AGS STUDIES REPORT NUMBER 116

Date 10/5,7/78 Time 2000-2400 Experimenters E. Raka, L. Ahrens

Subject Longitudinal Impedance Measurement VI

OBSERVATIONS AND CONCLUSION

Purpose

To repeat the measurements made at ≈ 5 GeV in order to understand the anomalies observed at that time (AGS Studies Report 115). Also to repeat the measurements made near transition at E ≈ 6.6 GeV (Report #114) with greater accuracy if possible.

Procedure

Similar to previous runs. Prior to the start time comb "F" was readjusted to minimize the ripple on the flat top at low energies. Flat tops at 5.04 GeV and 6.64 GeV were used. Excitation around both the 13th and 14th harmonics were used. The closed loop between the beam radius and flat top voltage was again employed in order to minimize momentum variations on the flat top. Going into the flat top, the Siemens MG set variations at times exceeded the ≈ .1% variation that the frequency synchronization loop can accommodate. These variations would slow down the process of data taking.

The nominal frequency at 5 GeV was 4,379,306 and at 6.64 GeV the same as on 7/16/78 4,412,406. In addition to using the 14th harmonic as well as the 13th, the rf accelerating voltage was varied (at 5 GeV) in an effort to reproduce the effects seen on 8/24/78. Considerable time was spent in trying to obtain precisely reproducible quadrupole excitation but with limited success at 5 GeV. At 6.64 GeV this was less of a problem.

Results

At 5 GeV and 3.5×10^{12} protons/pulse the observed frequency difference $f_q - 2f_d \approx -13$ cycles for excitation at both h = 13 and h = 14 with $f_d \approx 527$ $f_q \approx 1042$ for $V_{ext} \approx 255$ kV and $f_d \approx 507\sim$ $f_q \approx 1001\sim$ for $V_{ext} = 239$ kV. That is the difference $(f_q - 2f_d)$ did not change with an ≈ 6% voltage variation but the absolute values of f_d and f_q changed with $V^{\frac{1}{2}}$.

It is this change with V_{ext} that was observed on 8/24 and at that time misinterpreted as a change in the impedance. If one takes $(\sqrt{\frac{14}{16}} \times 1053 - 1053)$ where 14/16 is the voltage ratio and $f_q = 1053$ at 6.8×10^{12} and the higher voltage, he obtains 68 ~ compared to the ≈ 70 ~ shift observed at that time. What led to the misinterpretation was that when the voltage was reduced for the lower dipole mode at h = 13 and 6.8×10^{12} some signal was still present though the exciting frequency had not been changed. In fact it was the excitation off resonance that suppressed the growth of the signal until the excitation was over so that spontaneous growth which was responsible for the signal could occur. Actually the difference $(f_q - 2f_d)$ should vary as $V^{\frac{1}{4}}$, but this is only

a 1.6% effect for the voltage ratio used in the present run and is clearly lost in the noise of the measurement.

At 6.64 GeV and 4×10^{12} one obtained $f_d \approx 246 \sim$ and $f_q = 493 \sim$ for excitation around h = 14. This gives $f_q - 2f_d = +1 \sim$ or essentially the same value as obtained on 7/18. The quadrupole mode was more reproducible here for a given excitation frequency than at 5 GeV, but since f_q is about half the 5 GeV value the absolute accuracy is not much greater. The dipole mode at both energies and h's were much more reproducible than the quadrupole mode.

Discussion

The following expression is used to determine the Z/n from the observed $\Delta f = (f_q - 2f_d)$; $2\Delta f = f_d\, I_o\, V_T^{\frac{1}{2}}\, \mathrm{Im}\, (\frac{Z}{n})/6h^2 V_o^{\frac{1}{2}} \cos \varphi_s (\tau\ell/\tau o)^3$ where $\tau\ell$ is the bunch length, τo the rotation period of a bunch, I_o the current in h = 12 bunches, V_o is applied external voltage which can be calculated from f_d the measured dipole frequency and the beam energy and V_T is the effective voltage given by $V_T = V_o \pm 24\, \pi h I_o\, \mathrm{Im}\, (Z/n)/\varphi_L^3$ where φ_L is the bunch length in radians (< 1) and the plus sign applies below transition. Thus one must iterate between these two equations to obtain Z/n from the measured Δf. The principal assumption here is that the impedance producing the incoherent frequency shift Δf is independent of n over the range of frequencies given by $2.5/\tau\ell$ for sinusoidal modes and $2/\tau\ell$ for Legendre modes. For the latter which are most likely to be the case for a parabolic bunch, the expression for Δf should be multiplied by 0.75.

The measured bunch length at 5.04 BeV was 28 nsec and the calculated $V_o = 255$ kV for $f_d = 527 \sim$. With $\Delta f = -13$ this results in a $Z/n = -54.7 j\Omega$ and a $V_T = 233$ kV. One should compare this with the $-158\ j\Omega$ obtained on 8/24 at 4.92 GeV for a $\tau\ell = 36$ nsec and a $V_T \approx 230$ kV. The errors in these measurements are in the range of 10-20%, hence the impedance must have changed during the long shutdown separating them. One other noticeable difference is that the bunch length is now considerably shorter for the same V_T and one calculates a phase space area of 0.45^+ eV-sec. compared to the 0.74 eV-sec obtained on 8/24. The reason for this change is not yet know, but the smaller value is closer to what has been obtained by slightly different techniques in the past.

At 6.64 BeV the bunch length was unfortunately not measured before the run on 10/7 had to be terminated. However, the bunch length at 5 GeV was also measured at that time as well as on 10/5. These were used to calculate a $\tau\ell \approx 19$-20 nsec at the higher energy. One obtains a $V_o \approx 248$ kV which for a 20 nsec $\tau\ell$ and a $\Delta f = +1$ gives a $Z/n \approx 3\ j\Omega$. This is to be compared with the $\approx 16\ j\Omega$ obtained on 7/16, but with a much larger bunch. Since the narrower bunch should have produced more than twice the frequency shift for the same Z/n, one can conclude that the null of the impedance is very close here.

However, one cannot say whether the Z/n did change between the two 6.64 BeV measurements. If we take the two measured values of Im (Z/n) and compute A and B from Im (Z/n) = $A-B/\gamma^2$ we obtain B = 4.32 kΩ and A = 89.4 Ω. Had we used the values of 8/24 these numbers would be even larger. An inductive wall Z/n of ≈ 90 Ω is more than twice the value obtained at 28.4 BeV on 4/6/78 and tends to indicate that below transition we must be also seeing a frequency dependent impedance.

In addition, the change in the value of Im (Z/n) measured at 5 GeV indicates that the nature of this impedance was altered during the shutdown. One possible candidate for this is the fact that on about forty vacuum chamber flanges a shorting strap on the inside of the ring was replaced by the correct damping network. The networks on the outside of the flanges were not disturbed. Since there remains about twenty more flanges where this correction must still be performed, it would be interesting to repeat the 5 GeV measurement after this work is done.