MEASUREMENTS OF THE EQUILIBRIUM EMITTANCE AND TRANSVERSE COOLING RATE FOR 45 MeV PROTONS IN THE IUCF COOLER

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The transverse cooling rate in the horizontal plane, and the equilibrium horizontal transverse emittance as a function of current, have recently been measured in the IUCF Cooler for a 45 MeV proton beam. The measurements, summarized in this report, yielded a transverse cooling rate that was an order of magnitude faster than predicted by the simple nonmagnetized theory.

The transverse beam profile was measured using a new "flying wire" profile monitor installed in the T-region of the Cooler where the dispersion function is nominally zero and the measured horizontal beta-function is 13.2 m. A rotary pneumatic actuator swings a 6.4 μm diameter carbon filament through the beam at a speed of 8.1 m/s. Secondary electrons produced by the protons passing through the filament are collected by an electrode surrounding the fiber holder. This current is amplified by a low-noise current-to-voltage converter, recorded by an oscilloscope, and transferred to storage on a PC for offline analysis. Approximately 200 to 500 beam revolution periods are necessary to measure the profile, and consequently the monitor cannot differentiate between coherent betatron oscillations and the beam size due to incoherent oscillations.

Figure 1 is an example of a transverse beam profile. The long tail on the right-hand side of the profile is due to the interaction of the wire with the proton beam. One can also observe a relatively long tail on the left-hand side. This tail corresponds to an emittance $\approx$60 times larger than the rms emittance of the bright central core; such tails develop for relatively high ($> 1 - 2$ mA) peak beam currents and are believed to be related to the beam intensity limit in the IUCF Cooler.

Figure 2 shows the measured equilibrium horizontal rms normalized emittance as a function of the average beam current. Note the measurements were made with bunched beams and that the horizontal scale is the average beam current. One observes that the beam size (emittance) varies approximately proportional to the 1/3 (2/3) power of the beam current. Since the bunch length, to first order, also varies as the 1/3 power of the beam current,[1,2] we see that the particle beam density stays constant, as does the ratio of the longitudinal and transverse beam temperatures; the beam density in phase space decreases inversely with the beam current.

The measurements of the transverse cooling rate were made as follows. A 45 MeV proton beam with a current of about 300 μA was injected into the ring and cooled. The beam lifetime was about 120 s. When the current had decayed to 200 μA the beam was kicked transversely and a single transverse and longitudinal profile was taken at a preset time with respect to the kicker. This procedure was repeated while changing the profile sample time in 10 ms increments with respect to the kick time. Figure 3 shows beam profiles obtained immediately prior to and immediately after the kick. Figure 4 summarizes the transverse measurements for two different kick strengths.

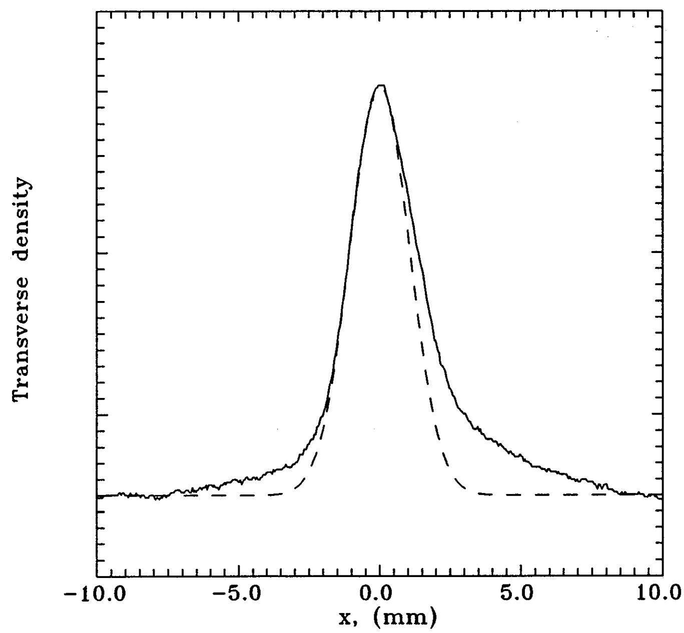

Figure 1. Transverse beam profile (solid) and Gaussian fit (dashed). Average (peak) beam current: 460 (2,000) μA; rms size from the fit: 1.05 mm.

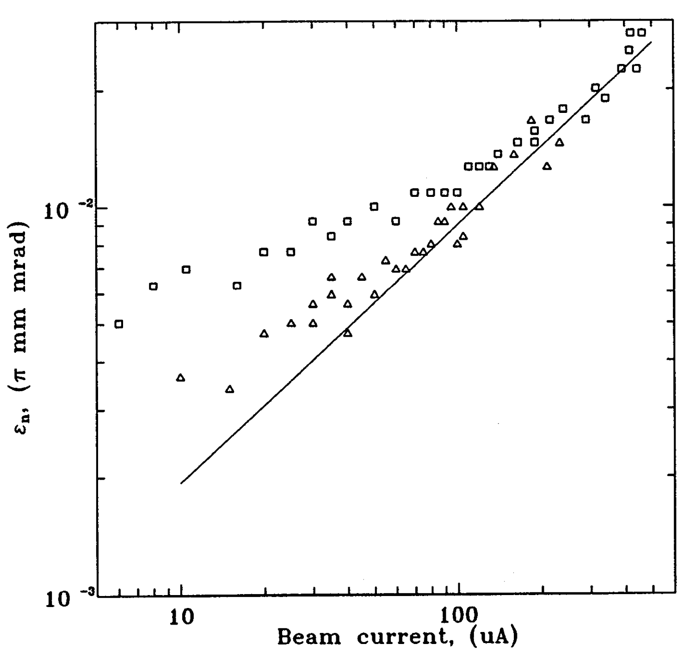

Figure 2. Normalized rms emittance as a function of the average bunched proton beam current before (□) and after (△) the alignment of electron and proton beams. Solid line is $I^{2/3}$.

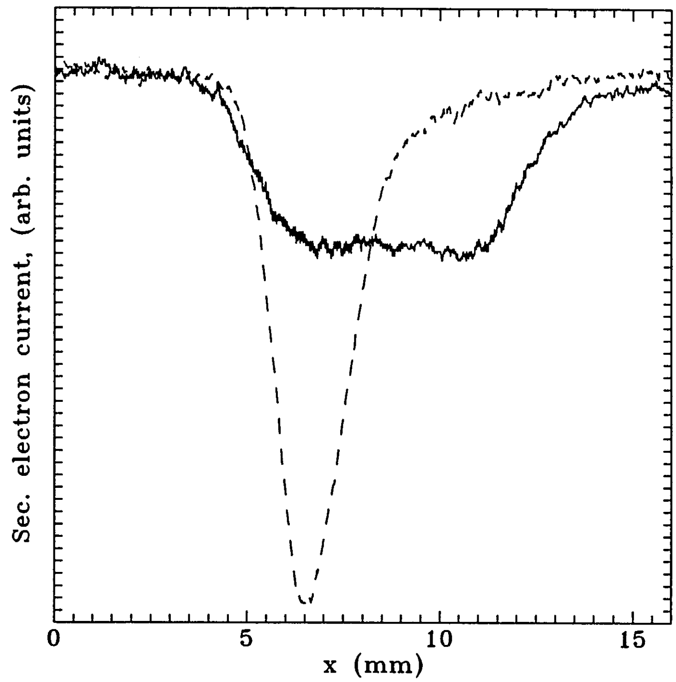

Figure 3. Secondary electron current produced by the filament traversing the proton beam immediately before (dashed) and immediately after (solid) the transverse kick.

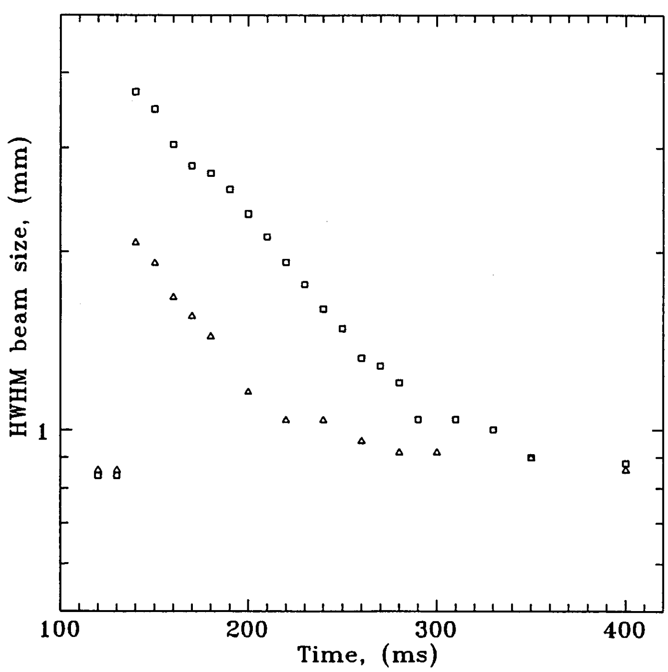

Figure 4. Transverse proton beam profile (HWHM) as a function of time for two different kick strengths. The transverse kick occurred at 140 ms.

A best fit of the data in Fig. 4 to an exponential yields a $1/e$ betatron oscillation amplitude damping time of $\approx$ 100 ms, corresponding to a 50 ms emittance damping time. The nonmagnetized theory, by contrast, predicts a 370 ms emittance damping time, almost an order of magnitude longer than the measured time. We have previously observed similarly large enhancements of the longitudinal cooling force above the predictions of the nonmagnetized theory.[3]

These data, together with the longitudinal profile data, allowed us to calculate the beam space charge tune shift.[4] We suspect that large tune shifts are what limits the amount of beam that can be accumulated with electron cooling. In the future we will use the profile monitor together with a "heating" system to try to develop techniques to adjust the equilibrium beam emittance; such a system may be used to increase the space-charge intensity limit in the ring.

1. Timothy J.P. Ellison, Sergei S. Nagaitsev, Mark S. Ball, David D. Caussyn, Michael J. Ellison, and Brett J. Hamilton, Phys. Rev. Lett. **70**, 790 (1993).
2. S. Nagaitsev, T. Ellison, M. Ellison, D. Anderson, in the *Proceedings of the 1993 Workshop on Beam Cooling*, Montreux, Switzerland, (1993).
3. Timothy J.P. Ellison, in the *1991 IEEE Particle Accelerator Conference*, San Francisco, (1991); Tim Ellison, Ph.D. thesis, Indiana University, March, 1991.
4. D. Anderson, M. Ball, V. Derenchuk, M. Ellison, T. Ellison, B. Hamilton, S. Nagaitsev, P. Schwandt, in this report.