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CHARGE EXCHANGE INJECTION AND DIAGNOSTICS WITH H$^-$ IN LEAR

E. Asseo, M. Chanel, P. Lefèvre, C. Mazeline, D. Möhl, G. Molinari,
E. Steffens* and M. van Rooij
CERN, CH-1211 Geneva 23, Switzerland

Reported by E. Steffens

Abstract

The new 50 MeV H$^-$ beam[1] from Linac I has been employed for first machine tests at the end of 1984. The H$^-$ can be injected in the normal sense ("clockwise") to test the ring in antiproton polarity. In this mode, the lifetime of a beam of 8 x 10^8 H$^-$ has been determined to be about 7 s. The H$^-$ can also be stripped in the injection line to inject protons for machine studies without changing the ion source.

Using a new injection line[2] and a foil stripper in the centre of the straight section SL4, protons can be injected anticlockwise into LEAR by stripping injection. By multiturn injection, intense beams of protons for the collider option can be produced. Secondly, by using the normal injection kicker, protons can be ejected to test the antiproton injection line up to the PS with antiproton polarity. First results of the injection tests and the diagnostics based on fast and slow electrons from the stripper foil are reported.

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* Visiting scientist at CERN 1984, from Max-Planck Institut für Kernphysik, D-6900 Heidelberg.

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INTRODUCTION

The new 50 MeV H^- beam[1] from Linac I came into operation in October 1984. It enables several new options for physics and machine tests with LEAR. In Figure 1, the transport lines and elements used for injection with and without charge exchange are shown schematically. In addition to the existing line E2, a new injection line E3 [2] has been constructed and tested in 1984. The following injection modes with H^- ions are possible:

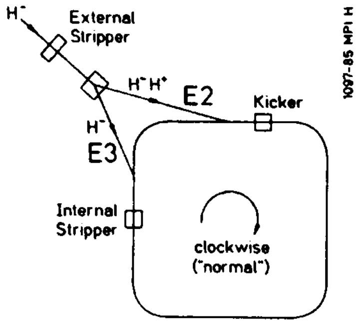

Fig. 1: H^- injection lines into LEAR. The E2 line is used to inject $\bar{p}$, H^- or, with reversed polarity, protons. The E3 line is used for charge exchange injection.

i) Kicker injection without stripping (via E2) : In this mode, LEAR can be tested in $\bar{p}$ polarity with (short-lived) H^- beams. Co-rotating beams of H^- and $\bar{p}$ can be obtained for the production of protonium in flight [3].

ii) Kicker injection with external stripper (via E2) : The purpose of this mode is to inject 50 MeV protons without change of ion source. In this way, the machine, including the cooling systems, can be tested with (long-lived) proton beams circulating clockwise, which requires however reversed polarity of all magnetic fields with respect to $\bar{p}$ operation. Since the startup of LEAR, such tests have been done routinely using the proton source installed on Linac I. Stripping in the transfer line will avoid the necessity to change the source during H^- periods.

iii) Stripping injection with an internal stripper (via E3) : Machine tests (except cooling and slow extraction) can be performed with protons "anti-clockwise", i.e. in $\bar{p}$ polarity. Kicker <u>ejection</u> of protons through E2 up to the PS should permit to optimize the setting of those lines in $\bar{p}$ polarity. In addition, intense proton beams for the collider option of

1) H^- LIFETIME IN LEAR

In a first attempt, H^- ions have been injected clockwise via the E2 line and up to about 8×10^8 ions were captured. From the decay of the beam transformer signal, a lifetime of about 7 s has been derived. The average pressure in LEAR during these tests was only about $2\text{-}4 \times 10^{-11}$ Torr because of the opening of the machine in October. The residual gas was 80 to 90% hydrogen (H_2). The measured life time is somewhat shorter than expected for residual gas stripping only [3]. This indicates that at these H^- intensities intra-beam stripping [3] seems already to play a role. More detailed tests are necessary to settle this question.

2) STRIPPING INJECTION, PRINCIPLE

The principle of stripping injection is shown in Figure 2. The closed orbit is displaced by a system of bumper magnets to traverse a thin foil. Injected H^- ions are stripped to H^+ which circulate in the ring and cross the foil several times without a significant emittance growth. The advantage of stripping injection is that by multiturn injection storage rings can be filled up to the space charge limit. Fast kicker magnets are not required. It is applied at various synchrotrons (e.g. Fermilab Booster [4], AGS Brookhaven [5] and SNS Rutherford Laboratory [6]). The H^- energy ranges from 20 to 200 MeV.

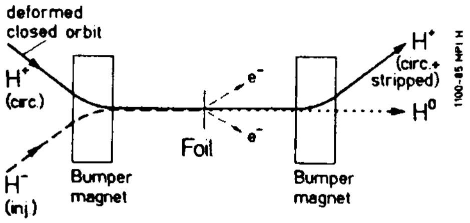

Fig. 2: Orbit bump for stripping injection. In LEAR the two bumper magnets are spaced by half a betatron wavelength

3) STRIPPER FOILS

Because of the Z proportionality of the stripping cross-section per target atom and the Z^2 dependence of emittance blow-up, a low Z material is required. In addition, the foil has to be very thin, typically 0.5 μm and, for LEAR, bakeable to 300° C. To be able to move the circulating proton beam away from the stripper, the foil has to be suspended on a C-shaped frame with on open side as shown in Fig. 3

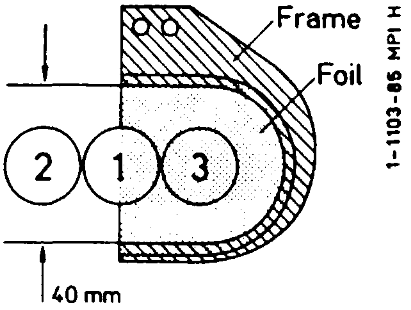

Fig. 3: Stripping foils and orbit position:
3) during injection,
2) after injection, fast bump off,
1) central orbit (foil withdrawn).

These requirements limit the choice of foil material to Carbon, Aluminium oxide or Aluminium Beryllium is usually ruled out due to its price and handling problems.

Carbon foils : delivered by "Arizona Carbon Foils" [7], they consist of Carbon evaporated on glass plates. Our attemps to mount 100 μg/cm^2 foils failed up to now, but 200 μg/cm^2 foils are used at Fermilab [4].

Al_2O_3 foils : a special technique of anodizing and etching has been developed at Rutherford Laboratory [6]. At CERN, 50 μg/cm^2 foils were made by Ch. Planner and M. Yates (Rutherford) after our test run. The foils seem to be very strong compared with Carbon.

Aluminium foils : Al foils of 220 μg/cm^2 supplied by Goodfellow [8] were used as a temporary solution during the test runs.

In Figure 4, the calculated stripping efficiency for 50 MeV H^- ions in Carbon is shown. A thickness of 50 μg/cm^2 is sufficient to obtain more than 95% H^+. Because the electron density (n_{el}/cm^2) is roughly proportinal to ρ.d, these curves can be taken in first approximation as universal for all light elements.

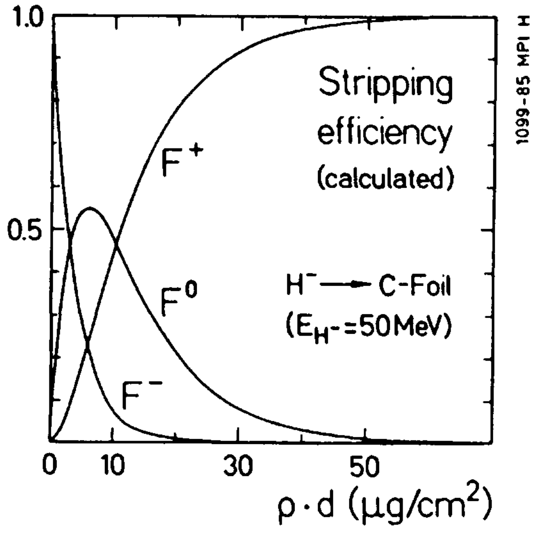

Fig. 4: Fraction of H^-, H^0 and H^+ as function of foil thickness

The emittance of the beam increases due to scattering on the foil. In Table 1, we summarize the blow-up[9] calculated for different foils. One notes that for the stripper used, the vertical emittance, of E_0 = 10 π mm mrad initially, will typically double during 10 turn injection followed by 2 turns to take the orbit off the foil or during 7 traversals of the whole beam through the foil.

Foil:	C, 100 µg/cm^2		$A\ell_2O_3$, 50 µg/cm^2		$A\ell$, 220 µg/cm^2	
Blow-up	horiz.	vert.	horiz.	vert.	horiz.	vert.
$\frac{\Delta E}{E_0}$ in 10 turns	6%	15%	6%	15%	30%	75%
Number of turns for ΔE = 10π mm mrad	150	60	150	60	30	15

Table 1 : Beam emittance growth[9] during injection of 10 turns and number of turns after which the initial emittance E_0 is doubled (E_0= 10 π x 10^{-6} m for 95% beam, β_{SH} = 2 m, β_{SV} = 5 m).
The table assumes continuous injection. At the end of the H^- pulse, when the whole beam (still) crosses the foil, the emittance growth is twice as fast. This is referred to as the circulating beam blow-up.

4) STRIPPER TANK AND DIAGNOSTICS

The newly installed stripper tank MST 42 is sketched in Figure 5.

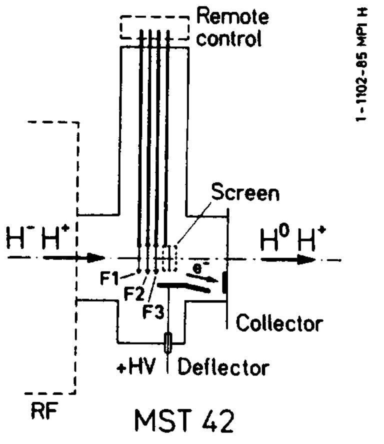

Fig. 5: Stripper tank containing 3 foils F1 - F3, a scintillator screen and a deflector - collector system to deflect fast electrons from the foil.

Three different foils and a screen are mounted on separate rods which are remotely controlled.

Two kinds of electrons are produced at the stripper foil:

i) Fast electrons detached from the injected H^- ions moving with beam velocity corresponding to 25 keV (electron) energy (2 electrons/H^-);

ii) Slow electrons (secondary electrons, $E < 10$ eV) generated in the foil by the injected and circulating beams.

In order to detect these secondary electrons for diagnostic purposes, the foil holders are insulated and the current from the foil is measured. To monitor the fast electrons, a high voltage electrode is used to deflect them onto a collector. The foil current I_f is a measure of the injected and circulating beam, whereas the collector current I_C is proportional to the injected current only. Because of the small distance of about 13 cm between the foil and the collector, a deflector voltage of up to 20 kV has to be applied.

5) ORBIT BUMP

For an efficient use of the aperture of the vacuum chamber, a sequence of slow and fast orbit bumps is applied (see Figures 3 and 6). For the slow bump, the backleg windings DWH41 and 32 of the main dipoles BHN40 and 30 are used. The fast bump is produced by new bumper magnets [11] DFH 42 and 41 at the extreme ends of straight section 4. Both pairs of bumpers are spaced by about ± 90° in horizontal betatron phase with respect to the centre of SL4. Therefore, an angular kick by one bumper leads to a parallel displacement of the beam in the centre of SL4. By the second bumper, the beam is bent back and moves on the central orbit in the rest of the machine.

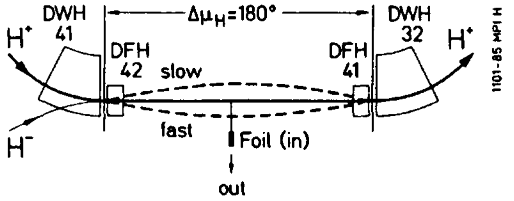

Fig. 6: Sequence of orbit bumps used.

The sequence of bumps for H^- injection is as follows. By powering the slow bump, the orbit is displaced slowly to the inside of the vacuum chamber ($\Delta r = - 2$ cm) and the foil is moved in from the outside. Its open edge now coincides with the centre of the chamber ($\Delta r = 0$). Then the fast bumper shifts the orbit by $\Delta r = + 4$ cm into the centre of the foil (Fig. 3). During the flat top the H^- beam arrives. The fast bump decays and the beam moves out of the foil. Then the foil is removed from the centre and the slow bump is switched off to center the beam.

6) FIRST TESTS ON STRIPPING INJECTION

In November 1984, stripping injection into LEAR has been tried for the first time. These tests suffered from various limitations.

The H^- beam pulses were less than 1 µs in length and only about 0.2 mA in intensity. Therefore, no test of multiturn injection was possible. A strong noise from the bumper magnets spoiled the signals I_f and I_c. Therefore, some preliminary tests on the stripper diagnostics have been done using only the slow bump with reversed polarity to center the beam onto the foil.

In Fig. 7a, the fast electron signal I_c from the collector is shown. A very sharp peak of about 0.2 µs in length, corresponding to the shape of the H^- pulse, is seen. The slow electron current I_f from the foil is shown in Fig. 7b.

Fig. 7a

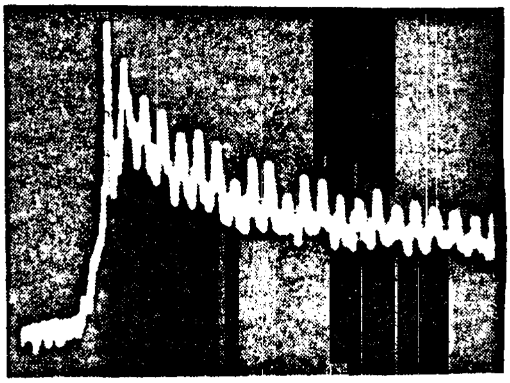

Fig. 7b

Pulse of fast (a) and slow (b) electrons from the foil monitoring injected and circulating beam.

It reflects both the injected and circulating beam. The first peak is the H^- pulse followed by about 20 turns of circulating beam visible on the photograph. The fall off is reasonably well explained by the vertical emittance blow-up of a factor of 3 for the circulating beam traversing the target (Table 3).

The maximum number of particles injected by stripping injection during these first tests was about 5.10^8. With an improved source injection of 5 mA H^- current should be feasible. This would correspond to more than 10^{10} protons injected per turn.

7) H^o DIAGNOSTICS

Using a thin Carbon foil of about 10 µg/cm^2 as a stripper, more than 40% of the H^- ions will be stripped to neutral H^o atoms. They are not affected by the bending field and leave the vacuum system through a thin stainless steel window, where they are stripped to H^+ and detected by the "H^o diagnostic system" (Figure 8).

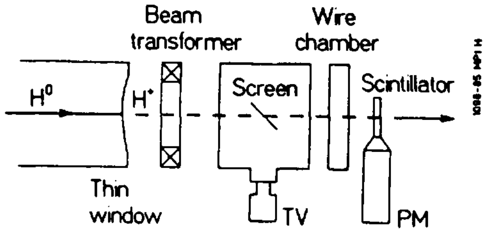

Fig. 8: System to detect H^0 from the foil

Thin foils were made by a glow-discharge technique which is used to produce stripper foils for electrostatic tandem accelerators[12]. These foils are mounted on a closed frame. A thin collodion layer applied to enforce the foils during mounting evaporates during the bake-out.

The intensity of the H^0 pulse was measured using a fast beam transformer to detect the H^+ after the window. In addition, the bright beam spot was seen on a screen viewed by a TV camera and the profile has been detected by means of a multiwire chamber. Finally, a scintillation counter served to determine the proton flux. Up to 2 x 10^8 protons per pulse were detected. This figure decreased to about 10^4 when the thick Aluminium foil was introduced. For such a low H^o flux, no beam was seen on the screen and the wire chamber.

Our results have shown that the H^o diagnostic system is very useful to optimize the conditions for stripping injection. A similar system will be used as a diagnostic tool for tuning the electron cooler.

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References

[1] C. Hill, this Conference.

[2] D. Dumollard, C. Mazeline, D.J. Simon et P. Birien, Optique de la ligne E3, PS/EA/BL/Note 85-1.

[3] U. Gastaldi, D. Möhl, Proc. 2nd LEAR Workshop, Erice 1982 (Plenum Press, London 1984), p. 649.

[4] C. Hojvat et al., IEEE NS-26 (1979) 3149.

[5] D.S. Barton et al., IEEE NS-30 (1983) 2787.

[6] V.C. Kempson et al., IEEE NS-28 (1981) 3085.

[7] Arizona Carbon Foil Comp., Tucson, Arizona 85711, USA.

[8] Goodfellow Metals, Cambridge CB4 4DJ, England.

[9] R.K. Cooper and G.P. Lawrence, IEEE NS-22 (1975) 1916.

[10] H. Bruck, Accélérateurs circulaires de particles, Presses Universitaires de France, Paris 1966, Chapitre XIV.

[11] D. Grier, K. Metzmacher, Design proposal for a LEAR Bump, PS/BT/Note 84-3.

[12] B. Huck et al., Nucl. Instr. Meth. 184 (1981) 215.

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