THE CERN ANTIPROTON ACCUMULATOR CLEARING SYSTEM WITH ION CURRENT MEASUREMENTS AS A RESIDUAL NEUTRALIZATION DIAGNOSTIC

F. Pedersen, A. Poncet, L.Søby
CERN, CH-1211 Geneva 23, Switzerland

Abstract

During the first 5 years of operation of the Antiproton Accumulator (AA) a whole set of limiting phenomena induced by the residual neutralisation by ions were observed and identified: charged dust particles causing beam blow-up, dipolar and quadrupolar coherent instabilities and excitation of high-order non-linear resonances. During the construction of the Antiproton Collector (ACOL) the AA was upgraded to cope with the higher antiproton flux, and new clearing electrodes were added together with individual computer control of applied clearing voltage and acquisition and recording of clearing currents. A general description of the new AA ion clearing system is given, together with a first account of the clearing currents behaviour.

Introduction

The CERN Antiproton Accumulator (AA) first came into operation in 1980[1], and is designed to accumulate and cool large stacks of antiprotons (up to 10^{12}, i.e. 300 mA). The Ultrahigh Vacuum system, which provides an average pressure of 5×10^{-11} mbar, is composed of a vacuum envelope designed to handle large transverse beam sizes (up to 500 mm horizontally) and housing numerous complex beam handling devices such as pick-ups and kickers, some of which are mobile (shutters).

To avoid beam space charge neutralisation by ions created on the residual gas, about 16 clearing electrodes providing a vertical DC electric field of a few hundred volts/m were initially installed, mainly located in quadrupoles (pick- ups) and at each extremity of the bending magnets. In addition, a careful screening of cavity like objects (bellows, chamber transitions..) was provided with metallic sleeves, with the dual aim of avoiding neutralisation pockets caused by localised potential wells, and a reduction of the beam coupling impedance. Despite these precautions, experience over the years showed that the machine residual neutralisation was a major cause of trouble, causing beam instabilities and emittance growth[2,3]. Inspite of the addition of a large number of electrodes (45 to date), the problems caused by neutralisation became even more severe with the advent of the new Antiproton Collector[4] in 1986, as more powerful stochastic cooling systems yielded lower emittances at higher beam intensities, thus reducing the natural Landau damping of instabilities.

Beam Neutralisation

The Coulomb collision of a passing antiproton with an atom of the residual gas may result in the creation of an ion-electron unbounded pair. Whilst the relatively energetic electron is repelled to the chamber wall, the ion is created at rest[5] and is trapped in the transverse beam space charge potential. In field free regions and for low neutralisation, the ion oscillates transversely with an amplitude equal to its distance at creation with respect to the beam axis, and a pulsation equal to the square root of the beam space charge force divided by its mass. It is accelerated along the beam axis due to the longitudinal variation of the beam potential resulting from the changing beam and vacuum transverse dimensions.

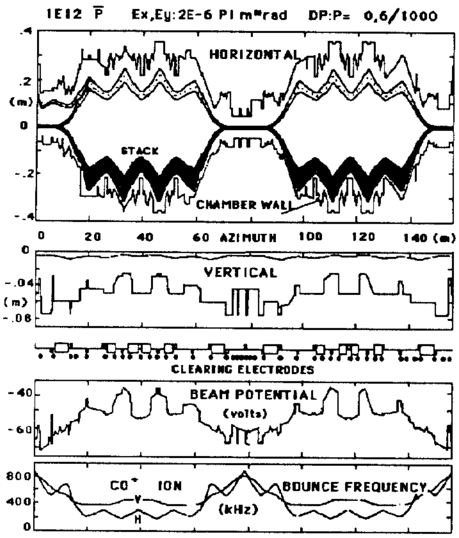

Figure 1 : AA nominal beam and vacuum chamber sizes, beam potential, ion bounce frequencies.[9]

Unless created inside a longitudinal potential well (ion pocket), the ion is cleared out of the beam by the first encountered clearing electrode. With the numbers given in Table 1, the neutralisation coefficient η should thus be very small. In potential well pockets created by vacuum chamber enlargements (bellows, transitions), very difficult to completely eliminate in practice, the local neutralisation can reach a few percent. In the AA, there is a strong suspicion that ion pockets can also exist due to positive or negative charge build up of highly resistive ferrites used to damp microwave propagation along the chamber, and of ceramic tubes.

In dipoles ions drift longitudinally in a cycloidal motion under the action of the crossed electric and magnetic forces, with a speed proportional to the beam electric field, whereas in quadrupoles the drift velocity is proportional to the gradient and the ion kinetic energy[5]. As the beam electric field and ion kinetic energy are low, particularly near the beam centre, and at the start of accumulation, these drift velocities ought to be small, possibly resulting in relatively high neutralisation coefficients in magnets.

Table 1 : AA typical neutralisation numbers :

Ionisation time = $\tau_i \sim 20$ s (5×10^{-11} T, 80% H_2 20% CO)
Total ion current collected for $10^{11} \bar{p}$: 0.8 nA
Clearing time in field free regions: $\tau_c < 2 \times 10^{-3}$
Expected neutralisation $\eta < 10^{-3}$
Measured neutralisation from tune shifts $\eta \sim 6$-7%

The Clearing and Ion Current Measurement System

The ion clearing system consists of 44 stainless steel or resistively coated ceramic plates (of which 20 are pick-ups or kicker electrodes).

If the transverse electric field created between the clearing electrode and the opposing vacuum chamber wall exceeds the magnitude of the strongest

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transverse beam field, as well as the beam potential being lowered by applying a negative voltage, an almost perfect clearing takes place, and the residual neutralisation is determined by the ion drift velocity.

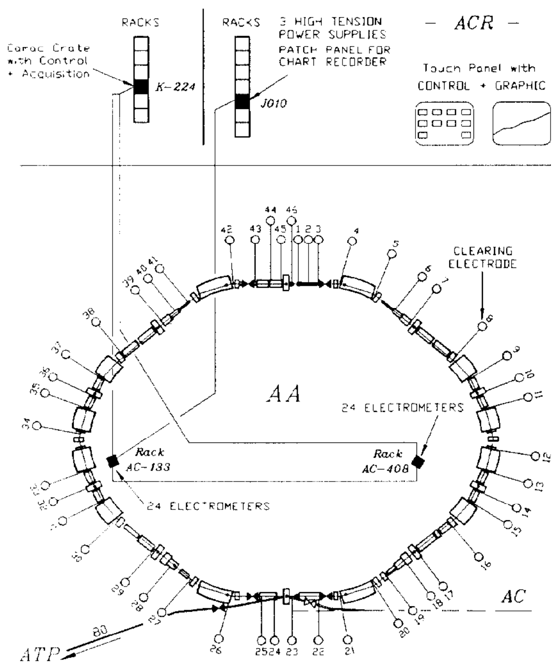

Figure 2 : The new AA clearing system

With the discovery of the first ion and dust particle related instabilities[1,2], it quickly became apparent that the ion clearing current measurement could be a valuable diagnostic tool to identify residual ion pockets. Therefore it was decided in 1986, with the ACOL upgrade, to equip each clearing electrode with an electrometer capable of measuring clearing currents down to 0,1 pA. Since the required voltage for good clearing is in the order of a kV, a leakage resistance in excess of 10^{16} ohms is required. The scheme used for the ISR clearing current measuring system[6] does not provide sufficient reduction of the leakage. A reduction in leakage current by about 5 orders of magnitude is achieved by using a floating electrometer at the clearing potential, and by shielding the clearing electrode conductor everywhere outside the vacuum enclosure with a shield or guard, which due to feedback around the Intersil ICH8500A MOSFET operational amplifier is kept within a few millivolts of the clearing potential. This technique requires use of triaxial electrometer cables, triaxial connectors, and triaxial vacuum feedthroughs. The floating electrometer is powered by a floating DC to DC converter, and the current acquired by opto-couplers. The electrometer is autoranging with four ranges : 1 pA, 10 pA, 100 pA, and 1 nA full scale. Special bias techniques have permitted the use of solid state MOSFET switches. The electrometer response time is 6 seconds and independent of electrode and cable capacity within certain limits. Careful design and assembly procedures have reduced triboelectric, piezoelectric, electro-chemical, and space charge currents to acceptable values. RF and microwave leakage into the shielded electrometer have been eliminated.

The triaxial ferrite filter at the input of the electrometer serves a dual purpose. Firstly to avoid the microwave leakage mentionned above, and secondly to prevent parasitic microwave coupling from one electrode to another through the common clearing voltage supply which might create instabilities in the high gain stochastic cooling systems.

The clearing voltage can be selected by the computer to be either zero or one of three manually adjustable voltages. Since the voltage differential between the two inner conductors of the triaxial cable is changed, only the charging current due to the clearing electrode capacity is measured. This permits verification of the continuity of connections inside the vacuum chamber without the presence of a beam.

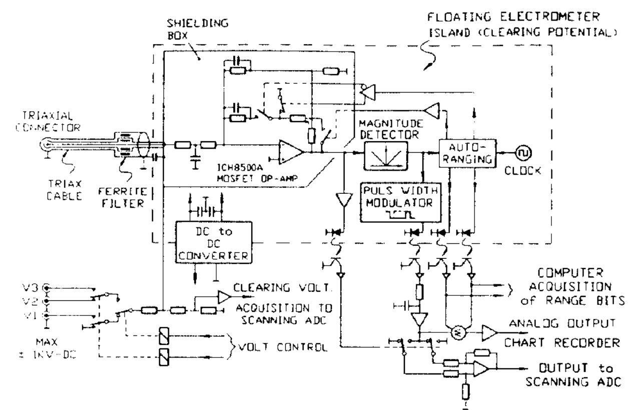

Figure 3 : Clearing electrode floating electrometer

Saturation Current Measurement

For a given circulating beam, the collected ion current is expected to saturate as the magnitude of the voltage applied is progressively increased to a value for which the extracting electric field is sufficient to divert the beam channelled ions. This is indeed generally observed (Fig.4).

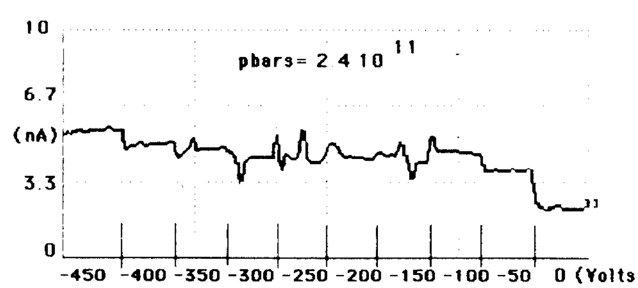

Figure 4 :Total ion current vs clearing voltage, Large fluctuations around -450, -150 volts, are thought to be due to potential barriers.

Potential Barriers

In some locations of the machine, in particular in regions where microwave - highly resistive - damping ferrites are placed in the vacuum chamber, the continuous recording of the clearing currents shows some large amplitude variations as if some positive potential barriers would erraticaly appear and disappear, thus monitoring the flow of ions to the nearest electrodes (Fig.5.).

Clearing Currents Deficit in Presence of Ion Induced Dipolar and Quadrupolar Instabilities

When the condition for an ion-beam coherent instability is fulfilled, namely for sufficiently populated ion pockets having ion transverse bounce frequencies close to a beam dipolar or quadrupolar unstable mode[7], ions gain large amplitudes and may be lost to the chamber wall before having a chance to reach the nearby electrode. The resulting effect can be seen as a dip in the continuous recording of the current, and this may help in locating the offending pockets.

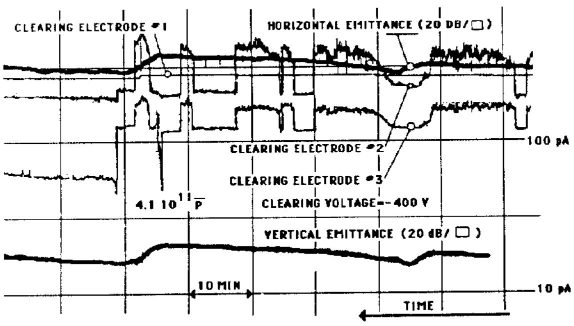

Figure 5 : ion current recording indicating the presence of potential barriers.

Ion Current Versus Beam Intensity

For sufficient clearing voltage, low neutralisation, and at constant gas pressure, the clearing current is expected to vary linearly with the beam intensity. If, however, the trapped ion density is comparable to the residual gas molecule density, multiple ionisation of already trapped ions becomes a significant contribution to the ion current, and this is revealed by a non-linear variation of the clearing current with beam intensity (Fig. 6).

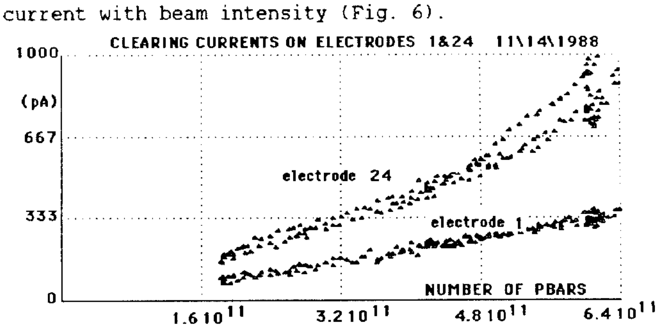

Figure 6 : Clearing current vs beam intensity.

Clearing Currents in Presence of Beam Shaking

It has been shown that a substantial reduction in beam neutralisation effects could be obtained by shaking the beam vertically at a fixed frequency, close to one of its transverse modes[8]. When this excitation is applied, the clearing currents collected at the exits of some long bending magnets where the applied frequency corresponds more or less to CO^+ ion bounce frequencies react conservatively. This may be an indication of a significant neutralisation (Fig.7).

Ion Currents with Captured Solid Microparticles

During the years preceding the ACOL shutdown, 1984 to 1986, capture of solid, charged microparticles in potential well pockets[2,3] occurred frequently, in particular after shutdowns where the vacuum chamber had been opened. At one occasion a step in clearing current was observed at the same time. After the ACOL startup in 1987, there has been no documented case of solid microparticle capture in the beam. There may be several reasons for this. Limited use of the AA shutters cause less dust to be stirred up, higher beam densities (due to improved stochastic cooling) may reduce the maximum size of thermally stable microparticles to a harmless value, and improved clearing has reduced the number of uncleared potential well pockets.

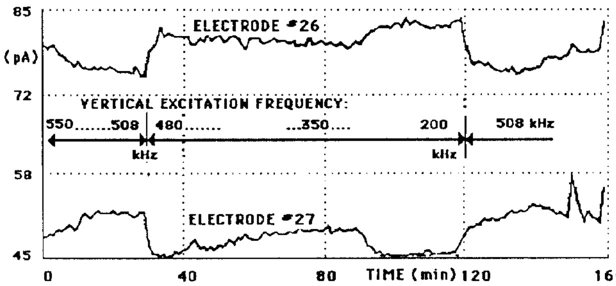

Figure 7 : Clearing currents vs time with shaking.

Conclusion

One of the main performance limiting phenomena of the CERN Antiproton Accumulator has clearly been demonstrated as being due to the residual neutralisation of the beam by ions trapped in the beam space charge, despite the large number of clearing electrodes installed. A new computer controlled clearing system based on specially designed electrometers capable of measuring each individual clearing current in the pA range is actually being commissioned. There is hope that the continuous monitoring of these currents will help to precisely locate the neutralisation pockets, and that it will provide a better understanding of the neutralisation processes.

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