Sensitivity of the Bergoz "New Parametric Current Transformer" to Time Structure in the Recycler Beam

Jim Crisp, February 8, 2008

Introduction

The recycler is a fixed energy storage machine that holds beam longitudinally in a 'barrier' bucket. The recycler beam intensity (acnet device R:BEAM) has shown up to 3% error that depends on the time structure of the circulating beam. Typical operating batch lengths range from 3.5 to 6.2uSec with an 11.134uSec rotation period. A "New Parametric Current Transformer" (NPCT-115-C100-HR) manufactured by Bergoz Instrumentation is used to measure beam intensity. The 200mAmp range measures beam intensity up to 1400e10.

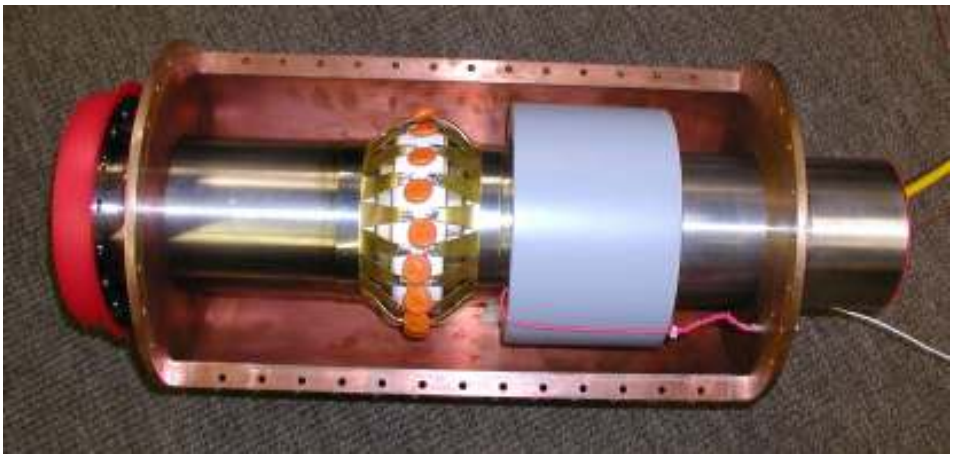

Figure 1: The Bergoz "New Parametric Current Transformer" shown with the electrical shield, ceramic break, and capacitor ring. Twenty 10nf capacitors provide 200nf across the ceramic.

Anti-protons (pbars) are accumulated and added to an existing recycler 'stash'. About 10 to 20e10 are transferred at a time. Pbars enter the recycler in four 2.5MHz bunches. These bunches are adiabatically transformed into a 1.6uSec barrier bucket and merged with the larger barrier bucket holding the 'stash'. Sufficient pbars (up to 450e10) are accumulated to replenish the Tevatron collider about once a day.

A movie has been made to demonstrate the injection sequence, "rr_pbar_inj.wmv".

m:ss	event
19	inject four 2.5MHz pbar bunches
39	change to 1.6usec injected barrier bucket
56	shorten injected barrier bucket
1:08	merge injected pbars with stash
1:34	move rising edge of stash
2:00	move falling edge of stash (ready for next injection)

Observed Errors

Figures 2 and 3 demonstrate batch length sensitivity. There are 588 'buckets' in the 11.134uSec rotation period.

R:BEAM	measured beam intensity
R:CBKTLN	barrier bucket length setting for the stash
R:NOTCH	measurement of the number of buckets without beam

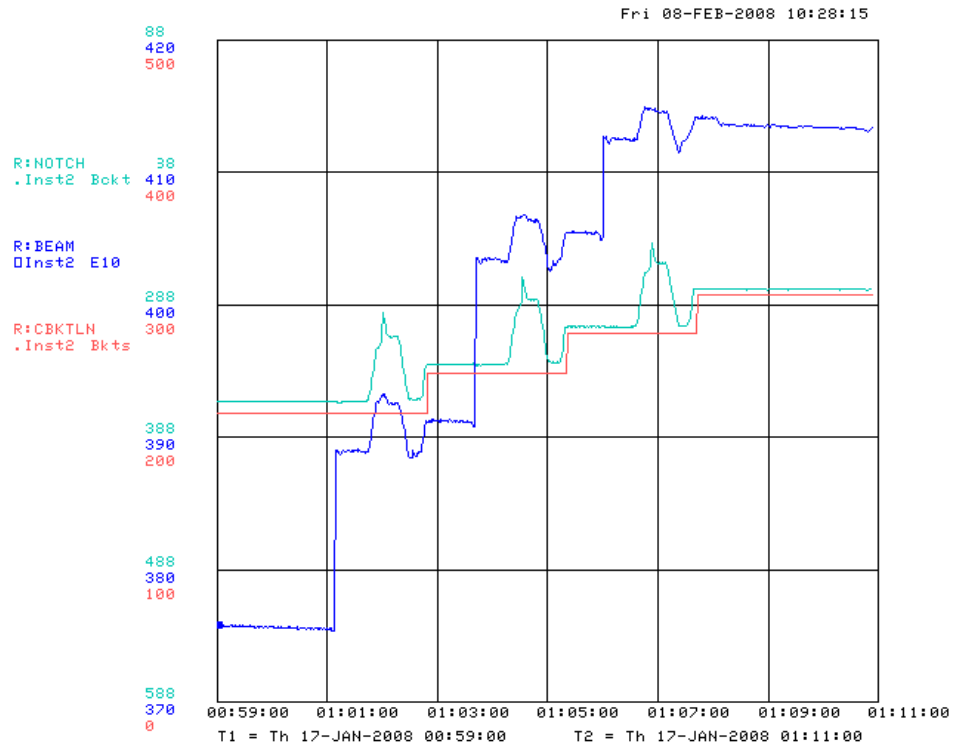

Figure 2: Plot showing 1 set of 3 pbar injections of about 10e10 pbars each over a 12 minute period. Errors of about 5e10 are clearly correlated with the time structure of the stash.

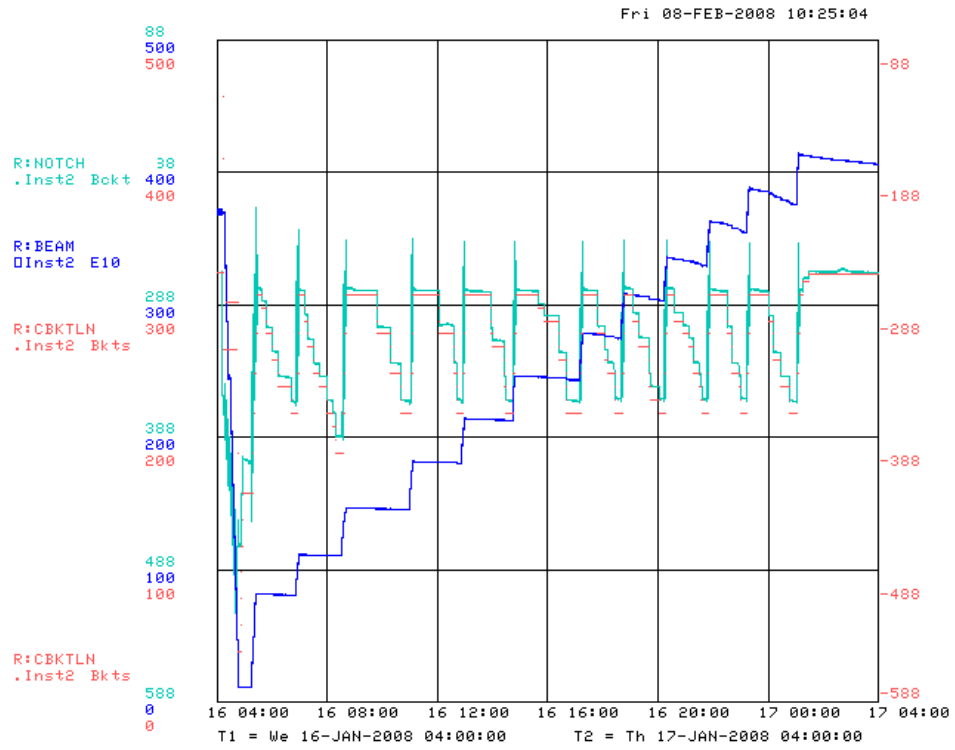

Figure 3: Plot showing 12 sets of pbar transfers over a 24hour period. The beam intensity reads about 10e10 low just before transfers when the length of the stash is the shortest.

Cause and Solution

Because of the typical time structure of recycler beam, harmonics of the 89811Hz rotation frequency must be the source of the errors. According to the Bergoz manual, the gap capacitance should be more than 10nf and less than 220nf. At the first rotation harmonic, 200nf is 8.9ohms and provides little or no effect. The 200nf capacitor ring across the ceramic break was replaced with 88uf (20 x 2.2uf). Measurements of both frequency response and noise revealed no problems with the larger capacitance, Figures 4 and 5.

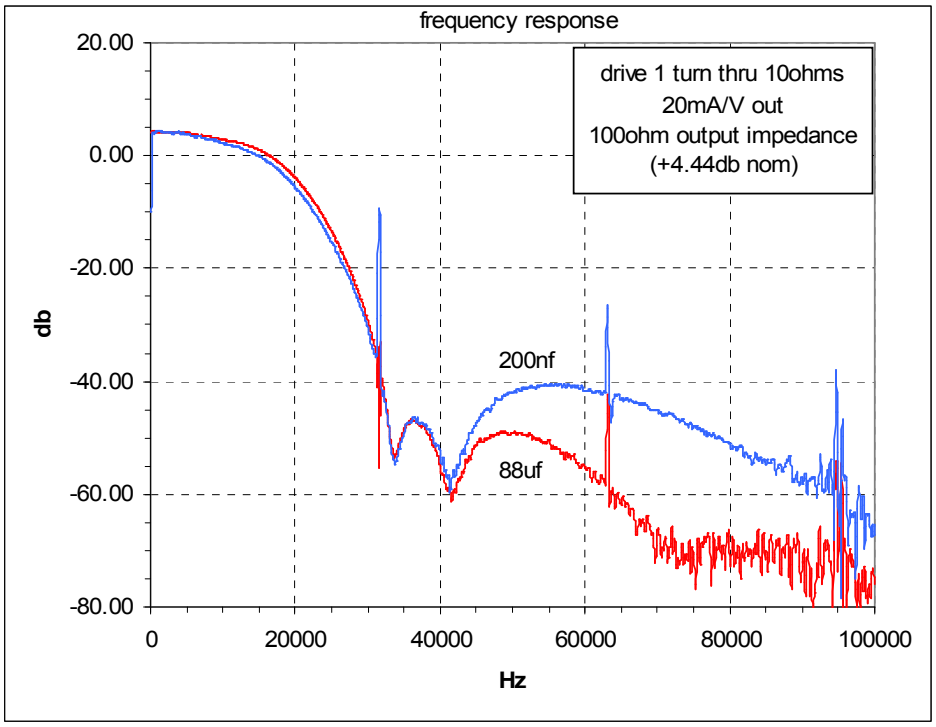

Figure 4: The 10KHz frequency response remains unchanged with 88uf.

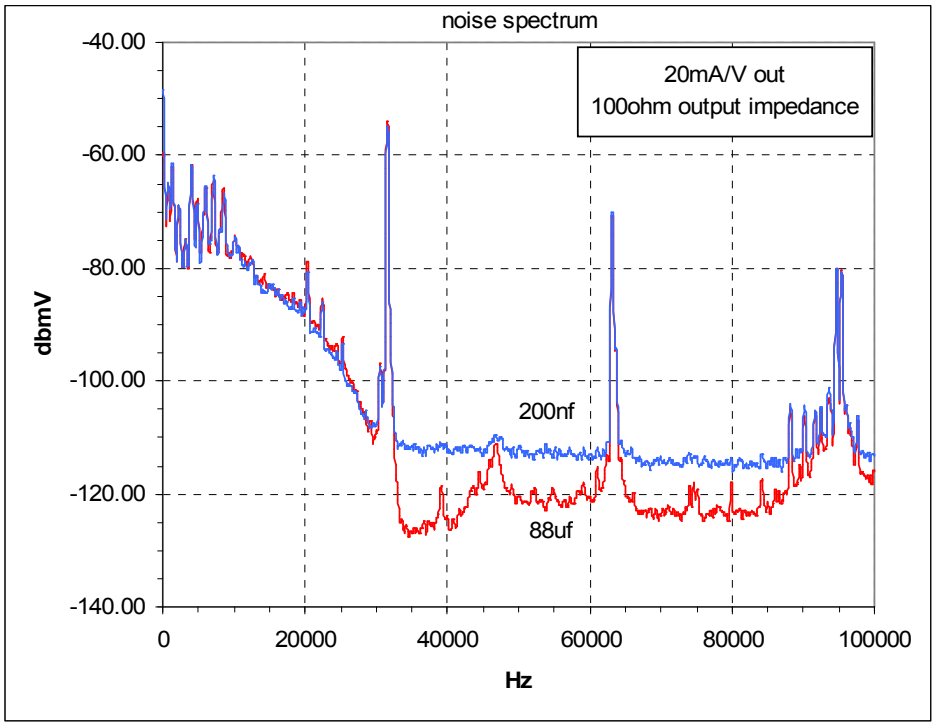

Figure 5: The noise spectrum remains unchanged with 88uf. The 31.5KHz spike is the modulating frequency used in the NPCT.

To test the theory a dc current source and pulse generator where used to simulate typical beam conditions. Figure 6 demonstrates that the sensitivity to time structure of the beam is substantially reduced with 88uf across the ceramic break. Actual beam measurements also show substantial improvement, Figures 7 and 8.

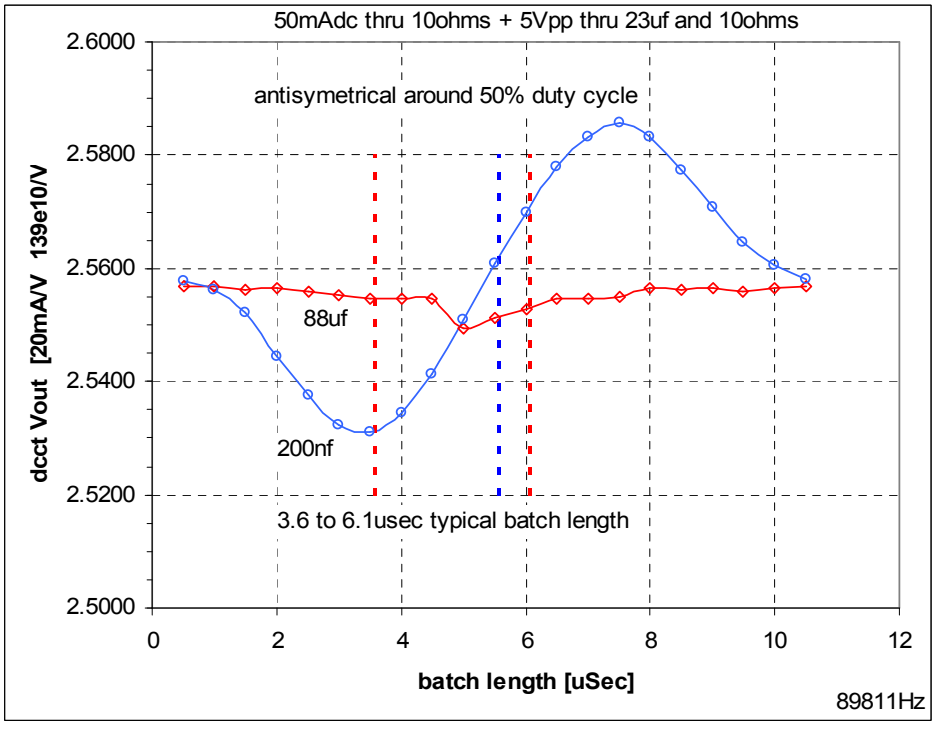

Figure 6: Measured sensitivity to the duty cycle of an 89811Hz pulse.

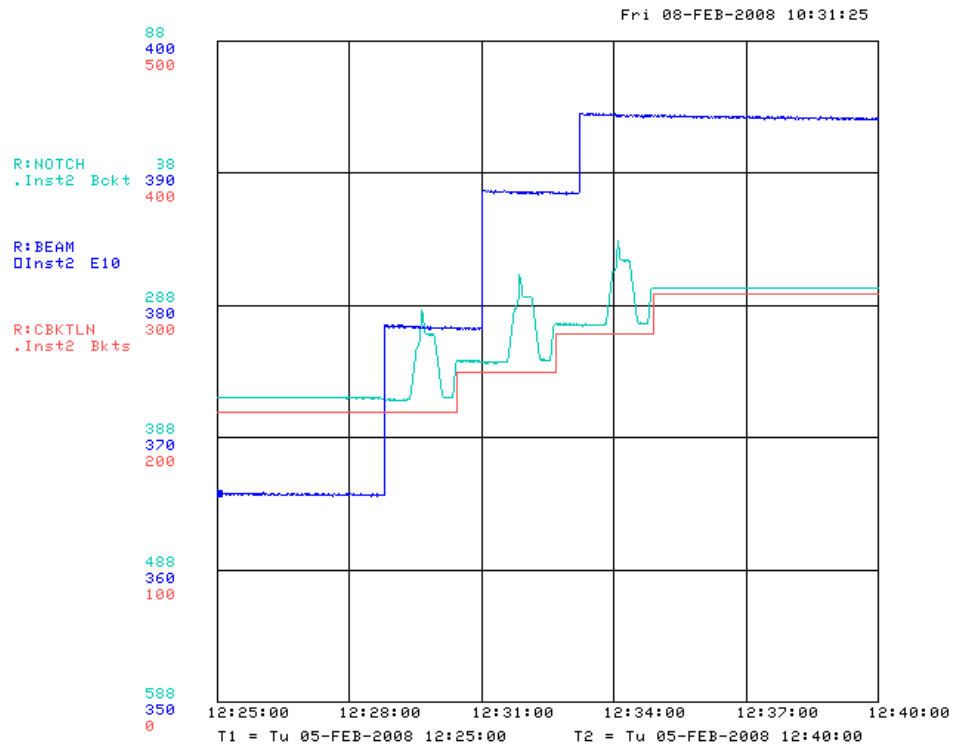

Figure 7: Plot showing 1 set of 3 pbar injections of about 10e10 pbars each over a 15 minute period. Errors are substantially reduced with 88uf capacitance.

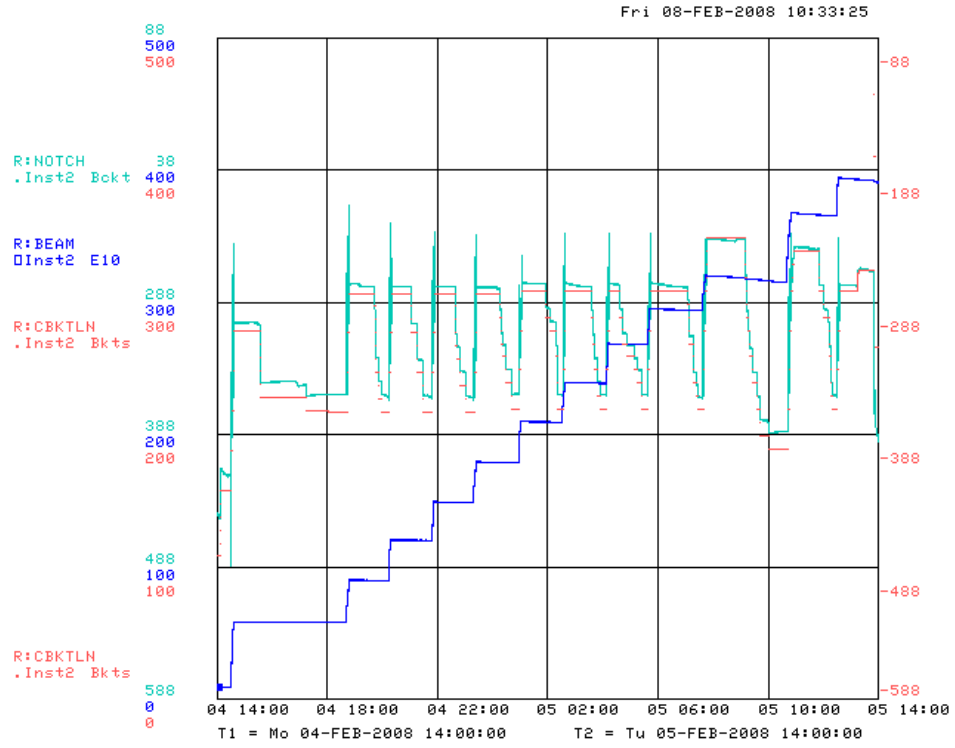

Figure 8: Plot showing 12 sets of pbar transfers over a 24hour period. Errors are substantially reduced with 88uf capacitance.

Conclusion

Substantial reduction of sensitivity to the time structure of beam was realized. Although the Bergoz manual indicates the gap capacitance should be less than 220nf, significant improvement was demonstrated with 88uf. No detrimental effects where observed.

The "New Parametric Current Transformer" appears to have only a 'dc' section based solely on a pair of modulated cores. The older "Parametric Current Transformer" (PCT-113-0100MA-115V) incorporated an 'ac' coupled section to extend the bandwidth beyond the modulation frequency. The NPCT has a modulation frequency of 31.5KHz and bandwidth of 10KHz. The older PCT used a 7KHz modulation frequency but delivered 20KHz bandwidth.

The Fermilab designed beam current monitor (or dcct) uses a 200Hz modulation frequency but provides a full 1MHz bandwidth via the 'ac' or transformer section. This larger bandwidth allows the feedback current to cancel many of the rotation harmonics generated by the time structure of the beam. Without this bandwidth in the feedback, the modulation cores are balanced on average but are heavily saturated one way or the other depending on the instantaneous beam current.

The 20KHz bandwidth of the older PCT compromised it's ability to cancel large rotation harmonics and may have contributed to it's untimely demise. It is believed the permeability of the two modulated cores became so different that the second harmonic generated with beam current could not be resolved. The failure may have been aggravated by the higher beam currents and longer stores that prevailed toward the end of it's life.