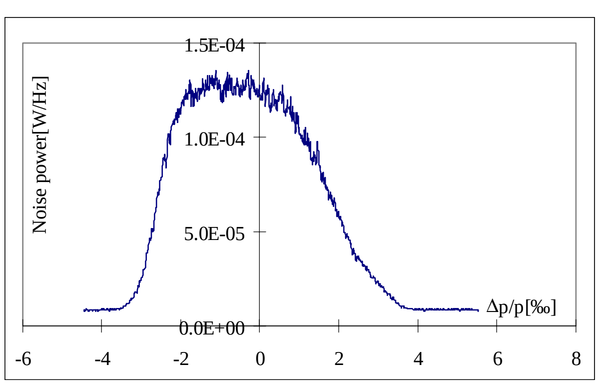

Figure 4: Measured momentum Schottky power spectrum of a combined multiturn injected beam. The momentum spread of the linac beam is Δp/p=0.2‰ rms.

3 MULTI-INJECTION AND STACKING

To fulfil the specifications, it is foreseen to stack 12 injections from the Linac3 pulsing at 10 Hz. During the 0.1 s the injected beam has to be cooled and transferred to the stack. The momentum of the stack is such that the beam does not hit the septum during the next injection, thanks to the high dispersion at the septum. Two types of cooling and stacking procedures were tested in 1997 with the linac pulsing every 0.4s.

The first procedure consists of leaving the electrons at the same speed as the ions in the stack. The injected ions are then decelerated and cooled to the stack despite the large momentum difference and the strong effect of the space charge of the electron beam. This is particularly adapted to MACH1 as the dispersion at the cooler is not zero.

The second procedure is the “dragging”. Just after the injection, the electron beam energy is changed (Fig. 5,6) to improve the transverse cooling of the injected ions. This energy is such that the ions having large amplitudes of oscillation experience optimum cooling forces taking into account the space charge of the electron beam. Then the electron energy is decreased to drag the cooled ions to the stack. If the dispersion is zero (MACH97) at the cooler, there is no need to manipulate the ion orbit during the whole process.

Using the linac Pb^{54+} beam (20 µA, 170 µs long), stacks of 6 10^8 (5 10^8) ions have been accumulated (Fig.7) after about 12 successive injections with lattice MACH97 (MACH1). The stacking process comes to saturation when the amount of new injected ions is compensated by the losses due to recombination of the Pb^{54+} with the residual gas molecule’s and with the cooling electrons. No significant differences, in terms of accumulation, were observed when using an electron cooler current larger than 100 mA. For larger currents, smaller beam dimensions were measured giving less losses at the next injection but stronger losses appeared during cooling.

Figure 5: Transverse beam dimension measured during beam stacking and cooling (Ie=110mA) with a cycle of 0.4 s. One should notice that the transverse cooling is not completed at the end of a cycle, giving some stack losses during the next multi-turn injection.

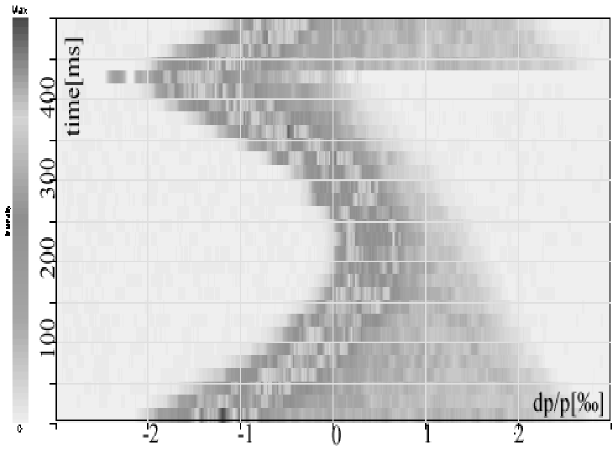

Figure 6 Longitudinal cooling using the dragging method. The picture represents successive longitudinal Schottky spectrum taken every 16 ms and seen from the top. The darker, the denser the beam is. Immediately after injection (bottom) in presence of the stack, the electron beam energy is suddenly changed and then after 150 ms, slowly decreased to the stack energy. The injected beam is cooled to the stack but, in the mean time, the stack has been dragged by the electrons. Finally the whole beam is decelerated to the stack energy leaving space for a new injection (top) .

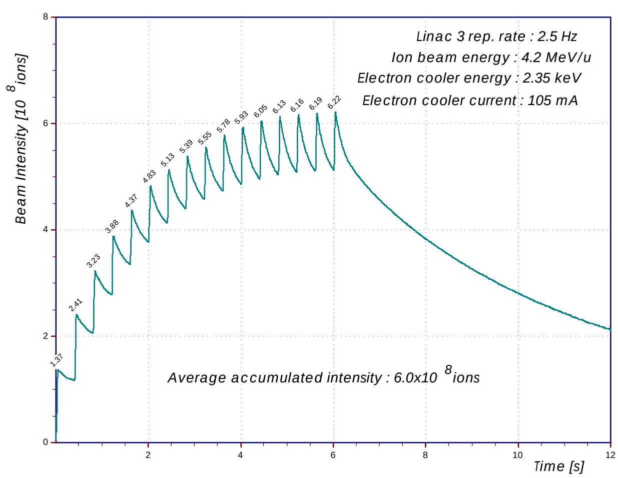

Figure 7 : Accumulation of lead ions for 16 injections. The increased losses after each injection are clearly visible. After stopping injection the beam life time is 6.5 s.

4 HIGH INTENSITY EFFECTS

No sign of transverse instabilities were observed with the high density stack, thanks to the 70 MHz bandwidth of the active feedback system. The main problems arises from the recombination of the ions with the cooling electrons and from charge exchange with the residual gas.

The static LEAR vacuum is about 5 10^{-12} Torr, but the lost ions hit the vacuum chamber in the arcs giving outgasing of the wall. In some portion of LEAR, the vacuum was then increased by a factor of 10 to 20, resulting in more charge exchange and more losses. A specific gas (CO) was mainly responsible for this increase (Fig. 8).

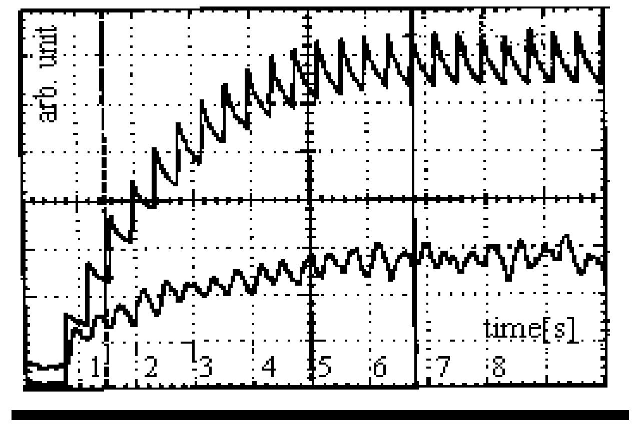

Figure 8: Ion beam current (top curve) and CO partial pressure (bottom curve) during accumulation.

5 THE FUTURE

The 1997 tests have shown that the proposal of using LEAR as an ion accumulator is feasible providing some modifications of the machine are made. A factor 120 has been gained in the number of ions compared to mono-turn injection. The final goal is already reached except a factor 2 in the number of ions and a factor 2 in accumulation time. We are confident that this goal can be achieved by increasing the linac current, improving the multiturn injection, decreasing the outgasing of the walls and improving the electron cooler.

REFERENCES

[1] D. Brandt, K. Eggert, A. Morsh, “Luminosity Considerations for different Ion Species”, CERN/AT/94-05(DI) and LHC Note 264.

[2] P. Lefèvre and D. Möhl, “A Low Energy Accumulation Ring of Ions for LHC”, CERN/PS 93-62(DI) and LHC Note 259.

[3] S. Maury and D. Möhl, “Combined Longitudinal and Transverse Multiturn Injection into a Heavy Ion Accumulator Ring”, Internal Note PS/AR 94-12.

[4] J. Bosser, C. Carli, M. Chanel, R. Maccaferri, S. Maury, D. Möhl, G. Molinari,” Electron Cooling of Pb^{54+} Ions in the Low Energy Ion Ring (LEIR)”, this conference.

[5] C. Carli, “Simulation of Multiturn Injection into LEAR in View of Ion Accumulation”, Internal Note CERN/ PS/DI 96-24.