AGS STUDIES REPORT NUMBER 128

Date 1/30/81 Time _____ Experimenters E. Raka

Subject Synchronization of AGS rf to External Oscillator at 29 GeV

OBSERVATIONS AND CONCLUSION

Purpose: To study the operation of PLL that locks the AGS beam frequency to an external reference oscillator. Also to measure the "noise" or frequency and phase modulation that exists after the synchronization loop is closed. If possible to identify the sources of this residual modulation.

Procedure: On 12/11/80, the AGS was running for the SEB so it was decided to carry the bunched beam from the end of a 200 msec flat top at ≈ 29 GeV down to about the transition energy of ≈ 8 GeV and then dump it on the inside using a radius shift. This was done at a low intensity (≈ 1.5×10^{12}) but the setup took almost three hours, so only about thirty minutes were left to do synchronization tests. On 1/8/81, the AGS was running for FEB, but due to an earlier vacuum problem the beam was not available until 1000 hours. This time it was decided to extract the beam at the end of the 200 msec flat top using the FEB apparatus. However, the constant momentum servo loop had to be activated (normally used on SEB only) and some difficulty was encountered in doing so. Finally this loop and the extraction timing were operated simultaneously and the studies were started (1330!).

Observations: During the first run reliable synchronization was achieved with a frequency of 4,454,960 which was about 20~ different than the beam frequency. No attempt was made to control the bunch shape after transition or on the flat top. There were indications of considerable 360~ frequency modulation present after synchronization but no useful measurements could be made before the run ended.

On the second run, stable synchronization was obtained at 4,455,278 cps or about 30~ above the zero beat frequency. The synchronization loop gain was near maximum as was the case on the first run. The loop gain could be reduced to minimum or ≈ 1/10 the maximum d.c. gain with no noticeable effect on the pull in of the loop. However, considerable 60~ frequency modulation could be seen both on the output of the frequency discriminator and the phase detector inside the loop. This could also be seen on the radial position signal and was present under normal operation, i.e., without the PLL but with the radial loop closed.

Just before the run ended a large non-adiabatic decrease in the total cavity voltage was programmed in after synchronization. This produces large bunch shape oscillations and during the first half cycle ($\omega\phi/4$) the beam was observed to move inside and the frequency to increease. Such a step change in rf was used on 12/13/79 to study bunch rotation (see AGS Studies Report 124) and the same changes were seen. Also, one observed that the tuning currents of the individual cavity servo loops all increased when the step was introduced. This is consistent with the cause of the radial excursion being due to a non-adiabatic change in beam cavity loading (see below).

Finally, some photos were taken of the residual phase and frequency modulation present after the synchronization loop is activated.

Results and Discussion: As noted above, satisfactory operation of the phase lock loop that synchronizes the beam rf frequency to the external oscillator was achieved. An offset of ≈ 30~ is well within the pull in range of the loop. One observes that the maximum jitter in synchronization time from machine cycle to cycle is ≈ 30 msec and the radial excursion is less than 1 mm when the loop is closed. Also, as noted above, it is necessary to increase the synchronization loop gain at low frequency in order to reduce the 60~ modulation that is present on the flat top. The source of this driving term was not investigated. The residual phase modulation at 60~ was measured to be ≈ 1.6° peak to peak which should result in a residual frequency modulation of Δf_{60} = 60 x .028 rad = 1.6 ~ p.p. However, the output of the FM discriminator which has a small modulation index bandwidth of > ± 400 cycles did not show this amount of 60~ signal.

One sees a 360~ modulation on the discriminator output with a p.p. swing of about 3.7~. This corresponds to a phase modulation of .6° p.p. However, the output of the synch loop phase detector which exhibits both the 60~ and the 360~ signal gives a p.p. phase swing of ≈ 1.2° for this modulation. The reason for this discrepancy is not know at present.

If we take the FM discriminator mesurement then the maximum residual modulation is δf_{rf} = ±3.7~/2 which means a Δ p/p = ± 78 x 3.7/2 ÷ 4.45 x 10^6 = ± 3.2 x 10^{-5}. The max. phase error of ± .3° would result in only a ±4 x 10^{-6} Δ p/p error after transfer to the ISA.

The source of the 360~ modulation which is beating with small amounts of 60~ and 120~ (most likely) was not investigated. This should be done in the future so that its contribution to momentum or phase error is ⩽ 10^{-5}.

One can explain the dynamic beam loading effect mentioned above as follows. In the steady state the bunch frequency component of the beam current I_b leads the net cavity voltage V_c by 90°. The effective generator current I_g is in phase with V_c due to the action of the tuning servos. The net cavity current I_c leads V_c by an angle α while the cavity impedance Z lags V_c by an angle $\beta = \alpha$, i.e., the cavity is tuned below f_{rf}. When I_g is rapidly reduced, α increases but at first β does not. Then the angle between I_b and V_c becomes $< \pi/2$. This means $\phi_s > \pi$ and deacceleration takes place causing the beam to move inside. The synchronization loop sees this as a frequency error, but it is much to slow to track the change with a negligible error. The tuning loops are faster but not fast enough. Hence, a momentum error will develop if the bunch rotation process is used for matching unless one puts into the loop a programmed signal to compensate for this effect. Such a correction is readily made and can be tested on a future run.