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Subject Longitudinal Phase Space Measurements

OBSERVATIONS AND CONCLUSION

Purpose:

To carefully measure the AGS bunch area at 29 GeV with the machine operating at ISA intensity, i.e., 2.7×10^{12}/pulse. Also to partially debunch the beam on a 29 GeV flat top using phase space rotation in order to investigate this method of matching the bunches to the ISA prior to transfer.

Procedure:

A flat top was set up at ≈ 29 GeV using a closed loop between the Gauss clock and flat top voltage. Then the frequency synchronization loop was activated in the usual (i.e. as in previous measurements of the longitudinal Z/n) manner.

The intensity was reduced to ≈ 2.8×10^{12} with good capture efficiency. Minimum phase space dilution at transition was achieved with the usual outward radial jump and use of the bunch shape damper immediately thereafter.

Then the coherent dipole frequency was determined by driving the rf cavities with a signal at $(13f_o + f_s)$; again as in the Z/n measurements.

The up minus down counts of the Gauss clock were recorded along with the external oscillator frequency and the mean radial position of the beam as determined by the PUE system. This data is necessary to determine the beam energy and hence $\eta=(1/\gamma_{tr}^2 - 1/\gamma^2)$.

The debunching was performed by programming a step (< .5 msec) decrease of ≈ 80% in the rf voltage near the middle of the .8 sec flat top.

Observations:

During the set-up, the intensity was held at 1.6×10^{12} to minimize machine irradiation. When it was increased to 2.8×10^{12} an instability causing beam loss (up to ≈ 75% on some pulses) appeared near the end of the flat top. All bunches were affected but there was no evidence of longitudinal oscillations. Hence it was tentatively assumed to be transverse in nature although the narrow band (n=9 mode) coherence detectors exhibited essentially no signal.

Another unexplained effect was seen during the debunching test. The first quarter cycle of bunch shape oscillation induced by the rf amplitude step took about 3 msec and produced the expected spreading (see below). However during this time the beam radius which had been constant executed an inward excursion of about .5 mm. In addition after the first quarter cycle the beam synchronization loop went into oscillation with a slowly growing amplitude which eventually results in beam loss.

Results:

The external synchronization frequency was f = 4,4,54,932 cycles with a Δr = -.2 mm. Using Equation 6 of AGS Tech Note 145, we obtain a p = 29.17 BeV/c. Using Equation 5 and the u p minus down counts of the Gauss clock 56,510 yields 28.62. If we make a 2% correction for saturation effects, this yields 29.19 BeV/c. So we take E = 29.18 BeV and find $\eta = \pm .0128$ (γ_{tr} = 8.5) The measured coherent dipole frequency was 178 ± 1 cycles. We then calculate $V_{rf} = (f_d/f_{rf})^2 \; 2\pi E/12\eta$ = 273.6 kV. Now the bucket area on the flat top is given by $A_o = (8/\omega_{rf}) \sqrt{2EV_{rf}/\pi h\eta}$ = 51.9 eV sec. And we know that the bunch area is less than 1 eV sec. Hence the small amplitude linear approximation can be used to find the bunch area.

We define $\rho = h\Omega_o \frac{\Delta W_m}{\beta} \sqrt{\frac{2\pi h\eta}{EV_{rf}}}$ so that the trajectories in $\rho, \Delta\varphi$ space are circles. Here $\Delta W_m = \Delta E_m/h\Omega_o$ where ΔE_m is the maximum energy deviation of particles in the bunch. In this space $\rho = \Delta\varphi$ numerically and since $A_b = \pi\Delta W_m \Delta\varphi$ where $\Delta\varphi$ is the bunch half width in radians, we have $A_b = \pi\Delta\varphi^2/K$ where $\rho = K\Delta W_m$. We find K = .308 from the values of E, V_{rf}, η obtained above. For $\Delta\varphi$ we use the average of several photographs of AGS bunches as seen by the new very wide band (> 800 MHz) pick-up station at F20. A value of 17 nsec or $\Delta\varphi$ = .238 radians was obtained and this results in an A_b = .58 eV sec at 29.18 GeV. If we take the minimum observed width of 16 nsec, we obtain A_b = .51 eV sec. Since there was clearly a small amount of dilution at transition an assumption of ≈ .5 eV sec as the minimum bunch area attainable at ISA intensity is quite reasonable.

If we take the .58 eV sec value for A_b and calculate the bunch length expected at transition assuming that V_{rf} = 273.6 kV and $\dot{B}$ = 25.6 kG/sec we obtain a $\Delta\varphi$ = .148 rad or a τ_ℓ = 10.6 nsec. The measured value was 12 nsec which is only fair agreement.

The voltage step used for debunching was from a 3 volt level (or 273 kV) on the rf sum signal to a .6 volt level corresponding to 54.6 kV (assuming no changes in cavity tuning). This level would result in a small amplitude dipole frequency of f_φ = 79.5 cps or a $\tau\varphi$ = 12.57 msec or $\tau\varphi/4$ = 3.14 msec. The observed time required for the bunches to reach their maximum width was ≈ 3 msec. From ISA Tech Note 50 we find that the necessary matching voltage would then be $V_3 = V_2^2/V_1$ = 10.9 kV where V_1 = 273, V_2 = 54.6. No attempt to jump to this level was made however. The measured bunch length was 36-37 nsec while one calculates a value of 38 nsec from $\tau_2 = \sqrt{V_1/V_2}\, \tau_1$ where we took τ_1 = 17 nsec. Since we did not make a correction in V_1 for the longitudinal impedance (see ISA Tech Note 50) which is inductive and would hence reduce the effective value of V_1 the difference between measurement and observation could be due to this omission. (Note that since this correction is ~ τ_ℓ^3 it will be much smaller when $\tau_\ell = \tau_2$ than when $\tau_\ell = \tau_1$.)

Finally we remark that the voltage step used here is greater than what would be required for ISA injection which also requires a much larger initial bunch area (≈ 1 eV sec). Future studies will be made at the nominal ISA values (see ISA Tech Note 50).