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MEASUREMENTS ON THE LOW-INTENSITY BEAMS OF LEAR AND THE ANTIPROTON ACCUMULATOR

J. Bosser

Abstract

This report is complementary to that written by H. Koziol entitled "Diagnostics for Low Intensity Beams" (CERN/PS 95-23 BD). Within this framework, we present and comment upon measurements made on some of the detectors already in use on the LEAR, AC and AA accelerators. Emphasis is placed on low-intensity beams and on the processing of weak signals, resulting from special diagnostics.

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J. Bosser
CERN, Geneva, Switzerland

1. INTRODUCTION

In this paper we aim to report on measurements made on the CERN Antiproton Collector (AC), the Antiproton Accumulator (AA), and the Low Energy Antiproton Ring (LEAR) proton and antiproton beams. The AC/AA machines operate at fixed energy but with various intensities while LEAR operates at various intensities and at momenta which can range from 105 to 2000 MeV/*c*. Besides its present use, it is also foreseen that LEAR will operate with low-intensity Pb^{53+} ion beams.

In the spirit of the present report the definition of low intensity is therefore given with respect to measurements made on existing machines and hence in a real environment.

The report is in two main parts. The first part reports on some measurements made on LEAR, while the second part deals with a few experiments made on the AC/AA machines. The measurements, made on both machines, were intended to determine the limits of beam diagnostics.

2. MEASUREMENTS MADE ON LEAR

As for many accelerators, the LEAR beam detectors are used for monitoring the circulating (or stored) and extracted beams.

2.1 Circulating beams

For the purpose of our measurements we ran the machine at a fixed momentum $p = 200$ MeV/*c* ($\beta = 0.2$, $f_{rev} = 0.79$ MHz) and performed intensity, position, and transverse profile measurements with a number of different proton intensities stored in the machine.

2.1.1 Intensity measurements

For these measurements [1] we used two types of detectors namely the DC Beam Current Transformer (BCT) and the longitudinal Schottky pickup.

When the unbunched beam, consisting of N protons, has a relatively small density $N/(\Delta p/p)$ (which happens in our case for $\Delta p/p \geq 10^{-3}$), the integrated Schottky power spectrum P in each band centred around a multiple of the revolution frequency is proportional to N and therefore to the beam intensity I (at a given energy).

The lower intensity limit which can be attained by the BCT is limited by external noise and by various drifts (temperature variations, etc.). However, for intensities in excess of 100 μA the BCT provides an accurate measurement of the intensity such that it can be used to calibrate the Schottky detector.

Figure 1 gives the plot of the stored proton-beam intensity measured with the BCT against the longitudinal Schottky integrated power. One can notice a quite linear relation between the two measurements which can be expressed by:

$$I_{BCT}\,[\text{mA}] = 0.049 \cdot P_{\text{Schottky}}[\mu\text{W}] + 0.002\,. \qquad (1)$$

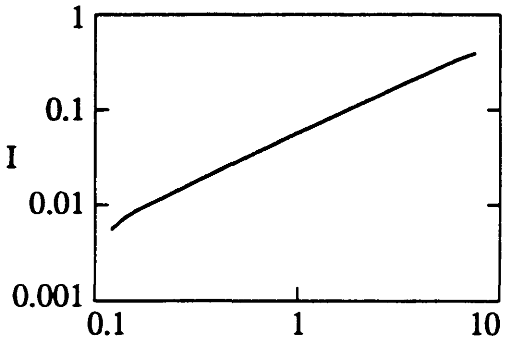

Fig. 1 Intensity I [mA] versus the integrated Schottky power [μW] (logarithmic scales).

Having calibrated the spectrum analyser, as mentioned before, we can make use of the longitudinal Schottky pickup for intensities as low as 0.1 μA so as to detect at least 7.8×10^6 stored protons.

In addition to the technical difficulties inherent in the construction and exploitation of an accurate BCT, the filtering of the output signal is of prime importance. Figure 2a shows the non-filtered signal (upper trace) where the observed perturbations are induced by the mains phase jumps which are synchronous with the PS Booster cycle (1.2 s). The lower trace shows the low-pass filtered output (low-pass filter with 0.05 Hz bandwith) of the same measurement. In order to determine the resolution or precision of the BCT we looked at the residual noise. This lower limit can be estimated from Fig. 2b where it can be seen that the uncertainty is about ± 2 μA. This is coherent with the constant intensity given in the right-hand part of Eq. (1). This determines our present resolution. Studies are under way in order to improve the actual resolution and accuracy.

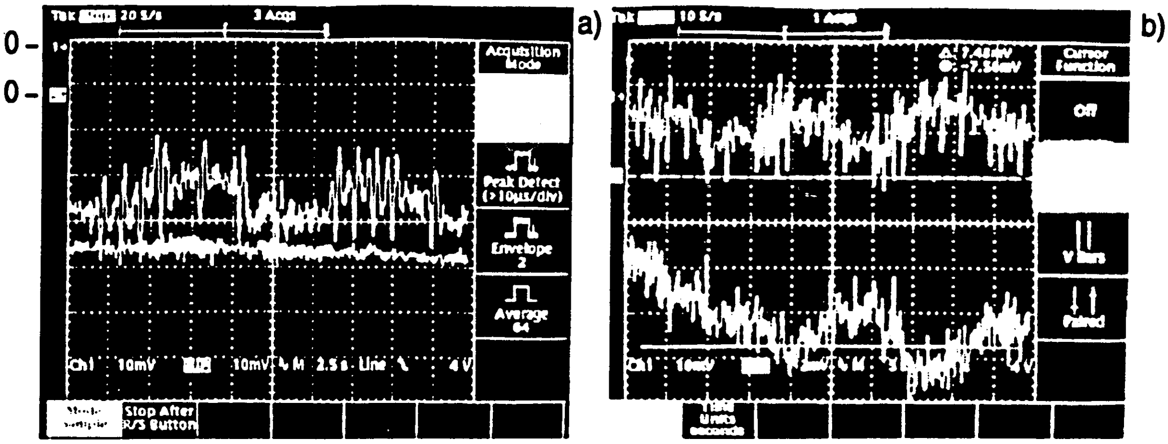

Fig. 2 BCT output voltages: (a) upper trace non-filtered signal, lower trace filtered signal (38 μA), vertical scale 10 μA/div., horizontal scale 2.5 s/div.; (b) raw signal from BCT. Upper trace 10 μA/div., lower trace 2 μA/div. The mean current = 7.5 μA, horizontal scale 5 s/div.

Table 1

Position measurements with a gain of 40 dB

DC intensity	Network settings		PU 31		PU 32	
[μA]	Amplitude [V ptp]	Bandwith [kHz]	Average pos. [mm]	r.m.s. error [mm]	Average pos. [mm]	r.m.s. error [mm]
383	1	3	9.63	0.16	15.93	0.06
131	1	3	0.73	0.06	15.86	0.23
40	1	3	9.93	0.26	16.7	0.1
40	0.1	3	10.0	0.6	16.5	0.4
40	0.1	0.1	0.3	0.01	15.4	0.01
10	0.1	0.1	9.0	0.01	15.46	0.4
5	0.1	0.1	10.0	0.3	16.6	0.3

If one considers that a 20% accuracy with the BCT is obtained when $I_b = \pm 10$ μA, we can foresee the detection of 3×10^6 stored lead ions Pb^{53+} expected to be stored at $\beta = \sigma/c = 0.1$).

2.1.2 Position measurements

As for most of the monitors (including the BCT) which have to cover a large range of intensities and energies, the beam-position measurement system is far from being optimized for low-intensity beams.

The principle is described in Ref. [2]. The sum (Σ) and difference (Δ) signals, from electrostatic pickups, are first amplified and then routed, via a multiplexing system, to the input of a network analyser which computes the absolute value and the sign (phase) of Δ/Σ. The network analyser input voltage range and filter bandwith can be adjusted in steps.

In our experiments we first performed an orbit bump at the level of the so-called LEAR 31 and 32 position pickups. The current was then reduced in steps, and for each intensity we made three or four measurements to check for the reproducibility and to estimate the measurement errors. For the same intensity we also analysed the influence of the network analyser settings.

Part of our measurements are summarized in Table 1 from which it is possible to check that the measurements are quite accurate. Using the highest available gains in the Δ and Σ electronic channels we were able to get the same accuracies but with DC intensities as low as 1.0 μA ($\beta = 0.2$).

2.1.3 Profile measurements

Ionization profile measurements [3] are commonly used at LEAR for each transverse plane. The circulating high-energy particles ionize the residual gas molecules. The ionized electrons and/or ions are directed, by an electric field, towards a microchannel plate (MCP) amplifier. The amplified electrons coming out of the MCP are collected by strip foils. The integrated currents from the foils enable the reconstruction of the transverse profile.

In the case of LEAR the low pressure ($P \leq 10^{-11}$ torr) and the large betatron amplitude function ($\beta_h = 11$ m; $\beta_v = 6.4$ m) entail some difficulties which limit the use of this type of detector to intensities larger than 40 μA. Figure 3 shows one of our measurements at this intensity.

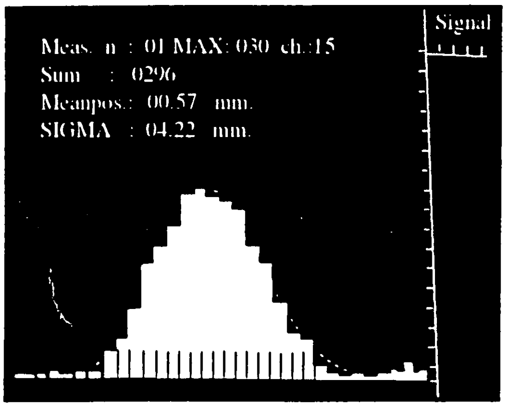

Fig. 3 Measurement from ionization beam-profile monitor (horizontal plane, resolution: 1 mm).

2.2 Transfer line

LEAR delivers antiproton beams to the physics experiments by means of fast and slow extractions at momenta which can be as low as 105 MeV/c. In the case of ultra slow extraction it is essential to estimate the intensity and the ripple of extracted beams having a flux of between 10^3 and 10^6 particles per second for a period of about two hours. Together with the extracted rate the measurements of the transverse profiles are of prime importance. The detectors used for the latter purpose are interceptive.

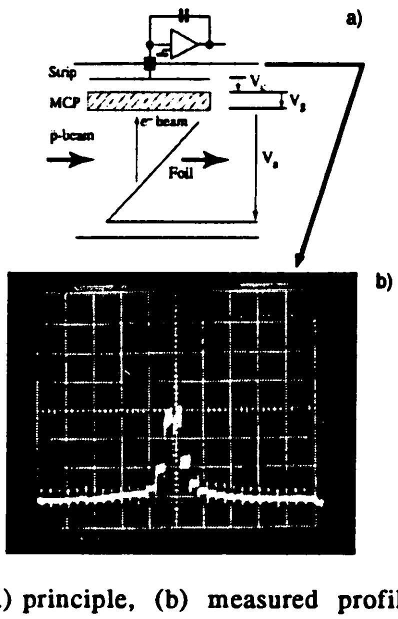

Fig. 4 (a) principle, (b) measured profile, N_p = 8×10^4 p/s, V_g = 1300 V, V_a = 1700 V, vertical scale 100 mV/div., grid interval 1.5 mm, p = 105 MeV/c.

One method [4] consists in the use of a thin metallic foil crossed by the extracted antiproton beam (Fig. 4a). The secondary electrons coming out of the foil are accelerated towards a microchannel plate (MCP) where they are amplified. The electrons coming out of the MCP are collected on strips in order to obtain the profile as shown in Fig. 4b. The replacement of the MCP ensemble by a scintillator–photomultiplier system permits an accurate measurement of the spill rate down to a few 10^3 particles per second [5]. Another arrangement consists in the use of a thin scintillator (CsI) instead of the metallic foil together with a highly sensitive image detector to replace the MCP arrangement. Again profiles are measured with about 1200 antiprotons/(s $\cdot$ mm^2) [4].

Multiwire proportional chambers are commonly placed at the end of the transfer line. We are able to measure horizontal (resolution: 2 mm) and vertical (resolution: 4mm) distributions with spill rates as low as 1000 p/s.

3. MEASUREMENTS ON THE AC AND AA

The antiprotons are produced by a target which is hit by an intense and energetic proton beam delivered by the PS. A PS pulse of 8×10^{12} protons, at 26 GeV/c, results in about 3.7×10^7 antiprotons injected into the AC together with 10^{10} pions (which have a lifetime of a few turns) and about 10^9 muons (which have a lifetime of 100 turns). The bunch in the AC is subject to an RF rotation followed by strong stochastic cooling, in all planes, prior to its transfer to the AA. Once in the AA the bunch is again cooled and deposited into a dense stack circulating in the same beam pipe but on a different orbit. On request, part of the stack is transferred to the PS and then to LEAR. The AC/AA setting-up can be made with protons coming from the PS in the reverse direction, through the antiproton ejection line.

The classical detectors (intensity, position) are of course extensively used with bunched and unbunched beams of about 10^7 antiprotons. As for LEAR, the intensities are monitored by the integrated longitudinal Schottky power signals calibrated by the BCT. Therefore we intend to mention a few of the detectors which are specific to these machines.

3.1 Longitudinal Schottky pickups on AC/AA

Both the AC and AA have sensitive resonant longitudinal Schottky pickups (working near harmonic 40, i.e. $f \approx 70$ MHz, of the revolution frequency) to measure the total intensities (integration over frequency of the total spectral power minus the integral of the noise power spectral density over the same band) of injected antiprotons and their momentum distribution. Typical antiproton intensities are between 3×10^7 and 8×10^7

and the resolution is of the order of 10^6 particles. Intensities and momenta are thus routinely measured during all stages of the cooling and stacking processes.

In the AA, together with high sensitivity, one has to cope with a large dynamic range as the observation of low intensities must work in the presence of an antiproton stack typically 10^4 times more intense.

An example of particle distributions as measured with these pickups in the AC is shown in Figs. 5a and 5b.

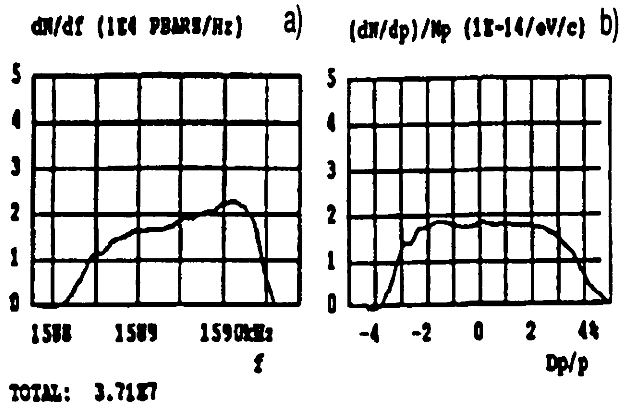

Fig. 5 Longitudinal Schottky distributions.

3.2 Transverse profiles in the AC

In order to determine the transverse particle distribution a destructive device is used. It consists of a horizontal or vertical scraper driven from the border to the centre of the beam. The showers induced by the lost particles are detected by a scintillator–photomultiplier ensemble placed outside the vacuum chamber. The transverse profile distribution and emittance can thus be determined as in Fig. 6.

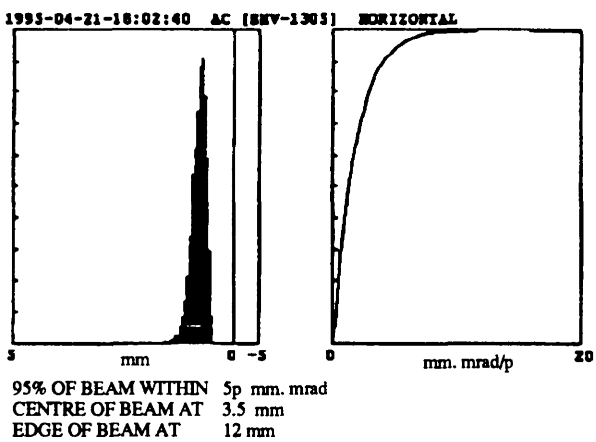

Fig. 6 Horizontal profile after horizontal scraping, $N_{\bar{p}} = 3.5 \times 10^7$.

It is worthwhile to mention that both in the AA and the AC emittances are routinely obtained from transverse Schottky scans.

3.3 The resonant dipolar pickups in the AA

These are used exclusively to verify and correct (via a 2 × 2 transfer matrix) the injection oscillations of the low-intensity antiprotons injected from the AC. Observation times, of the order of 100 μs (200 turns), are used to extract the minute signals from the noise.

A measurement is displayed in Fig. 7a. The FFT of the horizontal signal is given in Fig. 7b. It clearly shows a line appearing at $(3 - Q) \times f_{rev}$).

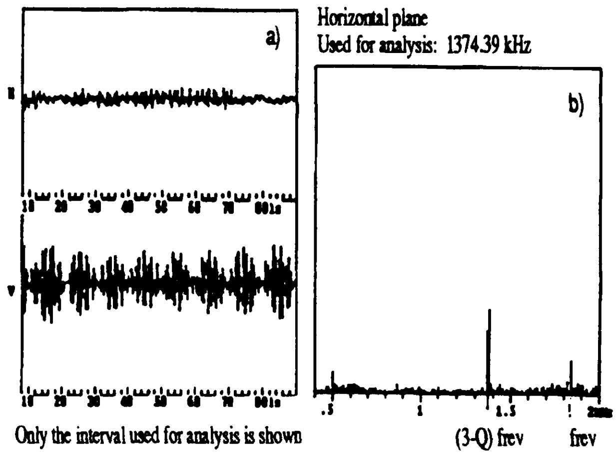

Fig. 7 Resonant dipolar pickup diagnostics: (a) H and V signals, (b) FFT of the horizontal signal.

3.4 The quadrupolar pickup in the AA

It is used for two totally different purposes.

1) The observation of coherent antiproton–ion quadrupolar transverse instabilities [6] (breathing mode) occurring in the fairly intense ($>3 \times 10^{11}$) antiproton unbunched stack [at $(n \pm 2 \times q) \times f_{rev}$]. The dipolar instabilities are damped by active damping.
2) The verification and correction of transverse matching of bunched test protons (intensity: few 10^{10}) from either the PS (normal magnet polarity) or the AC (reverse magnet polarity) [7]. Figure 8 displays such a measurement. In this case a high degree of common-mode rejection is required since the quadrupolar signal from the injection quadrupolar oscillation (due to mismatch) is minute compared with the common-mode signal from the bunched beam. This effect is not relevant in case 1.

The quadrupolar signals from injection mismatch of low-intensity antiprotons from the AC are far too small to be observable, even if the pickup plates were made resonant.

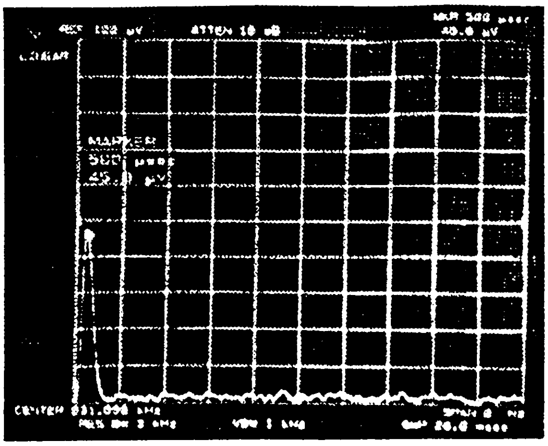

Fig. 8 Evolution of quadrupole coherent oscillation at injection from the PS. Vertical scale: quadrupolar signal amplitude; horizontal scale: time.

4. CONCLUSIONS

In the framework of low-intensity beams [8] a limited number of classical detectors have been selected to illustrate their use for the monitoring of proton and antiproton beams. The measurements show that, for intensities as low as 10 µA, accurate data are obtained on all the machines concerned.

The diagnostics of faint dipolar and quadrupolar modes of beam oscillations are also mentioned.

Acknowledgements

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