IMPROVED CHROMATICITY CONTROL FOR 100 GeV STORAGE AT FERMILAB

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ABSTRACT

The current capability of the horizontal sextupole magnets in the main ring has recently been doubled. This allows the chromaticity to be adjusted to near zero at 100 GeV. Effects upon beam lifetime are discussed.

Introduction

Even in an idealized synchrotron with perfect dipole and quadrupole fields there is a dependence of the betatron tunes ν_x and ν_y on the relative momentum error $\Delta p/p$. In a real synchrotron, in addition to this so called chromatic aberration, there is dependence due to remanent fields, eddy current fields, and structural field errors of sextupole and higher order; the dependence in general is called chromaticity and is represented by

$$\xi_x = \Delta\nu_x/(\Delta p/p)$$

and

$$\xi_y = \Delta\nu_y/(\Delta p/p).$$

The correction magnet system for the Fermilab main ring employs 186 six-pole magnets to correct horizontal and vertical chromaticity up to about 50 GeV, including some of the decapole and higher order contributions.[1] Correction at higher momentum has not been important for routine operation; however, the investigation of the main ring as a storage ring has required much more precise control of the tunes and reduced sensitivity to the tune shifts caused by magnet power supply ripple and synchrotron oscillation.

Correction Magnets

The main ring chromaticity correction system contains 84 sextupoles located next to the vertically focusing quadrupoles which affect primarily ξ_y and 102 asymmetric six-poles next to the horizontally focusing quads which primarily affect ξ_x. The voltage available from the power supply for the horizontal six-poles had limited current to about 7A through two parallel circuits, providing a maximum of about 3.6×10^3 kG/m of B''L. By recabling to provide four parallel paths it has been possible to achieve more than enough current for substantial correction of ξ_x at 100 GeV. The power distribution for the vertical correction sextupoles has not been modified; the available 4.3×10^3 kG/m of B''L is not adequate to completely correct ξ_y.

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Chromaticity at 100 GeV

The tunes have been measured on a 100 GeV "front porch" (dB/dt = 0) portion of a 350 GeV accelerator cycle for various values of momentum offset introduced by biasing the radial position feedback to the RF system. The fractional part of the tune is found by exciting coherent betatron oscillation with a pulsed dipole and analyzing the output of a position detector with a 256 point fast fourrier transform. Thus, the tunes were in principle measureable to $\sim$.004; measurements taken with the correction sextupoles off have somewhat greater uncertainty because of the loss of coherence caused by the momentum distribution of the beam. These results are plotted as the outline points on Fig. 1. In the absence of a zeroth azimuthal harmonic of the structural sextupole field the ν_x and ν_y curves should show the same natural chromatic aberation $\xi_x = \xi_y = -22.1$ determined by the main ring lattice because neither remanent fields nor eddy current fields are significant. The observed average slopes of the tune curves are $\xi_x \simeq -17$ and $\xi_y \simeq -11$ with curvature showing the presence of at least octupole and probably higher order contributions as well.

The current needed in the six-poles to reduce the average ξ_x to zero while running maximum available vertical correction has been calculated from their strength and location,[2] viz., $I_x = 9A$, $I_y = 5.6A$. The solid points in Fig. 1 represent the results of a second set of tune measurements with the calculated correction in effect. As may be seen, ξ_x has been nearly eliminated while ξ_y has been little changed from its uncorrected values. The amount of octupole strength available in the present correction system has no significant effect on the curves shown.

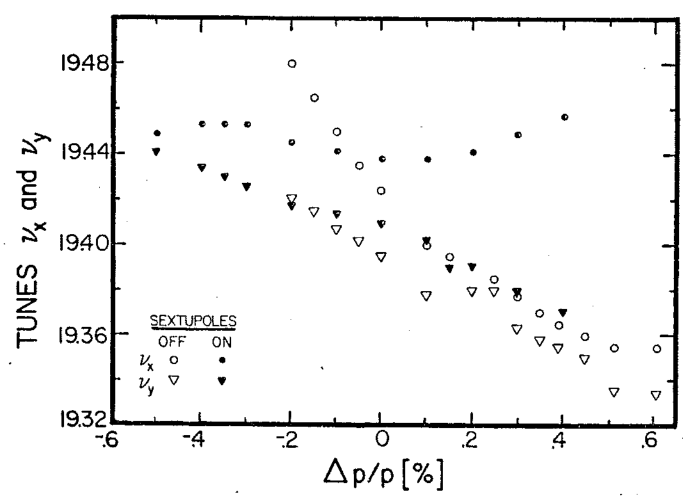

Fig. 1. Betatron Tunes vs. Momentum Offset

Effects on Beam Lifetime

The momentum spread within the 100 GeV beam has been measured[3] as high as ±.06% depending on various features of the operating conditions including generally an intentional dilution of the longitudinal phase space introduced after transition to stabilize the beam. With this momentum spread the horizontal tune spread due to momentum has been reduced from ∿±.01 to insignificance while the vertical tune spread from this source remains ∿±.006. The observed coherence of the betaron oscillations introduced to measure the tunes is consistent with these values. The significance of this tune spread reduction for the lifetime of stored beam depends on the relative importance of various loss mechanisms. At current levels of main ring vacuum, $P \lesssim 10^{-7}$ torr, one may not see dramatic effects from improvements of this kind, but there has been consistent evidence[4] that simple gas scattering diffusion does not fully account for observed lifetimes nor in particular for early losses. In a set of beam stores made both with and without chromaticity correction it was observed that the momentum aperture available for beam storage, $-.0045 \leq \Delta p/p \leq .0025$, was not affected by the correction so long as the tunes were controlled. However, as one can see from the beam current halflife results plotted vs. $\Delta p/p$ in Fig. 2, there is evidence that the sextupole-off lifetime is shorter by ≃20% at each $\Delta p/p$. The five measurements for $\Delta p/p = 0$ given in the table below show this effect but also a spread which indicates some inadequately controlled and perhaps even unsuspected influence. Certainly both improved vacuum and better power supply regulation would help establish a cleaner experimental situation. For the purpose of pursuing other quantitative studies of the main ring as a storage ring even the partial chromaticity correction described here has a practical significance in making it far simpler to manipulate the stored beam and to isolate phenomena which are hidden by momentum induced tune spread or losses due to regulation of the bending magnets. We expect the benefits of the chromaticity correction to be more obvious as other problems are identified and compensated.

Table
Beam Halflife at 100 GeV ($\Delta p/p = 0$)

	ν_x	ν_y	$t_{1/2}$[sec]	
Sextupoles on $I_x = 9A$, $I_y = 5.6A$	19.441	19.426	2070	
	19.441	19.426	1983	
	19.446	19.426	2951	
				2335 avg.
Sextupoles off	19.441	19.430	2000	
	19.449	19.434	1646	
				1823 avg.

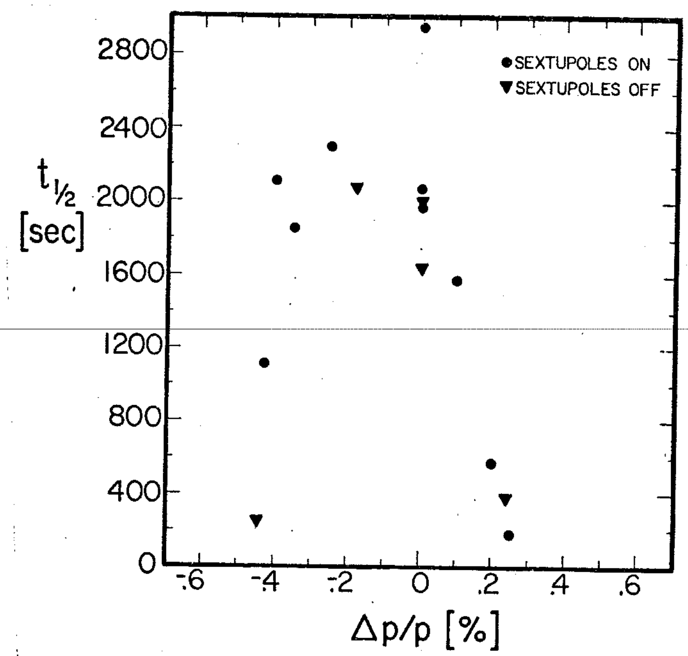

Fig. 2. Beam Lifetime vs. Momentum Offset

References

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4. A. Tollestrup et al., "The Present Status of the Main Ring as a Storage Device," 1977 Summer Study, v. 1, 97(1977).