SLAC–PUB–7546
May 1997

CONF-970503--275

ION EFFECTS IN THE SLC ELECTRON DAMPING RING *

P. Krejcik, D. Pritzkau, T. Raubenheimer, M. Ross, F. Zimmermann
Stanford Linear Accelerator Center, Stanford University, Stanford CA 94309

Abstract

We report on the ion-related beam behavior in the electron damping ring during unusually poor vacuum conditions in the weeks that followed a catastrophic kicker chamber failure that contaminated the ring vacuum system. The vacuum gradually improved over several months of beam operation, during which time the vertical emittance remained blown up by a factor of 2. The emittance blowup was accompanied by a transverse instability that produced jitter in the extracted beam size. Both the characteristic spectrum of self-excited betatron sidebands and the emittance blowup exhibited a threshold behavior with beam current and vacuum pressure. This behavior depended strongly on the betatron tune and it was found that the ion effects could be minimized by operating just below the 1/2 integer resonance.

Contributed to the 1997 Particle Accelerator Conference,
Vancouver, B.C., Canada, May 12–16, 1997

* Work supported by Department of Energy contract DE–AC03–76SF00515.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

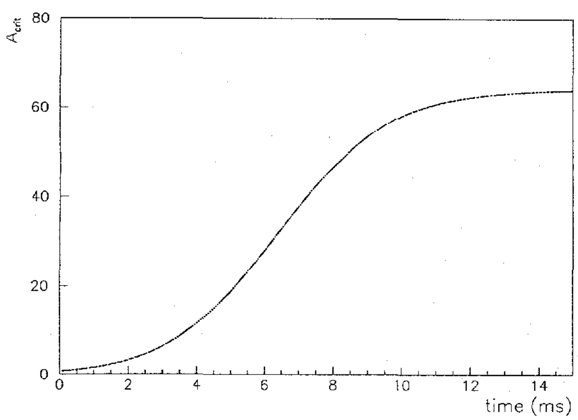

Figure 3: The critical ion mass (a.m.u.) above which ions can be trapped, increases during the store as the beam size shrinks.

equilibrium ion density will not exceed the neutral gas density [1]. The resulting line density depends on the shrinking beam size during the store, as seen in fig. 2.

The critical mass above which an ion is trapped

$$A_{crit} = \frac{N_{tot} C r_p Q}{n_b^2 2\sigma_y(\sigma_x + \sigma_y)} \qquad (2)$$

also depends on horizontal and vertical beam sizes σ_x and σ_y, and in fig. 3 it is seen that the lighter ions can only become trapped immediately after injection. Here we have a total number of electrons, N_{tot}=8•10^{10}, the number of bunches, n_b=2, ring circumference C=35 m, ion charge Q (in units of e) and classical proton radius r_p. The calculated beam size assumes an injected emittance $\gamma\varepsilon_{x0}=\gamma\varepsilon_{y0}\approx 20 \bullet 10^{-5}$ m and energy spread $\delta\approx 0.01$ and final emittances of $\gamma\varepsilon_x\approx 3\bullet 10^{-5}$ m and $\gamma\varepsilon_y\approx 0.2\bullet 10^{-5}$ m and $\delta\approx 7\bullet 10^{-4}$. Also assumed are $\beta_x\approx 0.7$ m and $\beta_y\approx 2.5$ m, $\eta_x\approx 0.1$ m, $\tau_{x,y}\approx 3.1$ ms $\tau_\delta\approx 1.5$ ms.

The ions can reduce the beam lifetime through either bremsstrahlung or single-Coulomb scattering [2]. A combination of these at an ion density of $2\bullet 10^8$ m^{-1} is consistent with the observed beam lifetime.

3 TRANSVERSE INSTABILITIES

Ion scattering alone does not account for the large discrepancy in beam sizes between one and two bunch operation. Evidence for a transverse instability causing pulse-to-pulse fluctuations in beam size is also seen in the form of self-excited betatron tune lines in the bunch spectrum, shown in fig. 4. When the beam is stored by disabling the extraction kicker, strong betatron sidebands can be seen around the 8.5 MHz revolution harmonics, even up to 200 MHz. The sidebands correspond to the vertical tune, with some lower amplitude activity also evident at the horizontal tune frequency. The instability can persist for over a minute as the beam intensity decays. On the shorter time

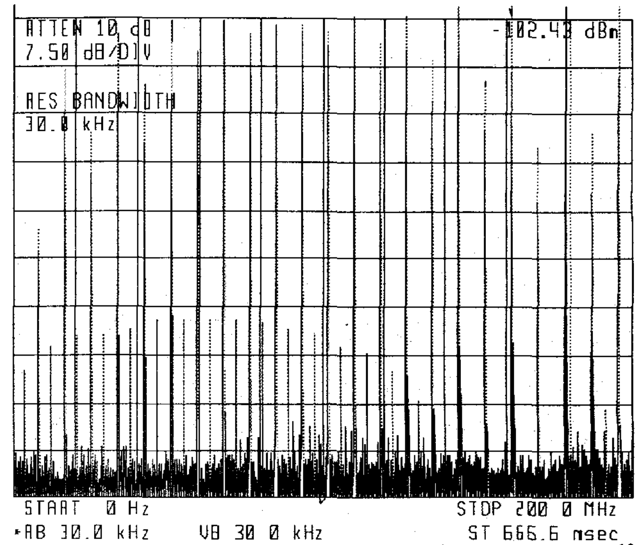

Figure 4: Bunch spectrum when 2 bunches of 4•10^{10} electrons each are stored, showing a large number of self excited vertical betatron sidebands.

scale between injection and extraction during normal ring operation the fluctuations in extracted beam size can be linked to rapid variations in the amplitude of the vertical betatron sidebands. In fig. 5 the spectrum analyzer is tuned to one such sideband frequency and the frequency span put to zero so that the sweep detects amplitude changes over a 20 ms interval, triggered at injection. After some milliseconds of damping the amplitude of the betatron motion increases with a sub-millisecond growth time until some self-limiting amplitude is reached and the beam damps once more. This process repeats itself irregularly several times during the store.

It seems reasonable to conclude that ions are captured when the beam is large at injection and remain trapped as the beam shrinks. Even though the critical mass threshold is passed as the beam shrinks, preventing further trapping of ions, the ions, once trapped, can remain in the beam potential.

The horizontal and vertical frequency at which the ions oscillate in the beam potential is given by

$$f_{x,y} = \frac{c}{2\pi}\left(\frac{N_{tot} 2 r_p \nu}{C\sigma_{x,y}\left(\sigma_x + \sigma_y\right)A}\right)^{1/2} \qquad (3)$$

and is shown in fig. 6 as a function of time as the beam size decreases, for two different ion masses, A (in a.m.u.). The ion frequencies are below 30 MHz and consequently too low to account for the observed sideband frequencies in the bunch spectrum. The spectral lines observed at 100 MHz frequencies can only be due to transverse dipole modes of the bunch.

4 TUNE RELATED BEHAVIOR

The additional focusing force from the ion cloud produces an upward tune shift, $\Delta\nu$, in both the horizontal, x, and vertical, y, planes, given by