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## Longitudinal Phase Space Measurements

L. Ahrens

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Collider Accelerator Department  
**Brookhaven National Laboratory**

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Date 12/13/79 Time 2200-0300 Experimenters Ahrens, Gill, RakaSubject Longitudinal Phase Space MeasurementsOBSERVATIONS AND CONCLUSIONPurpose:

To carefully measure the AGS bunch area at 29 GeV with the machine operating at ISA intensity, i.e.,  $2.7 \times 10^{12}$ /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  $\approx 29$  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  $\approx 2.8 \times 10^{12}$  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  $(13f_0 + f_g)$ ; 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  $\approx 80\%$  in the rf voltage near the middle of the .8 sec flat top.

Observations:

During the set-up, the intensity was held at  $1.6 \times 10^{12}$  to minimize machine irradiation. When it was increased to  $2.8 \times 10^{12}$  an instability causing beam loss (up to  $\approx 75\%$  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  $f = 4,454,932$  cycles with a  $\Delta r = -.2$  mm. Using Equation 6 of AGS Tech Note 145, we obtain a  $p = 29.17$  BeV/c. Using Equation 5 and the up 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  $\eta = .0128$  ( $\gamma_{tr} = 8.5$ ). The measured coherent dipole frequency was  $178 \pm 1$  cycles. We then calculate  $V_{rf} = (f_d/f_{rf})^2 \frac{2\pi E}{12\eta} = 273.6$  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  $\Delta E_m$  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  $E, V_{rf}, \eta$  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  $\approx .5$  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  $\tau_\ell = 10.6$  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  $f_\varphi = 79.5$  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  $\approx 3$  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  $\tau_1 = 17$  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  $\sim \tau_\ell^3$  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 ( $\approx 1$  eV sec). Future studies will be made at the nominal ISA values (see ISA Tech Note 50).