ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPME176

CERN ANTIPROTON DECELERATOR BEAM INSTRUMENTATION FOR THE ELENA ERA

M. Ludwig, L. Bojtar, M. Fernandes, M. Gasior, L. Søby, G. Tranquille, CERN, Geneva, Switzerland

Abstract

CERN is currently constructing an Extra Low ENergy Antiproton ring (ELENA), which will allow the further deceleration of antiprotons from the currently exploited Antiproton Decelerator (AD). In order to meet the challenges of ELENA the beam instrumentation systems of the CERN AD are being consolidated and upgraded. An updated controls architecture with a more flexible timing system needs to be adopted and obsolete systems must be replaced. This paper presents the status and plans for improved performance and measurement availability of the AD beam instrumentation with a decreased risk of failure.

INTRODUCTION

In order to provide the required flexibility, reliability and performance for AD setup and operation with antiprotons for ELENA the beam instrumentation needs to be consolidated. This renovation is a good preparation for developing ELENA beam instrumentation since both antiproton rings have some basic beam parameters in common (see Table 1) [1,2].

Table 1: Beam Parameters AD and ELENA

	AD	ELENA
Momentum [MeV/c]	3570...100	100...13.7
F_{rev} [kHz]	1589...174	1050...145
Beam current [µA]	12...0.3	4.7...0.4
intensity [#charges]	$5•10^7$...$3•10^7$	$3•10^7$

Even though the necessity for a proton pencil-beam, with an intensity of around 10^{10} charges (for AD set-up in reverse polarity with the target removed) cannot be entirely excluded, the beam instrumentation is specified for the more meaningful and largely preferred antiproton setup scenario. This paper highlights the state and progress made for existing instrumentation upgrades and for three new projects: a ring intensity monitor based on a superconducting quantum interference device (Cryogenic Current Comparator, CCC); a high resolution machine tune system; provision of beam position measurements during the deceleration ramps.

INTENSITY

The now dismantled DC ring beam current transformer (DCCT) permitted only measurements of proton beams. Present AD operation relies on extracting intensity measurements from the analysis of longitudinal Schottky noise from 2 ferrite-loaded combined AC low and high frequency transformers. This is capable of delivering intensity and momentum spread measurements throughout the deceleration ramps for bunched beams with an error of some 10% [3] and a time resolution of up to 20ms. The main limitation comes from the Schottky system's dependency on bunch shape. It can also measure un-bunched beam, but with errors greater than 10% and a factor 10 less time resolution.

Development has therefore started on a new ring intensity detector based on the measurement of the ultra-low magnetic fields generated by the beam current (in the pT range or as low as 10^{-7} of the earth's magnetic field). This Cryogenic Current Comparator (CCC) is based on a low-temperature, liquid helium-cooled (L-He), superconducting quantum interference device (SQUID), [4], and builds on prior experience at GSI [5]. The use of high-temperature superconducting technology has also been attempted for such monitors, but the attained resolution with such devices is currently insufficient for our needs. It is foreseen to cool the CCC using a pulse-tube cryogenic-cooler and a dedicated liquid helium re-condensation unit, to provide reliability compatible with routine operation while minimizing vibration levels. The expected current resolution from this device is <10nA with the lower end of the dynamic range descending to some 10µA.

The fast, AC-coupled BCTs of the transfer-line will also be refurbished with updated integrating electronics and a complete software rewrite up to latest CERN controls standards. Based on installations recently consolidated in other CERN accelerators the expected performance is deemed sufficient, giving a <5% error on the measurement of $3•10^7$ charges with 100...400ns bunch length.

POSITION

Existing Beam Position Measurement System

The beam position is presently measured in the AD ring using 27 vertical and 32 horizontal electrostatic pick-ups. The Δ and Σ signals of all pick-ups are multiplexed into a network analyser and sequentially sampled, such that between 9800 (at 3.5GeV/c) and 65000 (at 100MeV/c) consecutive turns are collected per pickup and averaged in order to achieve a sufficient S/N ratio [7]. The position is then calculated by normalisation in the frequency domain of the Δ by the Σ signal. Measurements lasting from 0.2s to 12s for one complete orbit with constant F_{rev} on flat-tops for bunched beam, give a maximum resolution of 0.1mm per beam-shot. In order to acquire an orbit during one of the deceleration ramps a specific measurement flattop has to be introduced at the selected energy. Due to field lag effects caused by the thick end-plates of the AD ring quadrupoles, orbit measurements on

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such extra flat-tops introduced during ramps have a reduced significance for operations. Position measurements using pick-ups in the transfer lines are not possible due to the very low beam intensity.

Upgraded Beam Orbit System

The feasibility of a new orbit system was investigated during study sessions in 2012, that would allow all pick-ups to be sampled in parallel, thus reducing the sampling time to 7ms...380ms for one orbit. The test was based on standard 100MHz ADCs sampling the Δ and Σ signals from one horizontal and one vertical pick-up for up to ~10000 consecutive turns. The position is again extracted by normalisation in frequency domain, with the added complication that due to the deceleration the frequency shifts during the acquisition time. A series of 8 successive measurements spaced 50ms apart were triggered throughout the AD cycle ramps. Fig. 1a and 1b show the measured beam positions for one horizontal 23H(a) and vertical 39V(b) pick-up during the 2nd deceleration ramp, leaving the frequency variation during measurements of a few 100Hz uncorrected. The observed positions that were obtained are compatible with operational experience.

Table 2: Position Std. Deviations σ

p[GeV/c]	σ_h [mm]	σ_v [mm]
2.312	0.08	0.07
1.975	0.06	0.04
1.205	0.03	0.05
0.4877	0.09	0.1
0.2395	0.04	0.04
0.1994	0.04	0.05

Deeper analysis of many shots at the same energy, using off-line re-sampling to correct for the frequency variation during each measurement, shows that a precision better than 100µm (shown in Tab.2) should be achievable with the new system.

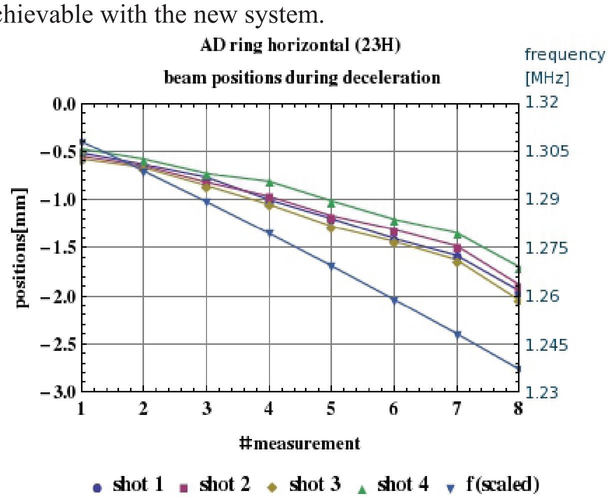

Figure 1a: Horizontal beam positions (pick-up 23H) for several cycles, during the 2nd deceleration ramp, shown for 8 consecutive measurements spaced 50ms apart.

For the final system the Δ and Σ signals from all pick-ups will be acquired using a specialised multi-channel, digitally programmable acquisition board developed for the low-level RF system, and also foreseen to be used for the ELENA beam position measurement system.

The new AD orbit system will therefore be able to measure consecutive orbits with a repetition rate of up to 50Hz, during all parts of the AD cycle where the beam is bunched. The possibility to acquire orbits at the end of each ramp, immediately before the start of electron cooling, is especially interesting for electron cooler optimisation.

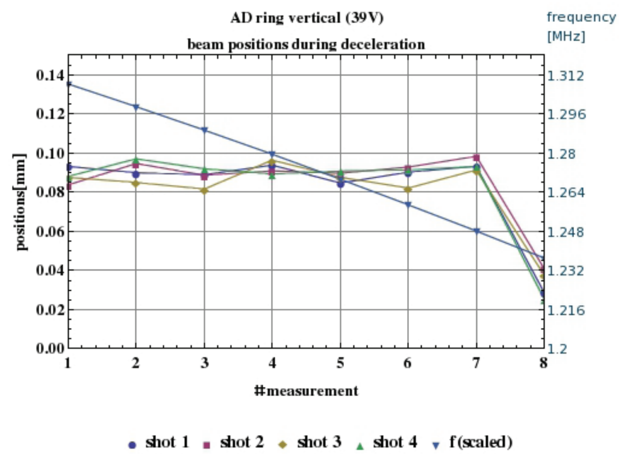

Figure 1b: Vertical (39V), same beams as in Figure 1a.

PROFILE AND EMITTANCE

Gas-Electron-Multipliers (GEM)

Beam profiles in the extraction lines are measured using Gas-Electron-Multipliers, which have recently replaced the now obsolete Multi-Wire-Proportional-Chambers [6,8]. They were already fully available in 2012 for AD operations and no additional upgrade or consolidation is foreseen.

Ring Ionisation Profile Monitor (IPM)

The IPM is the only non-destructive circulating beam emittance measurement available for the AD, and it is currently undergoing extensive renovation in order to improve its performance and reliability from 2014 onwards. A small quantity of nitrogen gas, not exceeding a maximum pressure of 10^{-7} Torr, is locally injected on-demand close to the IPM*. This IPM pressure bump is not fully compatible with AD physics beam production and hence the IPM is only used during dedicated machine development sessions. The ions resulting from the interaction of the beam with the rest gas are guided to a micro-channel plate for amplification. A strip read-out with 1mm resolution collects the charges and the signal is integrated over 20 to 50ms. From these signals the profile of the circulating beam can be continuously monitored. The AD IPM follows the design established at LEIR [9], and will also provide a fully integrated readout system according to CERN control standards.

* AD nominal vacuum is at 10^{-10} Torr

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Scraper-Photomultiplier

A classical combination of a moving beam scraper and a photomultiplier is used for destructive but absolute profile and emittance measurement, with a renovation of the photomultiplier readout system in progress.

Beam Image Cameras (BTV)

Precise steering and beam profile measurement is primordial for the AD experiments at their extraction lines. In order to improve measurement performance the existing BTVs have had their ZrO_2 screens changed to Al_2O_3:Cr ("Cromox") for better resistance and had standard CCD cameras providing higher sensitivity installed. Very encouraging results were obtained during operations at the end of the 2012 run. The new BASE experiment will also have its line installed with such BTV systems.

BETATRON TUNE

It is currently not possible to measure the betatron tunes during the AD ramps with sufficient precision, since a flexible tune measurement system, which does not require excessive beam excitation is not available. Initial ramp set-up is therefore basically done by iterative trial and error. To optimize AD performance a robust tune system capable of measuring throughout the ramps is essential, in particular for optimization of the tune at low energy where it would allow more margin to accommodate tune drifts in the tune diagram. Such drifts currently affect the operation and require periodic optimization needing a lot of beam time.

Tune on Ramps with BBQ

During the last few years all of CERN's circular machines have been equipped with Base-Band Tune (BBQ) measurement systems [10], employing the direct diode detection technique initially developed for the LHC. At the end of the 2012 run a prototype of such a system was installed in AD for testing with beam using a standard orbit pick-up. During these tests the BBQ system was also used to produce a frequency chirped excitation signal, that was fed as an input to the AD transverse damper and excited low amplitude oscillations on the beam. With 50W excitation the resulting beam spectra revealed tune peaks well above the noise level, and no measureable emittance blow-up was observed even at the lowest energies around 100MeV/c.

For the final installation a dedicated strip-line tune pickup will be installed and used exclusively for BBQ so that no orbit pickup needs to be sacrificed. Since little or no excitation is needed it is hoped that this system will be able to provide the AD with a flexible tune-meter capable of measuring on all ramps with a repetition rate of several Hz without disturbing operation.

CONCLUSION

The consolidation and upgrade of both the betatron tune and orbit measurement systems to give readings during the deceleration ramps will contribute significantly to a better understanding of the AD and will help to maintain good deceleration efficiency in the ELENA era. The use of chirped excitation has been shown to work in the AD and an operational system is foreseen to be deployed for the 2014 run. For the revised orbit system, the concept has been tested and the new system is expected to be installed within the next few years, benefitting from ongoing developments for ELENA. The measurement of un-bunched beam intensity with sufficient resolution is foreseen using a SQUID based device, currently under development in collaboration with GSI. Almost all other systems profit from upgrades, drawing on a wide range of previous experience from other accelerators at CERN and elsewhere.

REFERENCES

[1] V. Chohan (Editor), "Extra Low Energy Antiproton ring (ELENA) and its Transfer Lines Design Report", CERN-2014-002, ISBN 978-92-9083-400-7, Geneva, Switzerland.

[2] T. Eriksson, "Upgrades and consolidation of the CERN AD for operation during the next decades", IPAC13, Shanghai, China.

[3] M. E. Angoletta, L. Bojtar, V. Chohan, A. Findlay, M. Ludwig, O. Marqversen, F. Pedersen: "Antiproton beam parameters measurement by a new digital-receiver-based system", DIPAC2001, ESRF, Grenoble, France.

[4] M. Fernandes, J. Tan, L. Soby, C. P. Welsch: "Cryogenic Current Comparator as Low Intensity Beam Current Monitor in the CERN Antiproton Decelerators", IBIC2013, Oxford, UK.

[5] H. Reeg: "Experience with the DCCTs at GSI", LHC mini workshop on "Improving the accuracy of the BCT measurements", Geneva, 12 Jan. 2011 and Helmholtzzentrum fuer Schwerionenforschung GSI, Darmstadt, Germany.

[6] J. Spanggaard, P. Carriere, S. Duarte Pinto, G. Tranquille: "GEM detectors for the transverse profile measurement of low energy antiprotons and high energy hadrons", CERN ATS 2013-052, IPAC2013, Shanghai, China.

[7] M. Le Gras, L. Soby, D. J. Williams: "The Closed Orbit Measurement System of the CERN Antiproton Decelerator", CERN PS 99-043 (BD), DIPAC1999, Chester, UK.

[8] S.D. Pinto, J. Spanggaard: "Gas Electron Multipliers versus Multiwire Proportional Chambers", 2nd International Beam Instrumentation Conference IBIC2013, Oxford, UK.

[9] C. Bal et al: "First Results from the LEIR Ionization Profile Monitors", CERN AB-2007-022 BI, DIPAC2007, Venice, Italy.

[10] M. Gasior: "Faraday Cup Award: High sensitivity tune measurement using direct diode detection", CERN-ATS-2012-246, BIW2012, Newport News, USA.