BEAM QUALITY MONITORING IN THE CERN ANTIPROTON DECELERATOR (AD)

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Abstract

The CERN Antiproton Decelerator (AD) has now reached a stable mode of operation, regularly delivering batches of 100 MeV/c antiprotons to the ATRAP, ATHENA and ASACUSA collaborations.

Experience during the commissioning and initial physics runs revealed difficulties in achieving design goals and maintaining stable performance levels.

This paper will deal with the specific difficulties in monitoring and improving beam quality in a slow cycling machine operating with low beam intensities of a few 10^7 circulating particles.

1 INTRODUCTION

AD, the low energy antiproton facility at CERN (Fig.1) routinely produces and delivers 100 MeV/c antiprotons to the three experiments ASACUSA, ATHENA and ATRAP. Commissioning of the AD started in fall 1998 and after a lengthy period of running-in, physics started in July 2000.

Since the start of AD physics, regular machine development sessions have been organized with the aim of improving machine performance, improving stability, recovering from performance degradations that occur during the run and installing and testing new beam diagnostic equipment.

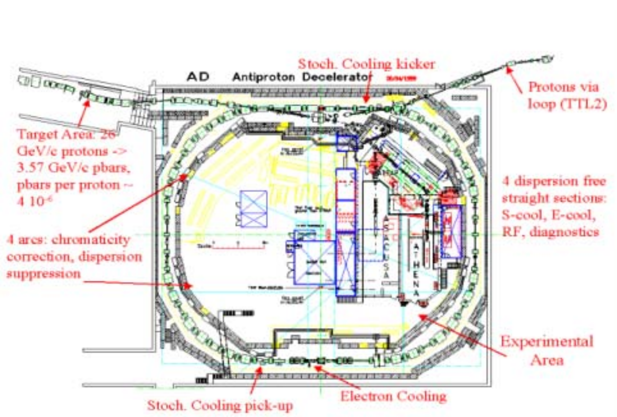

Figure 1: AD layout.

To produce the low energy antiproton beam, protons of 26 GeV/c are ejected from the PS and transferred to a target. There, antiprotons are produced and transferred to the AD ring via a curved transfer line. After injection at 3.57 GeV/c (Fig.2) the antiproton bunches are rotated by 90 degrees in longitudinal phase space, taking advantage of the short bunch length of about 25 ns to reduce the initial momentum spread. Then the beam is debunched, stochastically cooled, bunched again and decelerated down to 2 GeV/c. There it is stochastically cooled once more, primarily to reduce the momentum spread to fit the requirements of the deceleration RF system. After the stochastic cooling, the AD working point is moved from Q_x=5.385, Q_y=5.37 to Q_x=5.45, Q_y=5.42 taking advantage of the small emittances to cross the 5^{th} order resonance $5Q_x$=27. The first working point provides maximum machine acceptance at injection, while the second places the beam in a region of the tune diagram where more resonance free space is available. This is particularly important at low momenta.

The antiproton beam is then decelerated down to 300 MeV/c and cooled by the beam from the electron cooler. After cooling, the beam is rebunched on harmonic number 3 (the deceleration RF cavity only operates in the range 0.5 – 1.6 MHz) and decelerated to the ejection momentum of 100 MeV/c. The antiprotons are again cooled by the electron beam, rebunched on harmonic number 1 (this is necessary to extract all the particles in one bunch, for which the RF cavity resonant frequency is lowered to 174 kHz by means of a relay-switched capacitor), rotated by 90 degrees in longitudinal phase space (if experiments demand shorter beam, which is typically the case) and finally ejected.

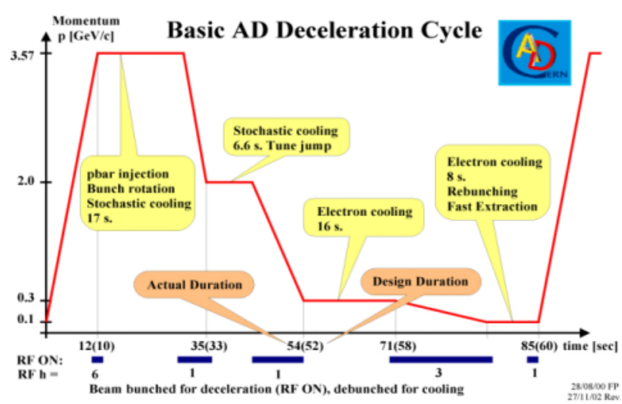

Figure 2: AD cycle.

2 PERFORMACE REVIEW 2000-2002

During the commissioning and initial startup, it was found that setting-up the AD and improving/maintaining its performance is very time-consuming. Making accurate measurements of intensity, tunes, orbits and machine acceptance with beam intensities in the order of 1-4*10^7 pbars requires sophisticated equipment and patience. The long (1-2 minutes) cycle with 4 different flat parts for beam cooling also makes adjustments very slow.

Nevertheless, machine performance was gradually improved over the first years of operation and is now up to or exceeding the design specifications in most respects (Table 1). Efforts will continue in order to further reduce the cycle duration by attempting to improve beam-cooling speed and reduce the duration of the deceleration ramps. Note the relatively large number of hours spent on startups and machine development. This is in part explained by the need to regularly re-optimize the machine, which is often suffering from drifts in beam trajectories and beam cooling performance.

Table 1: AD performance and operation 2000-2002.

	2000	End 2001	End 2002	Design
Intensity at 3.5 GeV/c ($*10^7$)	3.0	3.2	3.3	5
Intensity at 100 MeV/c ($*10^7$)	2.0	3.0	3.0	1.2
Deceleration efficiency (%)	65	95	90	25
Cycle repetition rate (s)	140-110	96	86	60
Flux (pbars/s)	$1.8*10^5$	$3*10^5$	$3.5*10^5$	$2*10^5$
Emittances at 100 MeV/c (85% beam)				
ε_h(π.mm.mrad)	4	1	1	1
ε_v(π.mm.mrad)	2	1	1	1
$\Delta p/p$ (after cooling)	$1.5*10^{-4}$	$1*10^{-4}$	$1*10^{-4}$	$1*10^{-4}$
$\Delta p/p$ (bunched, after rotation)	$3*10^{-3}$	$2*10^{-3}$	$8*10^{-4}$	$1.7*10^{-3}$
Minimum extracted bunch length (ns)	600	220	90	200
Total hours for physics	1500	2250	2100	3000
Total hours for startup/md/recovery	2050	800	700	
Downtime (%)	14	11	10	

3 MONITORING AND IMPROVING BEAM QUALITY

3.1 Beam intensity

Measuring proton beam intensity and trajectory through the injection line up to the production target is done using beam current transformers and screens equipped with TV cameras. Production beam intensities in the order of $1.5*10^{13}$ protons are common. After the target and through the "dog-leg" only $3\text{-}4*10^7$ antiprotons are collected making the use of such devices impossible. To some extent, beam steering can be done blindly by scanning steering dipole currents, but this is rarely successful due to the low cycle repetition rate (1-2 minutes). Complete trajectory correction through the dogleg would take several hours, during which time other machine and beam parameters often change. The correct method is to setup the AD with protons. In this mode, 3.5 GeV/c protons are injected and made to circulate in the AD in the reverse direction via a special transfer line. Beam intensities of a few 10^9 protons are sufficient for correct operation of transformers and screens. Setting up the proton scheme is however not a simple task and also very time-consuming. It is only done when no other solutions can be found.

For routine beam intensity monitoring during the physics runs, a special Digital Signal Processing-based system (Fig.3) has been implemented to measure circulating beam intensities and momentum spread throughout the deceleration cycle. The system performs FFT spectral analysis on the signal from two combined low-noise longitudinal Schottky pickups covering 0.02-30 MHz. Averaging of many scans is necessary for analysis of the low intensity beam. This is perhaps the most important tool used in operation since it gives non-destructive, continuous and reliable information in real-time (Fig.4).

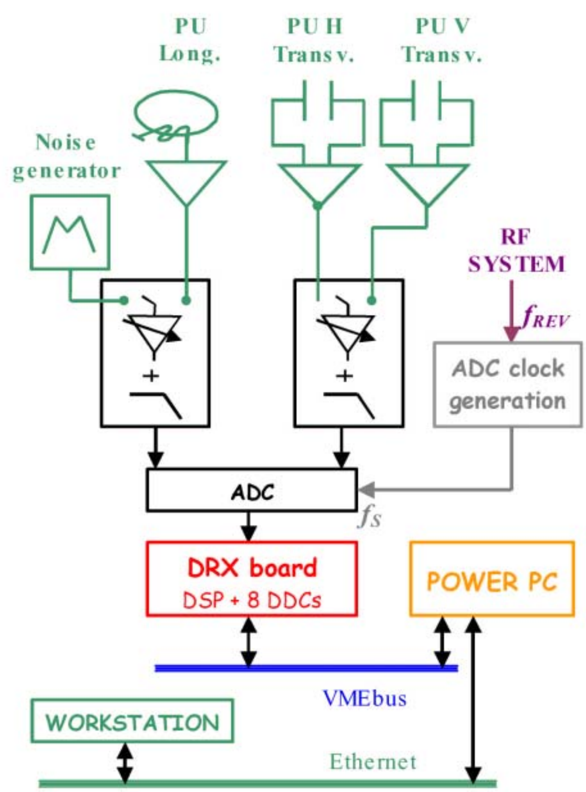

Figure 3: DSP Schottky analysis system.

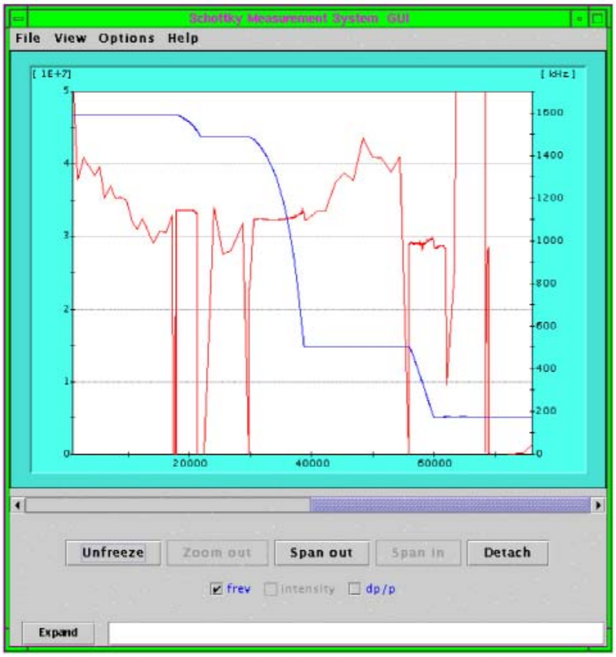

Figure 5: Measured intensity over AD cycle.

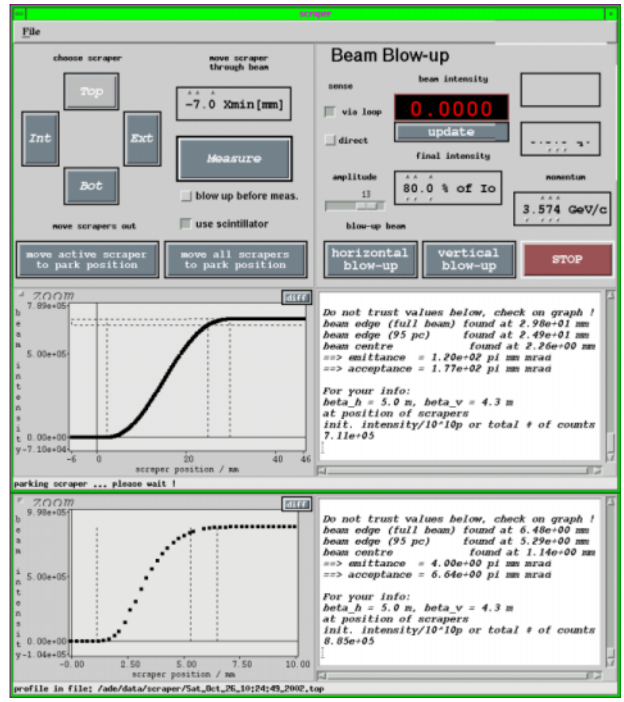

Figure 6: Vertical beam profiles before and after cooling at 3.5 GeV/c.

3.2 Beam emittances

To keep beam emittances low and losses during deceleration to a minimum, beam cooling must work well. At low beam energies, there are problems maintaining good beam cooling performance, which results in higher than normal beam emittances and losses. Regular tuning of the electron cooling is necessary almost every week. To optimize cooling, the position and angle of the pbar and/or electron beams are scanned and transverse emittances measured for each step. Emittance measurements are done by stepwise entry of a scraper blade into the beam, and simultaneously detecting created secondary particles with a scintillator/photomultiplier system. (Fig.5) Beam profiles can be measured with good precision at all energies. (Fig.6) This method is however destructive and very slow due to the long cycle and the need to stop the cycle for measurements at certain energies. It is not unusual to spend several hours on such tuning.

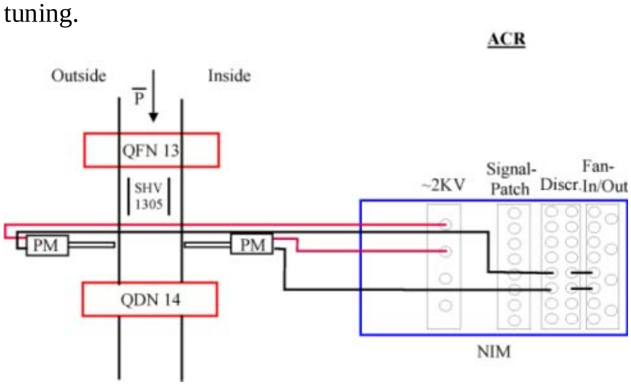

Figure 5: Beam profile measurement layout.

To improve the situation, a new Beam Ionization Profile Monitor system is now under development. This device allows non-destructive monitoring of beam position and transverse emittances throughout the cycle. Identification of sources for cooling degradation would also be greatly helped with this device. Promising results have been obtained, but more work is necessary before routine measurements are possible. (Fig7).

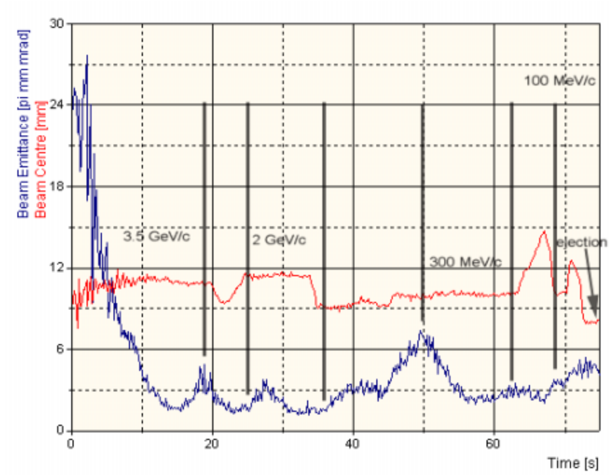

Fig.7: Horizontal beam width and position during the cycle as seen with the beam ionisation profile monitor.

An additional way of analyzing longitudinal Schottky noise is used routinely in the AD. The signal is down-mixed and analyzed by a commercial FFT signal analyzer in real-time. No numerical results are produced, but a visual interpretation of the frequency domain of the circulating beam is possible. (Fig.8) This is an extremely useful device for general beam quality monitoring over the machine cycle, giving the operator a good “feeling” and a very quick initial diagnosis of:

- Distribution in frequency domain.
- Intensity.
- Cooling speed and centering.
- Initial and final momentum spread.
- Losses during the cycle.
- Instabilities.

Fig.8: Longitudinal Schottky analysis at 3.5, 2, 0.3 and 0.1 GeV/c.

3.3 Stability of orbit and ejection trajectory

In 2000 and 2001, the AD experiments suffered from instabilities and drifts in the trajectory of the ejected pbars. The RFQ decelerator in the ASACUSA experimental area requires very high transverse and longitudinal stability in order to maintain good efficiency. Much time was spent by the operations team to retune the 100 MeV/c transfer lines. Analysis showed that the machine orbit before extraction was the cause. However, both slow drifts and fast jumps occurred pointing either to a single or to several locations around the ring. Fortunately, closed orbit measurements and corrections can be made at low beam energies thanks to the improved low-noise beam position pickups and closed orbit measurement system (Fig. 9), which allow accurate measurements with as little as $1*10^7$ circulating particles at 100 MeV/c. During normal operation, orbits are now continuously measured and logged at 300 and 100 MeV/c in order to detect any abnormalities. The situation improved during 2002 when several possible hardware and software causes were eliminated.

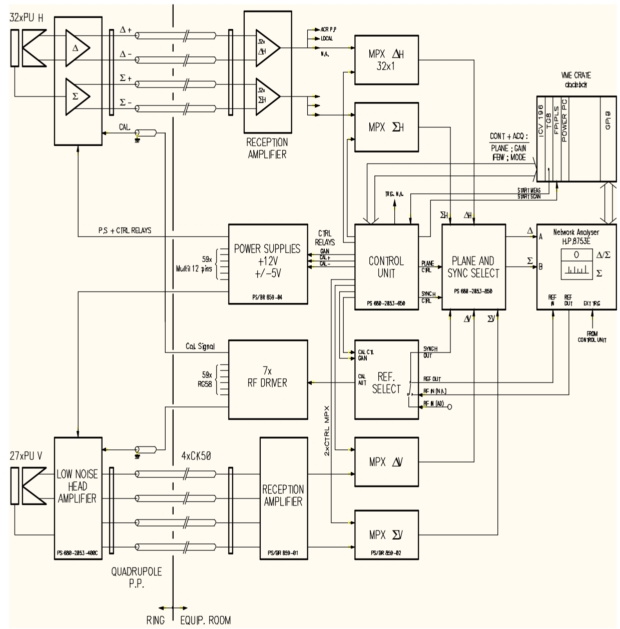

Figure 9: AD H/V ring pickup system.

4 CONCLUSION

Initial setup problems were encountered in the AD, mainly due to the low beam intensities and a slow cycle. Beam monitoring and improvements turned out to be more difficult and slower than foreseen.

The long startup period and subsequent improvements and tune-up sessions have made it possible for the operation team to get to know the AD quite well. Not always using the latest or most high-tech diagnostic equipment makes things slower, but it can be more interesting for the operator, giving opportunities to learn more about accelerator physics.