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Damping Transverse Instabilities in the Tevatron Using AC Chromaticity *

V. H. Ranjbar, Fermilab, Batavia, IL

Abstract

Several papers [1],[2] have suggested possibility of using varying chromaticity to damp the head-tail instability. We test this by cycling the chromaticity sextupole magnets in the Tevatron near the synchrotron frequency to see if the head-tail stability threshold is increased. Further we compare the turn-by-turn evolution of a bunch slice in the presence of varying chromaticity to a model previously developed.

INTRODUCTION

The quest for higher integrated luminosities requires the control of beams at high energies and intensity. The issue of impedance driven instabilities becomes more and more relevant. In the Tevatron transverse wake field driven instabilities have been controlled by running with high chromacities. However high chromaticities adversely effect beam lifetime. To run with lower chromaticity transverse dampers have been used and more recently octupoles have been installed. We explore now another method to damp out wake field driven instabilities using ac chromaticity. This idea has been explored in several papers [1], [2]. But to our knowledge it has never yet been actually tested in a high energy machine.

IMPACT OF AC CHROMATICITY ON PROTON BEAM

We can include a time dependence in the chromaticity by introducing ξ_1 and ω_1,

$$\xi(s) = \xi_0 + \xi_1 \cos(\omega_1 s/c) \tag{1}$$

The incoherent tune spread induced by this chromaticity can be estimated using,

$$\begin{aligned} \sigma_\nu &= \xi_1 \sqrt{< (\delta^2 \sin^2(\omega_1 s/c)) >} \\ &= \xi_1 \sqrt{\frac{3}{8}} \sigma_\delta 2\pi \end{aligned} \tag{2}$$

Here ξ is the chromaticity, ω_0 angular revolution frequency and σ_δ the rms distribution of $\delta = \frac{\Delta p}{p}$.The coherent tune shift in the Tevatron was measured in 2003 to be $\Delta\nu_{coh} = 1.1 \times 10^{-3}$ [4]. However this measurement was prior to installation of liner at the F0 lambertson which reduced the total impedance in the Tevatron so we can estimate that our coherent tune shift is now no more than 8×10^{-4}. An approximate stability criterion for Landau damping is,

$$\sigma_\nu > |\Delta\nu|. \tag{3}$$

Given that $\sigma_\delta = 4.9 \times 10^{-4}$ for a typical coalesced proton bunch in the Tevatron, the necessary AC chromaticity needed should be $\xi_1 = 0.422$. In addition simulation work published previously [2] claimed a stability threshold for $\chi = 0.026$ with $Y = \Delta\nu_{coh}/\nu_s = 0.22$ where,

$$\chi = \frac{\omega_0 \xi \sigma_\tau}{\eta}. \tag{4}$$

Here $\sigma_\tau = 2.6 \times 10^{-9} sec$ is the rms bunch length for a typical coalesced proton bunch in the Tevatron and $\nu_s = 1.77 \times 10^{-3}$ is the synchrotron tune. This translates into $\xi_1 = 0.082$ units of ac chromaticity, however since in the Tevatron $Y = 0.45$ we guessed that the ξ_1 necessary should at least be twice as large or $\xi_1 = 0.16$. Being lower than our previous estimate for our experiment we used the larger value of $\xi_1 = 0.422$

EXPERIMENTAL SET-UP

The chromaticity in the Tevatron is controlled primarily by a family of sextupole magnets named SF which mainly effect the horizontal chromaticity and SD sextupole magnets which primarily affect vertical chromaticity. Both magnets are connected to two 460 CAMAC ramp cards. We used the C:SFB2 and C:SDB2 ramp card used for compensating chromaticity drift due to magnet hysteresis . The 460 CAMAC ramp cards have time tables which can be played out on any event. Using the 0F 15Hz event we built time table ramp which would drive a 90 Hz sinusoidal cycle for both the SF and SD magnets. We chose 90 Hz since given the events we could use it was the closest we could get to the synchrotron frequency of 84 Hz. The current to chromaticity transfer function for the SF magnets is $\xi(I) = .17 \times I/E$ where E is energy in TeV and I is current in Amps. For the SD magnets the transfer function is $\xi(I) = .3 \times I/E$. Based on this we calculated that we needed to cycle 20-10 mA at 90 Hz. We chose to cycle both at 20 mA. This requires a slew rate of 6.72 A/s which is below the 15 A/s which is the maximum speed the magnets can move.

With octupoles off we began with 1 coalesced bunch of 90×10^9 protons per bunch and explored the stability region with ac chromaticity on and off. We did not observe any difference in the stability threshold in either the horizontal or vertical planes.

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ANALYSIS AND MULITPARTICLE SIMULATIONS

After performing our own multi-particle simulation developed by A. Burov [3] we ran 1000 particle simulation under a resistive wall wake field of $8.7 \times 10^5/\mathrm{cm}^2$ at chromaticity of 1.87 units. Under these conditions as shown in Fig. 1 an instability sets in. The effect of adding 0.4 units of ac chromaticity is not readily observable in the beam envelope behavior. In fact we don't begin to see anything until around 0.844 units of ac chromaticity, where the growth rate is clearly reduced but the instability not eliminated. When we reach 1.2 units of ac chromaticity then the beam is completely damped. Our initial estimates have underestimated the amount of ac chromaticity needed. Additionally

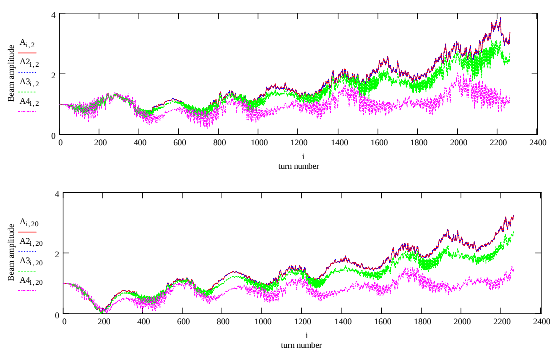

Figure 1: Multi-particle simulation results with 1000 particles under the influence of a resistive wall wake of 8.7×10^5 $\xi = 1.87$ with total charge equal to 260×10^{11} protons. Top graph is head of bunch (4 nsec from center) and bottom is tail (4 nsec from center). Top two traces are the beam envelope with $\xi_1 = 0$ and $\xi_1 = .422$ (no real difference), middle trace $\xi_1 = .844$ and bottom trace $\xi_1 = 1.26$

our simulations showed that one of the byproducts of an ac chromaticity are the appearance of additional frequency components in the Fourier spectrum. It may be possible to consider the ratio between the tune peak and these peaks to estimate the strength of the wake field as shown in Fig 2.

CONCLUSION AND FUTURE PLANS

Given the maximum slew rate of 15 A/s means that we should be able to generate at least .9 units of ac chromaticity in the vertical plane and 1.6 units in the vertical plane. We will try to repeat this experiment cycling at ±45 mA in the horizontal plane. This will allow us reach at least 1 unit of ac chromaticity in the horizontal plane.

REFERENCES

[1] W. Cheng et. al. PRL Vol 78 N24.

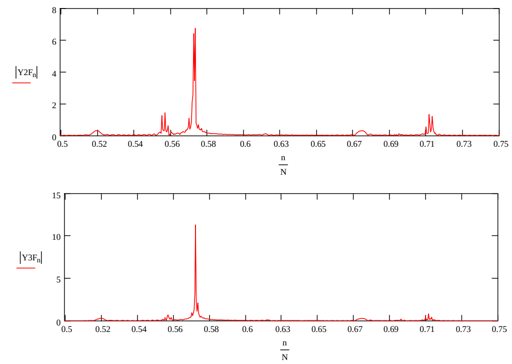

Figure 2: Fourier spectrum from multi-particle simulation with 1000 particles with total charge equal to 260×10^{11} protons and $\xi = 1$ and $\xi_1 = 1.2$. Top graph is under the influence of a resistive wall wake of 8.7×10^5, bottom graph is under the influence of wake 4.7×10^5. The ratio between the largest off tune peak for the larger wake field is 0.18 and 0.07 for the smaller wake.

[2] W. Cheng et. al. PRE Vol 56 N4.

[3] software written by A. Burov.

[4] private communication with P. Ivanov