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**BEAM MEASUREMENT SYSTEMS FOR THE CERN ANTIPROTON  
DECELERATOR (AD)**

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# BEAM MEASUREMENT SYSTEMS FOR THE CERN ANTIPROTON DECELERATOR (AD)

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## Abstract

The new, low-energy antiproton physics facility at CERN has been successfully commissioned and has been delivering decelerated antiprotons at 100 MeV/c since July 2000. The AD consists of one ring where the 3.5 GeV/c antiprotons produced from a production target are injected, rf manipulated, stochastically cooled, decelerated (with further stages involving additional stochastic and electron cooling and rf manipulation) and extracted at 100 MeV/c. While proton test beams of sufficient intensity could be used for certain procedures in AD commissioning, this was not possible for setting-up and routine operation. Hence, special diagnostics systems had to be developed to obtain the beam and accelerator characteristics using the weak antiproton beams of a few  $10^7$  particles at all momenta from 3.5 GeV/c down to 100 MeV/c. These include systems for position measurement, intensity, beam size measurements using transverse aperture limiters and scintillators and Schottky-based tools. This paper gives an overall view of these systems and their usage.

## 1 INTRODUCTION

The AD provides antiprotons at low-energy for physics in a much simplified manner than the series of machines that were necessary in the past. Full details about the AD are well-documented [1], [2], [3] with the functioning best illustrated in Fig 1, which shows the essentials of the AD operation. Starting with  $\sim 5 \times 10^7$  injected antiprotons in  $190\pi$  mm.mrad machine acceptance and  $\pm 3\%$  momentum spread, the beam ejected is of the order of 2 to  $3 \times 10^7$  antiprotons in a single bunch of 230-400 ns with a momentum spread of  $\sim 0.2\%$  and transverse emittances  $< 1.5\pi$  mm.mrad. The different beam cooling systems in the deceleration process not only compensate for the adiabatic beam blow-up but also cool the beam even further. Great emphasis had to be put on certain beam measurement systems, e.g., monitoring of the beam position, size and intensity through the AD cycle with the beam intensity of  $\sim 10^7$  particles, corresponding to  $\sim 260$  nA at 100 MeV/c. Hence, greater exposure has been given to these particular systems in this paper, with other installed systems briefly mentioned at the end.

## 2 POSITION MEASUREMENTS

During deceleration, several plateaux are introduced to permit different stochastic or electron cooling systems to act on the beam. It was desirable that at each intermediate

energy level, the orbit should be measurable and if necessary, corrected.

The closed orbit measurement system [4] employs 59 electrostatic pick-ups (PU). The intensity range from  $2 \times 10^{10}$  down to  $10^7$  particles poses challenging demands on the dynamic range and noise of the head amplifier. A low-noise amplifier was developed, having an equivalent input noise of  $0.6 nV / \sqrt{Hz}$ , allowing beam positions to be measured to  $\pm 0.5$  mm with as few as  $5 \times 10^6$  particles. Two different gains take care of the large dynamic range. After amplification and multiplexing, the PU signals are fed to a network analyser, where every measurement point corresponds to one PU. The network analyser is locked to the rf of the AD, thus acting as a "tracking filter" instrument. An orbit measurement takes from 0.5 to 12 s depending on the IF-bandwidth of the network analyser, which is selected according to the beam intensity, and the precision required. At the end of the network analyser sweep, the data are read via a GPIB interface and treated by a real-time task running in a VME crate.

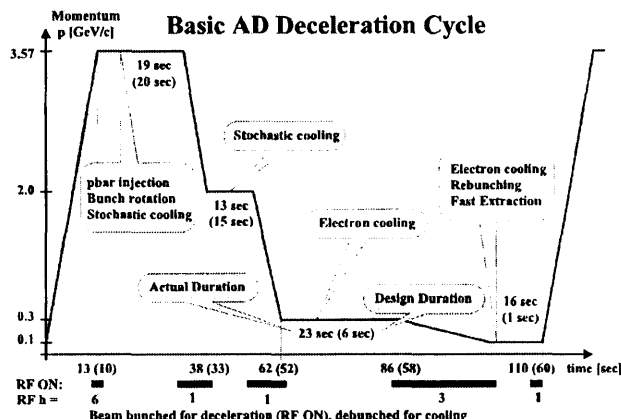


Figure 1: AD Cycle & Plateaux with Processes

## 3 INTENSITY MEASUREMENTS

### 3.1 Higher intensity ( $\sim 10^9$ ) circulating beams

A dc Beam Transformer (DCBT) is used to measure the bunched or unbunched circulating beam current. The device has been particularly adapted to the AD needs, deceleration and control system. In order to provide a measurement of the beam charge through out the energy range, a so-called relativistic  $\beta$  normaliser has been added. It is essentially an amplifier whose gain is proportional to  $1/\beta$ ; the value of  $\beta$  is deduced from the

position is subtracted from the total number of counts, yielding an amplitude distribution similar to the one for the beam current. Using the scintillators extends the measurement range to very low beam intensities, where the DCBT is not sensitive enough.

The beam current or the scintillator counts rate as a function of the scraper position may be differentiated to obtain the "betatron amplitude distribution". The function is plotted at the end of the measurement and numerical fits are applied to the positions of the edge and centre of the beam. The "95%-edge", i.e., the scraper position where the remaining beam current is 95% of the initial current, is determined by interpolation. For the projected one-dimensional Gaussian distribution characterised by value  $\sigma$ , the emittance  $\epsilon$  is calculated as  $\epsilon = (2\sigma)^2 / \beta$ , where  $2.45\sigma$  (for two-dimensional Gaussian) is the distance between the 95%-edge and the centre, and  $\beta$  is the value of the betatron-function (horizontal or vertical) at the scraper position.

For acceptance measurements, an rf signal is used to "blow-up" the beam horizontally or vertically. If this is done until a pre-selected decrease in beam current, one is assured that the beam fills the entire acceptance of the machine. Again, the scraper blade is moved in and the remaining beam current decreases quadratically with the blade position in the vicinity of the beam edge. This is used to determine the exact position of the beam edge by fitting a parabola to the measured points around the edge. The acceptance is calculated as  $(X_{edge} - X_{centre})^2 / \beta$ , where  $X_{edge}$  and  $X_{centre}$  are the respective positions at the beam edge and centre.

## 5 TUNE MEASUREMENTS

It is desirable to measure the machine tunes in real time during the deceleration cycle, both at the plateaux and during ramps. The low intensity of the antiproton beam in the AD prevents the use of standard transverse Schottky techniques to measure the tunes using the new resonant Schottky pickup shown in Fig. 4. Therefore, a Beam Transfer Function (BTF) technique with the excitation of sidebands is necessary. For AD operation to date, tune measurements on different momentum plateaux are carried out using a swept BTF method and a network analyzer. This technique is slow due to pauses required on the plateaux, causes beam blow-up and is not applicable to measurements on the ramps. Hence, an improved system is under development [7]. This method uses an M-shaped power spectrum to excite the beam in a band around the expected frequency of a betatron side band. Excitation at the betatron frequency, where the beam response is highest, is thus minimised and the measurement of the BTF, hence the tune, may be performed with much reduced emittance blow-up.

The receiving system consists of: (a) an electrostatic PU made resonant at 5.7 MHz with a Q factor of 900 and (b) a low noise amplifier using feedback to simulate a "noise free" resistor that de-tunes the system to a Q of 3. The high Q of the PU is obtained by having the coil inside the vacuum chamber, as shown. This ensemble gives a bandwidth of 1 MHz, wide enough to always contain at

least one betatron side band, in which the Johnson noise from the losses in the coil is dominant. The system Q of 3 means that tuning of the PU is not needed. After signal conditioning to overcome the quantisation noise, the signals would be digitally down-converted and post-processed in the same DRX board used for intensity evaluation [5]. In this manner, the DRX system will permit rapid measurements of tunes, intensity and other parameters in an integrated manner, i.e. all along the AD cycle, on the plateaux and on the ramps and using the same beam, without recourse to cycle pauses at different momenta as at present.

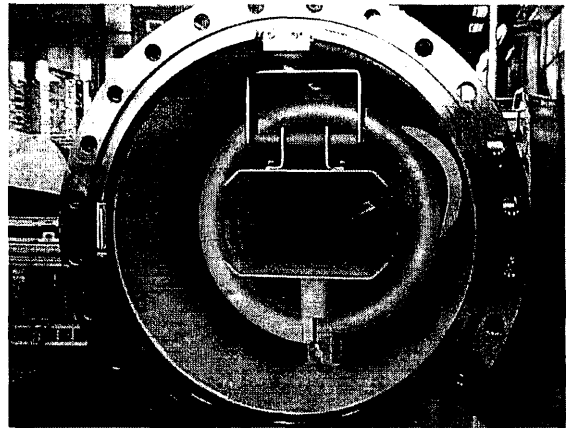


Figure 4: The Transverse Resonant "Schottky" PU.

## 6 OTHER SYSTEMS

The AD and the beam lines have other measurement systems installed for routine usage. There are 8 fast beam current transformers used for the production and test beams as well as for the extracted beam where feasible. There are 18 scintillation screens used for beam observation with TV cameras. A 100 MHz set of digitizers perform measurement & correction of test beam coherent oscillations. Several Multi-wire Proportional Chambers provide beam profiles in the beam extraction lines. Special devices are used in the 60 keV decelerating RFQ beam line.

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