PERFORMANCE UPDATE OF LEAR

E. Asseo, S. Baird, J. Bosser, M. Chanel, P. Lefevre, R. Ley,
R. Maccaferri, D. Manglunki, D. Möhl, G. Molinari,
J.-C. Perrier, Th. Pettersson, G. Tranquille, D. Vandeplassche, D.-J. Williams

CERN - PS Division
CH - 1211 Geneva 23

Abstract

A description is given of the recent performance of the LEAR storage ring. This includes the improvements made on the ultra-slow extraction (time structure, flux limitation), the progress on the semi-slow extraction (~ 500 µs) at 61.2 MeV/c, and the results obtained from internal jet target operation at momenta higher than 800 MeV/c.

1. INTRODUCTION

Since 1982, LEAR has been running with ultra-slow extraction providing fluxes of 3.10^3 to 1.10^6 antiprotons per second to physics experiments. The new experiments installed since 1988 asked for fluxes of more than 10^6 antiprotons per second with a better duty factor (> 95%). The results obtained by adding a small air core quadrupole in the machine to counteract the horizontal tune fluctuations at harmonics of 50 Hz are described. As the fine structure (in the nanosecond range) is also important, some measurements are also reported. One of the major improvements of the machine is the deceleration and extraction of antiprotons at 61.2 MeV/c (2 MeV kinetic energy). A special semi-slow extraction set-up (500 µs corresponding to the post decelerator pulse) is presented. The first test made with protons and the expectations for the future are reviewed. Finally an internal jet target has been installed in LEAR at momenta between 1 and 2 GeV/c. The implication for the machine, the results of the first year of operation and the improvements foreseen are shown.

2. THE ULTRA-SLOW EXTRACTION

This extraction is of the resonant type, where the third order resonance 3 Q_H = 7 is used. The centre of the beam stack is tuned to Q_H = 2.325 and the horizontal chromaticity to 0.6. The particles are driven to the resonance by applying an RF noise signal to the beam, with a well defined bandwidth around an harmonic of the revolution frequency. This noise covers the resonance frequency and the upper frequency of the distribution of the circulating particles [1]. The lower side of the noise moves into the stack with a speed depending on the extraction time needed, the width and shape of the beam distribution. At first, this distribution was made rectangular prior to extraction to obtain a quasi constant extracted flux over the whole spill. As the fluxes now required by the users have increased drastically, the number of particles in the stack has also increased. At low momenta (< 309 MeV/c) diffusion processes such as intra-beam scattering alter the distribution and increase transverse emittances during the spill. These phenomena make it difficult to maintain a constant spill over one hour and reduce the overall extraction efficiency due to losses of circulating particles. To avoid such losses, stochastic cooling was applied in all three planes during extraction. The sweep speed must then follow a special function taking into account the instantaneous distribution. This function is programmed using the observed form of the previous spill. Around 10 spills are needed to obtain a constant extracted flux of particles. Some improvements are foreseen to make the generation of the sweep function automatic.

In addition to maintaining a constant flux the coarse structure at harmonics of the mains (generally called ripple) must be minimized. The quality of the coarse structure is measured by the so-called duty factor which is defined as the square of the mean flux $<\Phi>^2$ divided by the mean flux squared $<\Phi^2>$. The Fourier analysis of the particle flux (integration of number of extracted particles during 100 µs) can be written as :

$$\Phi = \alpha_0 + \sum_i \alpha_i \cos(\omega t + \varphi)$$

and consequently the duty factor is :

$$DF = \frac{\alpha_0^2}{\alpha_0^2 + \frac{1}{2}\sum_i \alpha_i^2}$$

To reduce the ripple a strong RF noise called the chimney [2] was applied near the extraction resonance making the particles' diffusion much larger than the movement of the resonance frequency. The duty factor increased from 50% to 85%.

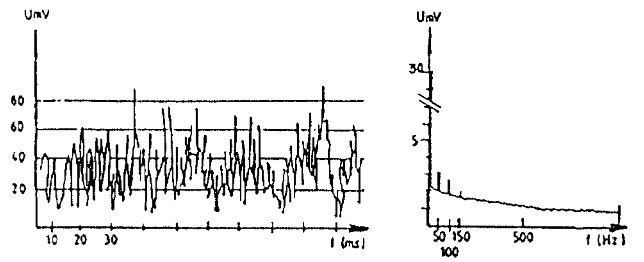

Figure 1 Time and frequency analysis of the coarse structure of a typical extraction at LEAR. The background of the frequency domain correspond to stochastic fluctuations of counting rate during 100 μs.

The arrival of more sensitive experiments requires a more advanced solution. Acquiring the flux of extracted particles in synchronism with the mains and making a Fourier analysis, we have observed a quasi-constant amplitude and phase of the most important frequency lines (50 Hz, 100 Hz) for a long period. Thus we installed a small air core quadrupole in the machine powered by a commercial hi-fi amplifier. The signal applied is created using a programmable function generator synchronized to the mains. Frequencies from 50 Hz to 300 Hz can be generated as needed. In this way duty factors better than 95% and overall efficiencies over one hour spill higher than 75%, even at 200 MeV/c, have been obtained (Fig. 1). A more sophisticated system is being constructed which will use a non pertubative detector of the extracted flux [3]. The signal obtained will be used in a feedback loop through the quadrupole.

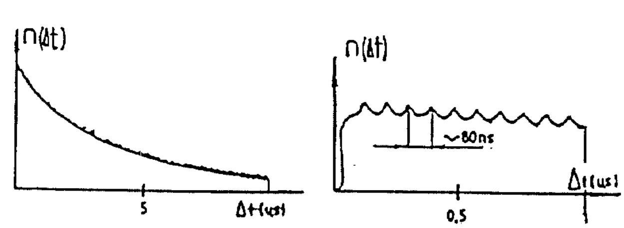

Figure 2 Distribution of particles arrival times (see text).

A fine structure in the nanosecond range is also present in the spill. By looking at the distribution of particle arrival times, we have found a decreasing exponential indicating a good stochastic extraction. A little ripple is seen in the distribution (every 80 ns) corresponding to the chimney frequency (Fig. 2) without consequences for the users.

3. THE SEMI-SLOW EXTRACTION

For the mass spectrometer experiment the whole beam must be extracted in 500 μs at 61.2 MeV/c for further deceleration in a dedicated RFQ [4] to 20 MeV/c (200 keV kinetic energy). During deceleration in LEAR electron cooling is used on different flat-tops to reduce the beam dimensions [5]. At 61.2 MeV/c the beam (4.10^8 to 10^9 particles) conserved under electron cooling has the following characteristics: $\varepsilon_{h,v}(2\sigma)$ around 10π mmmrad, $(\frac{\Delta p}{p})_{4\sigma} = 10^{-3}$, and life time = 30 mn.

The normal ultra slow extraction is used for testing the beam lines (15 mn per spill). Two methods are available to produce an extraction of 500 μs [6].

The first one is obtained by bunching the beam and accelerating it through the resonance. The frequency change per unit time has to be fast enough so that all the particles go through the resonance, but slow enough to leave time for the particles to migrate along the separatrices to the electrostatic septum. The first condition is given by the momentum spread of the bunched beam, the second by the initial amplitude of oscillations of the particles. The global efficiency can then be deduced from the speed of acceleration by using the convolution of the longitudinal and horizontal distributions (Fig. 3). The efficiency can be improved by increasing the horizontal emittance. This was done using RF noise applied on one horizontal betatron sideband prior to the extraction of the beam.

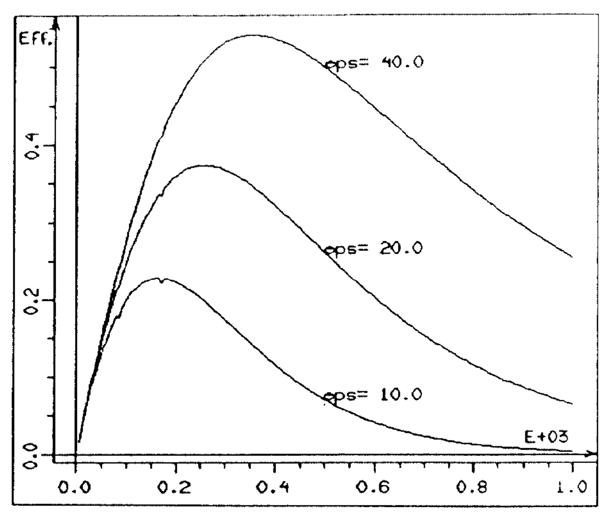

Figure 3 Computed efficiencies of semi-slow extraction versus the acceleration speed (Hz/ms) to the resonance for different beam emittances (95%) and for $(\frac{\Delta p}{p})_{4\sigma} = 1‰$.

The second method consists of accelerating the beam close to the resonance, and then applying a small transverse kick which brings the particles outside the stable area in the phase space diagram. Then, the particles diffuse to the electrostatic septum with a speed depending on their position after the kick. In this way, a 200 μs burst was obtained (50 turns in the machine) with a good efficiency.

In 1992, the second method will be used with some improvements on the kicker pulse (4 μs instead of 1 μs actually) to allow for the extraction of the whole beam in one shot.

4. THE INTERNAL JET TARGET

An experiment called Jetset is now installed in the straight section 2 of LEAR. It uses a horizontal hydrogen jet target and requires small vertical emittances and adjustment of the vertical beam position [7]. Up to now we have used a single injection into LEAR of one 0.2 eVs bunch from AA.

Stacks of 3.10^{10} particles are stored in LEAR. Transfer efficiencies from AA are better than 60%. The beam is cooled by stochastic cooling before acceleration to final momentum (between 609 MeV/c and 2000 MeV/c). Then further stochastic cooling is applied in all three planes to counteract multiple scattering by the jet target.

Due to the horizontal orientation of the jet, the vertical emittance has to be kept small to get the best possible luminosity. Values better than 2π mmmrad (95% of beam) were obtained for 2.10^{10} particles circulating in the presence of the jet. The beam instabilities which start to occur at this high beam density are damped by an active feedback system.

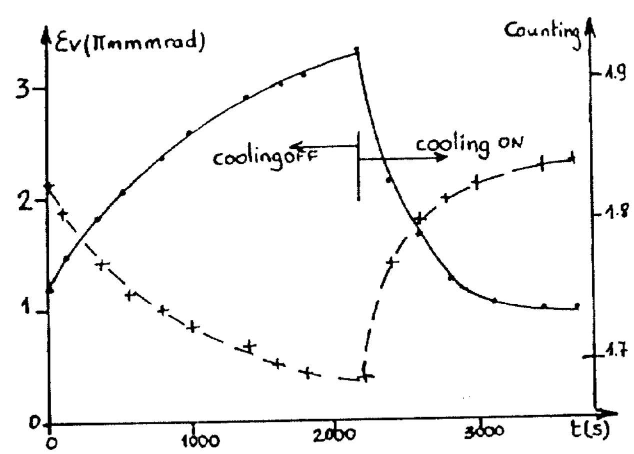

Figure 4 Evolution of the vertical emittance (solid) and elastics counting rate in jet set (dashed) with stochastic cooling ON and OFF at p = 1500 MeV/c and with 18.10^9 antiprotons.

Measurements of the evolution of the luminosity and of the vertical emittances are reported in figure 4. The measured blow up rate correspond to a luminosity around $6.10^{29}.cm^{-2}.s^{-1}$, for a jet density of 6.10^{12} atom.cm^{-2}. This is confirmed by the measured beam loss rate.

The jet density will be increased by a factor 4 by approaching the source and the recuperation closer to the vacuum chamber. We intend also to increase the number of circulating particles (up to 5.10^{10}) using multi-batch injection (topping-up) in the longitudinal phase plane as was done in LEAR with oxygen ions [8].

5. CONCLUSION

The characteristics of the LEAR beam are as follow:

Beam	Type	Momentum	Flux
LEAR external beam	– ultra-slow extraction	0.06-2.0 GeV/c	• ≤ $3.10^6\,\bar{p}$ for 1 hour spill. • spill from 15' to 4 hours.
	– semi-slow extraction = 500μs	61.2-105 MeV/c Other momenta possible	one shot: $3.10^8\bar{p}$ $5 \times 3.10^7\bar{p}$/ shot
	– fast extraction = 50 . . 400 ns multishot	61.2-200 MeV/c	~ 10^7 to $10^9\,\bar{p}$/shot
LEAR internal beam	Internal gas jet target	0.6-2 GeV/c	$3\ 10^{10}\,\bar{p}$ circulating
	Other possible internal targets	Low momentum = 200-300 MeV/c	$10^{10}\,\bar{p}$ circulating.

6. REFERENCES

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