IEEE Transactions on Nuclear Science, Vol. NS-28, No. 3, June 1981

MEASUREMENT AND COMPENSATION OF COHERENT LASLETT TUNE SHIFTS IN THE FERMILAB MAIN RING

R. Gerig, C. Moore and S. Pruss

Fermi National Accelerator Laboratory*
P.O. Box 500
Batavia, IL 60510

We have measured the coherent Laslett tune shifts by measuring the dependence on circulating intensity of the coherent betatron oscillation frequency at 8 GeV. These were found to be $\Delta\nu_{radial}$=.038/10^{13} circulating protons and $\Delta\nu_{vertical}$=.031/10^{13} circulating protons. The power supply control was then modified to adjust the quadrupole currents so as to cancel these beam induced tune changes. We will report on running experience with this modification as well as on the data, its acquisition and reconciliation with the Laslett formulas.[1]

We recently noted a variation in the Fermilab main ring coherent horizontal and vertical betatron tunes during injection. This was measured by kicking the circulating beam with a fast dipole, then measuring the beam position at a particular location in the ring for 256 subsequent turns. These beam position oscillations were Fourier analysized and the peak frequency interpreted as the fractional tune. As the thirteen booster batches were injected, one after another, the horizontal tune gradually increased while the vertical decreased (see Figure 1). To the best of our ability to measure, this was dependent only on total circulating intensity and not on the azimuthal distribution of charge in the ring. That is, we measured the tune with one very low intensity batch (4×10^{11} protons). Then we measured the tune shift relative to this low intensity point due first to three high intensity batches (total of 6×10^{12} protons), and second to thirteen low intensity batches (again a total of 6×10^{12} protons). For both of these cases the tune shift was $\Delta\nu_H=.020\pm.002$, $\Delta\nu_V=.017\pm.002$.

We changed the injection bend field slightly and injected with the closed orbit at 0.2% $\Delta p/p$ to the inside. While we saw a small change (~.005) in the very low intensity tune due to incompletely corrected chromaticity, we saw the same tune shift with intensity. We measured the tune shift during acceleration and found a 1/p dependence (see Figure 2). At this point, F. Mills suggested that this effect could be the tune shift described by L.J. Laslett in 1963[1].

With much help from S. Ohnuma, we calculated the "Laslett" tune shifts induced by the beam using the magnets and vacuum of the Fermilab Main Ring to be[2]

$$\Delta\nu_H = 3.1 \times 10^{-13} (n_B/2\ rz) + 3.70 \times 10^{-15}\ N$$

$$\Delta\nu_V = -2.7 \times 10^{-13} (n_B/2\ rz) - 3.25 \times 10^{-15}\ N$$

where

n_B = number of particles in each R.F. bunch
2rz = longitudinal bunch length in meters
N = total number of particles in the ring.

Our measured tune shift intensity dependence is $\Delta\nu_H=3.8\times10^{-15}$ N and $\Delta\nu_V=-3.1\times10^{-15}$ N. We found[3] that (n_B/2rz) is nearly constant with varying booster intensity and so drops out. Given this agreement of experiment and theory we asked C. Briegel to modify the power supply control computer to vary the horizontal and vertical injection tune offsets with intensity. These injection tune offsets are made proportional to 1/p and so properly go to zero as the beam is accelerated. The horizontal and vertical proportionality constants were made free parameters that the accelerator operators were allowed to tune. During another study period we took a family of injection efficiency curves vs zero intensity tune offset for various values of the intensity proportionality constants. These showed large variations in the apparent widths of the half and third integer resonances but no obvious effect on the peak efficiency for variations of ±30% about "best" compensation. However, it was empirically found during the recent high intensity running that these were very important parameters for "peaking" intensity. The record breaking intensities were achieved with $\Delta\nu_H=2.8\times10^{-15}$ N, $\Delta\nu_V=-2.6\times10^{-15}$ N.

References

1. Proceedings of the 1963 Summer Study on Storage Rings, Accelerators and Experimentation at Super-High Energies, "On Intensity Limitations Imposed by Transverse Space-Charge Effects in Circular Particle Accelerators", by L.J. Laslett, pp. 325-367, BNL-7534.

2. We have used a value for the parameter ε_2 of .355.

3. Dependence of the Emittances of the Fermilab Injectors on Intensity, C. Moore, C. Curtis, J. Lackey, C. Owen, C. Ankenbrandt, R. Gerig, S. Pruss; I-102 this conference.

*Operated by Universities Research Association, Inc. under contract with the U.S. Department of Energy.

0018-9499/81/0600-2486$00.75

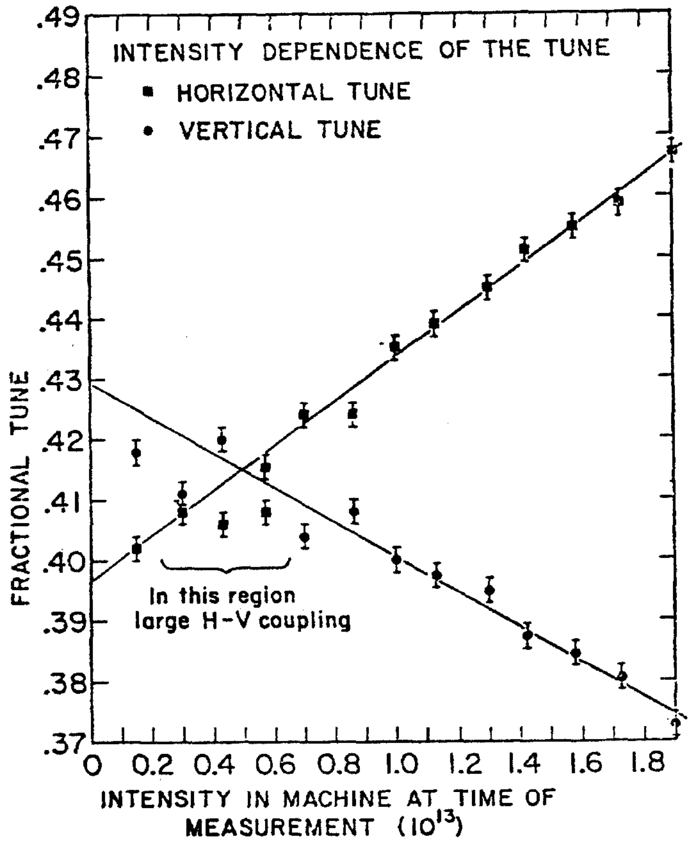

Figure 1

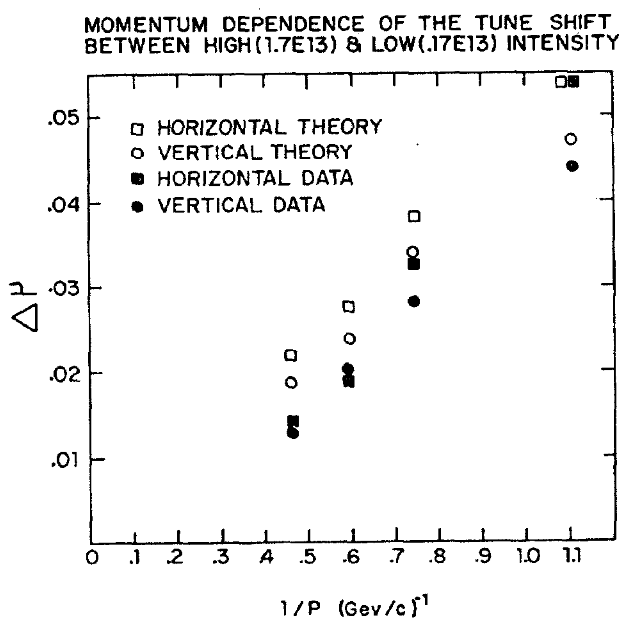

Figure 2