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Abstract

Oxygen ions were injected to the Low Energy Antiproton Ring LEAR at CERN from LINAC I, electron – cooled, and stacked in the longitudinal plane at 11.4 MeV/nucleon. Up to $13.8 \ast 10^9$ charges were accumulated. This beam was then accelerated to 408 MeV/nucleon and extracted into the experimental area for measurement of the Bragg peak in tissue equivalent material. This paper describes the results of stacking, cooling, acceleration and extraction.

Introduction

CERN's Low Energy Antiproton Ring LEAR [1,2] had already injected and stored oxygen ions during machine experiment sessions [3], taking advantage of the availability of such particles at CERN [4]. At that time the aim was to test the possibilities to stack and stochastically cool heavy ions, and to measure the beam lifetime in a good vacuum.

This time the machine experiment session was devoted to try and accelerate and finally extract the heavy ion beam at 408MeV/nucleon, to measure the depth dose distribution in tissue equivalent types of plastic [6].

Accumulation schemes

O^{8+} were delivered from the LINAC I at 11.4 MeV/nucleon. Each LINAC burst contained about $4 \cdot 10^8$ charges. This intensity was clearly insufficient for ultra – slow extractions of several minutes, so some stacking scheme was needed. The longitudinal stacking method had already been tested earlier [3]: the coasting beam was bunched on the first and then on the second radio – frequency harmonic. The incoming beam was injected in the empty second – harmonic bucket, then the two beams were merged together by adiabatic debuching. The process was automatically restarted at fixed intervals, which were multiples of the LINAC repetition rate (1.2 seconds), and stopped manually when the beam current did not increase any longer. To preserve the 6 – dimensional phase space, electron cooling was kept on during the whole injection sequence. A transverse damper prevented coherent oscillations from developing in this dense beam [5].

This scheme has led to an average intensity of $8 \cdot 10^9$ charges (though $13 \cdot 10^9$ were observed once), corresponding to 20 LINAC bursts,in 30 injections (Figure 1).

A transverse stacking scheme was also tried at the end of the session. The coasting beam was kicked in the horizontal direction by the magnetic kicker normally used for fast extraction, and started a betatron oscillation. Beam from LINAC was then injected and the coasting beam's oscillation was partially compensated by the injection kicker. Both beams then had large oscillation amplitudes – but should have stayed in the machine thanks to the large acceptance of the latter – until the electron cooling reduced their emittances down to less than 2πmm.mrad. This scheme has thus been tried but due to lack of time, we never succeded to increase the current by more than a factor two.

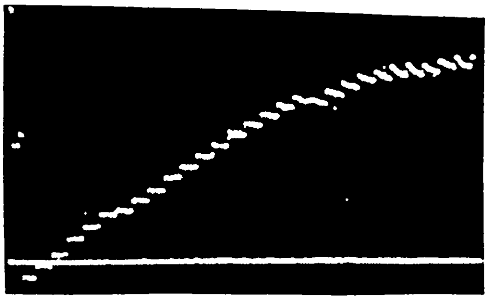

Figure 1: Current transformer reading during injection sequence. The repetition rate has been set to 7.2 seconds. Saturation occurs when the losses are of the same magnitude as the injected batch.

Electron cooling

Electron cooling experiments were made on the O^{8+} beam at the injection momentum of 147.4MeV/c/u. This meant an operational energy of 6.23 kV for the cooler with 250 mA of electron current effectively used for cooling. The solenoid field was set to 218 G and as usual the orbit deformation due to the toroids was corrected with two correction dipoles, DEH31 and DEH32, and two backleg windings, DWH22 and DWH31. Precise measurements of the longitudinal cooling time [5] showed a reduction in momentum spread by a factor of almost 10 in less than 700 msec (Figure 2). The final value of the momentum spread was measured to be around $4 \cdot 10^{-4}$. Emittances were measured by scrapers and were nominally of the order of 3πmm.mrad. Much lower emittances could be obtained but more time is needed to adjust the damper correctly for higher intensity beams.

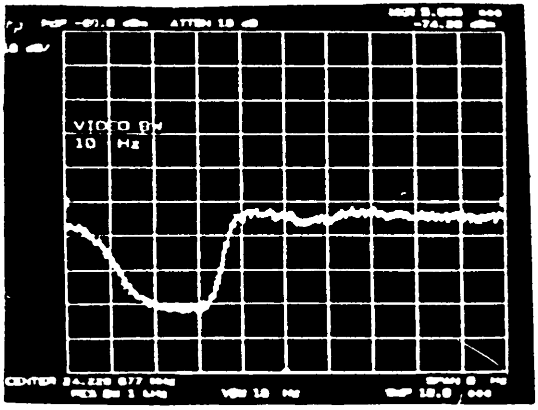

Figure 2: Longitudinal cooling time measurement. The increase in spectral density corresponds to the effect of longitudinal cooling as the energy of the electrons is stepped up to the operational value.

Acceleration

In LEAR, the accelerating frequency is derived from a pulse train generated by the derivative of the main magnetic field; a coil in a bending magnet provides this signal [1]. The frequency table had thus to be modified to take into account the value of q/m = 0.504 for O^{8+} ions. In order not to modify too much the LEAR cycle and to benefit from our knowledge of the machine, the beam was accelerated in 3 steps, each corresponding to a well-known momentum for antiprotons (see Table 1).

Table 1: Acceleration parameters

Ion kinetic energies, revolution frequencies and equivalent antiproton momenta during the acceleration cycle.

Flat Top	Ion Kinetic Energy (MeV/u)	Revolution Frequency (MHz)	Equivalent $\bar{p}$Momentum (MeV/c)
1	11.4	0.591	291.8
2	48.9	1.187	609.0
3	266.7	2.395	1500.0
4	408.5	2.738	1917.0

This allowed a relatively fast setting-up of the acceleration cycle, leading to a loss-free acceleration from 11.4 MeV/u to 408.5 MeV/u in three steps, with only small deviations from the central orbit (Figure 3).

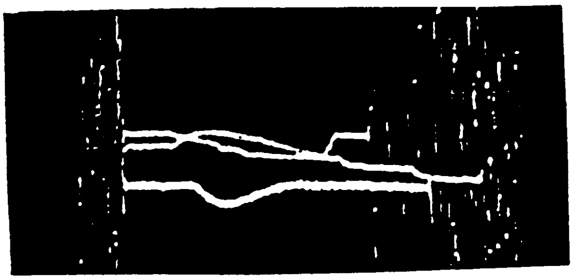

Figure 3: Beam position during acceleration. The observed signal is the Δ/Σ which is proportional to the beam horizontal position, and thus to the momentum deviation. The three traces correspond to the three acceleration ramps. The horizontal scale is 2s/cm and the vertical scale is 4.4mm/cm.

Extraction

LEAR's standard ultra-slow extraction [7] was used to eject the beam into the C1 line of the South Hall [8]. An attempt to extract the beam at 432 MeV/u was first made, but a lack of electric field on the electrostatic septum and of sextupolar correction power lead us to change our plans and set the extraction energy to 408.5MeV/u. The magnetic settings of the machine correspond to 1917MeV/c antiprotons, which had already been extracted from LEAR for the PS185 experiment,so the behaviour of the machine was well known and the setting-up was fast.

The extracted beam was monitored along the extraction line and in front of the target using multi-wire proportional chambers (MWPC). The display of the last MWPC in the line is shown in Figure 4.

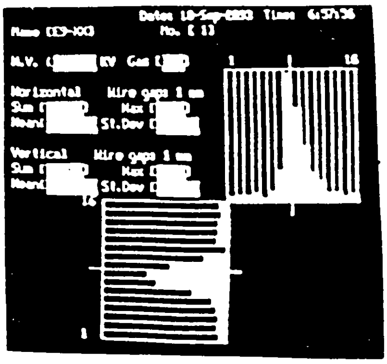

Figure 4: MWPC display of the extracted beam profiles. Both horizontal and vertical resolutions are 6.0mm.

Conclusion

LEAR has now demonstrated its ability to store and accelerate dense beams of heavy ions. These results are of interest for accelerator-based medical research (Figure 5) and for schemes to accumulate ion beams [9] for the high intensity option of the heavy ion programme at CERN.

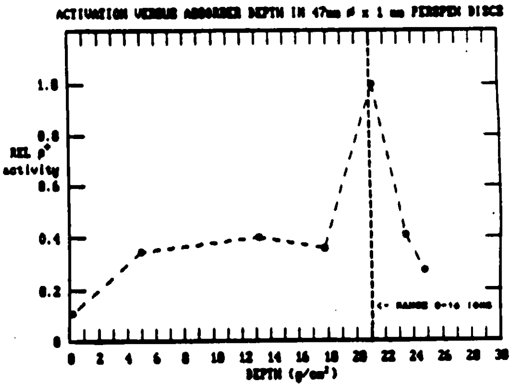

Figure 5: Bragg peak measurement. (from [6])

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References

1. P.Lefèvre, 'LEAR, present status and future developments.' in *Physics with antiprotons at LEAR in the ACOL era,Proc third LEAR workshop*, Tignes, France, 19-26 January 1985, Editions Frontières. pp33-46

2. P.Lefèvre, 'LEAR, present status and future developments.' in *Physics at LEAR with low energy antiprotons, Proc fourth LEAR workshop*, Villars-sur-Ollon, Switzerland, 6-13 September 1987, Harwood Academic Publishers. pp19-29

3. S.Baird et al, 'Stochastic cooling and storage tests with Oxygen ions in LEAR' in *Proc. 1989 IEEE Particle Accelerator Conference*, Chicago, USA, 20-23 March 1989, pp645-647.

4. H.Haseroth et al, 'Ion acceleration in the CERN LINAC I.' in *Proc. 1986 Linear Accelerator Conference*, Stanford, USA, June 2-6, 1986, pp355-357.

5. J.Bosser et al, 'Status of electron cooling experiments at LEAR', presented at the Workshop on electron cooling and new cooling techniques, Legnaro ,Italy, May 15-18, 1990.

6. Ch.Raffnsøe, A.H.Sullivan and J.W.N.Tuyn, 'Depth dose distribution of 408 MeV/nucleon $^{16}O^{8+}$ ions in tissue equivalent material.', TIS-RP/TM/90-01 (internal CERN, unpublished)

7. R.Cappi et al, 'Ultraslow extraction, status report', in *Proc. second LEAR workshop*, Erice, May 1982, Plenum press, pp49-54.

8. L.Danloy et al, 'The LEAR experimental areas: New layout for the coming AAC period' in *Physics at LEAR with low energy antiprotons, Proc fourth LEAR workshop*, Villars-sur-Ollon, Switzerland, 6-13 September 1987, Harwood Academic Publishers. pp31-40

9. D.Boussard et al, 'High intensity options for the CERN heavy ion programme ' This conference.