LONGITUDINALLY SPACE CHARGE DOMINATED BEAMS IN A SYNCHROTRON*

Timothy J.P. Ellison, Sergei S. Nagaitsev, Mark S. Ball, David D. Caussyn, Michael J. Ellison, Brett J Hamilton
The Indiana University Cyclotron Facility (IUCF) 2401 Milo Sampson Lane, Bloomington IN 47405 USA

Abstract

For a given rf cavity voltage amplitude, V_{rf}, there is a maximum attainable peak current in an ion storage ring. This occurs when the electric field from the beam space charge balances the rf cavity field. In this limit, the linear charge density distribution, $\lambda(s)$, is parabolic and incoherent synchrotron motion is suppressed. The beam energy spread cannot be determined from the bunch time spread, T_{FWHM}, which depends only upon the beam current, I, and V_{rf}.

This work has recently been published [1]; no beam time has been available since for further results. This 1 page paper summarizes this work, discusses planned measurements, conjectures about possible results, and does its small part to limit the explosive growth of the PAC proceedings!

I. SUMMARY OF PREVIOUS WORK

Electron cooling can reduce the beam emittance so that the electrostatic potential energy spread across the bunch exceeds the rest frame kinetic energy spread. In this regime $\lambda(s)$ is:

$$\lambda(s) = \frac{\gamma^2}{8\pi \ln(r_v/r_b)} \frac{heV_{rf}}{mc^2} \frac{e}{r_e} \frac{(L_b^2 - s^2)}{R^2} \quad (1)$$

where $|s| \leq L_b$ and $2L_b$ is the bunch length; γ the usual relativistic parameter; h the harmonic number; e, m, and r_e the electron charge, mass, and classical radius; R the ring radius; and $\ln(r_v/r_b)$, ≈ 3.2 in the IUCF Cooler, the logarithm of the ratio of the vacuum chamber to cooled beam radius.

Integrating $\rho_l(s)$ over s, where $\beta = v/c$ yields $I(T_{FWHM}, V_{rf})$:

$$I = \frac{h^2\beta^4\gamma^2}{24\sqrt{2}\,\pi^2 \ln(r_v/r_b)} \frac{eV_{rf}}{mc^2} \frac{ec}{r_e} \frac{c^3 T_{FWHM}^3}{R^3}. \quad (2)$$

The time structure of an electron-cooled 45 MeV proton beam was measured by recording the signal from a beam position monitor. Comparisons between Eq. (2), and measured T_{FWHM} are summarized in Fig. 1. The observed increase in T_{FWHM} with I has been previously attributed to an increase in the beam momentum spread, δ, due to intrabeam scattering. These theories, however, predict δ, and consequently T_{FWHM}, to increase as $I_{peak}^{1/3}$. With such scaling, T_{FWHM} should increase as $I^{2/9}$ rather than $I^{1/3}$ (Eq.(2)). This model clearly disagrees with our data.

In Figs. 2a and 2b Eq. (1) is compared with the measured $\lambda(s)$ for two different cases. The theoretical $\lambda(s)$, dashed curve, is modified to include the measured pickup RC time constant (212 ns) and filtering due to cable loss (~ $e^{-f/66\ \mathrm{MHz}}$).

*Supported by the Nat. Sci. Found. (Grant No. NSF PHY 90-15957).

[1] T. Ellison et al., Phys. Rev. Lttr. **70** No. 6 (8 Feb '93) p. 790.

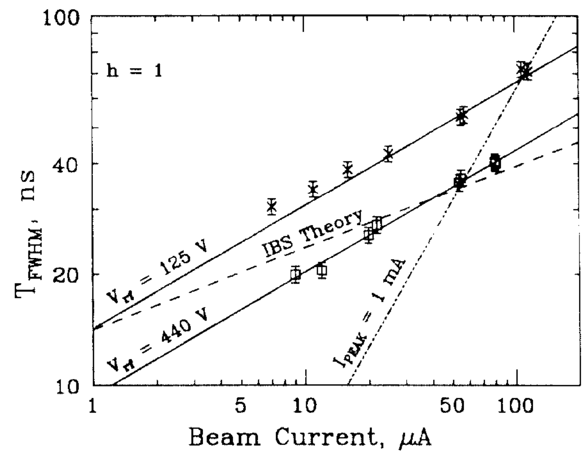

Fig. 1. Measured (x's, □'s) and theoretical (Eq. 2, solid lines) values for $T_{FWHM}(I)$; dashed curve is (IBS) theory.

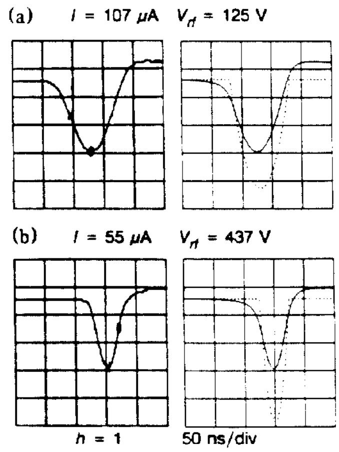

Figure 2. Measured (left) and theoretical (right) $\lambda(s)$, dashed curve is theory, solid includes filtering effects.

DISCUSSION

Since the synchrotron frequency, f_s, within the bunch is reduced, coherent oscillations do not decohere, but instead damp in accordance with the measured cooling force.

The space charge model predicts a bunch shape oscillation frequency of √3 times the unperturbed frequency, f_{so} and the emittance dominated model predicts $2f_{so}$. We, however, consistently measure $1.84f_{so}$ -- a mystery.

We conjecture that the transverse beam distribution may also be space charge dominated, having a uniform distribution with a radius increasing also as $I^{1/3}$. This will be measured.

We also conjecture that the transverse shape oscillation frequency may not be twice the coherent betatron oscillation frequency as predicted by the emittance dominated model but instead determined by the beam plasma frequency.