THE TEVATRON TRANSVERSE DAMPERS

C.Y. Tan, J. Steimel
FNAL, Batavia, IL 60510, USA*

Abstract

We describe in this paper the Tevatron transverse dampers. The goal of these dampers is to keep the beam stable when we operate at lower chromaticities. The reason for operating at lower chromaticities is to improve the beam lifetime. However, the beam becomes unstable at low chromaticies and thus dampers are required. Also included in this paper are the damper commissioning notes and their real-life performance.

INTRODUCTION

The motivation for building transverse dampers for the Tevatron is to improve the lifetime of the proton and pbar beam on their helices during pbar injection. Previous studies by Y. Alexahin *et al* [2] , showed that when octupoles were used to stabilize the beam, and chromaticities lowered, the lifetime of the beam of both species on the helix is improved. However, due to great difficulties in using octupoles in operations because of drifts in tunes, coupling and chromaticities at 150 GeV, this method was abandoned from use in operations. Therefore, when it was decided to resurrect the idea of lowering the chromaticity to improve beam lifetimes, we had to come up with some other way of keeping the beam stable and transversely damping the beam immediately came to mind.

The idea behind lowering the chromaticity ξ comes from the simple observation that the tune spread ΔQ is related to the energy spread dp/p by

$$\Delta Q = \xi dp/p \qquad (1)$$

Thus, if the chromaticity is lowered, ΔQ is smaller and the beam will occupy a smaller footprint in the tune plane. A smaller footprint means that the beam will enclose fewer resonances which means that less beam will be lost and thus the lifetime is improved. However, there is a competing mechanism which throws a spanner into this. As long as there is a non-zero transverse impedance, the beam naturally becomes more unstable when the tune spread becomes smaller because Landau damping becomes weaker. Stability is determined by the Keil-Schnell stability criteria which is given by

$$|(\Delta\omega_q)_{\rm coh}| \lesssim (\Delta\omega_q)_{\rm HWHM} F \qquad (2)$$

where $(\Delta\omega_q)_{\rm coh}$ is the coherent betatron tune shift which comes from the transverse impedance, $(\Delta\omega_q)_{\rm HWHM}$ is the betatron tune spread measured at half-width half-max and F is the form factor depending on distribution. $F = 1/\sqrt{3}$ for an elliptic distribution. This tells us that when we lower the chromaticity, which decreases $(\Delta\omega_q)_{\rm HWHM}$, at some point $|(\Delta\omega_q)_{\rm coh}|$ becomes larger than the rhs of (2), and the beam becomes unstable. Therefore, in order to keep the beam stable when we lower the chromaticity, we have to have a stabilization mechanism and in this case we choose to use active transverse damping.

In practice, for (36×36) bunch high energy physics operations after August of 2002, with both the horizontal and vertical dampers in service, the chromaticities of the horizontal plane is lowered by 6 units and the vertical plane by 4 units from their nominals which is about 8 for both planes on the central orbit and about 12 units for horizontal and 8 units for the vertical on the proton helix.

SETUP

In this section, we will go through each part of our setup used for our bunch by bunch transverse dampers and show that the open loop response < 1. Figure 1 is a block diagram of the setup. The damper system starts at the stripline pickups working in difference mode. A transverse kicker is installed at a position in the Tevatron so that it has a phase advance of of an odd multiple of $\pi/2$ w.r.t. pickup after 1 turn. In order to improve the dynamic range of the damper system, a method developed by McGinnis called the autozero circuit shown in Figure 2, is used to virtually centre the beam in the pickup. This signal is mixed down with the Tevatron RF and low pass filtered to produce a transverse position error signal. The error signal is processed with electronics which perform the following:

Autozero Circuit

The autozero circuit was developed by D. McGinnis to improve the dynamic range of the damper system. If the closed orbit of the beam is not in the electrical centre of the striplines in Figure 2, then clearly the induced voltage on the top plate is not equal to the voltage on the bottom plate. However, by changing the value of the attenuator connected on the bottom plate, we can make the induced voltages equal. Thus, the beam is now virtually centred in the stripline pickup and the dynamic range is immediately improved because we have essentially removed the DC component of the error signal, i.e. we can have much more gain downstream without saturating the amplifiers due to the DC component.

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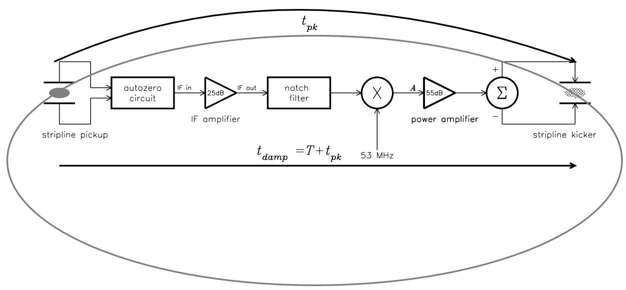

Figure 1: This is a block diagram which shows the overall setup of the transverse damper system. Note that the signal of the bunch which is detected at the stripline pickup is applied approximately one turn later to the same bunch at the stripline kicker. Each block is expanded further in Figures 2

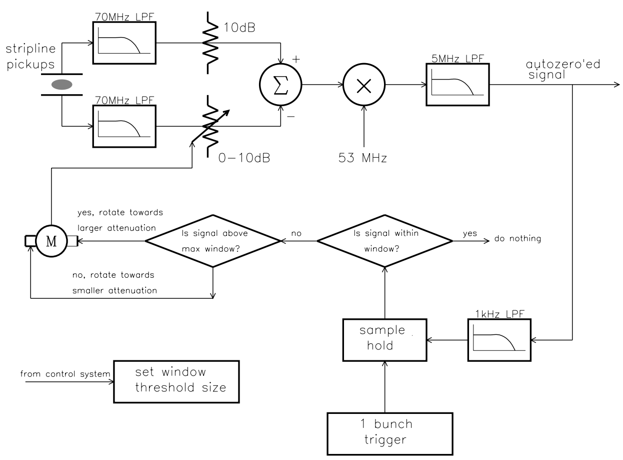

Figure 2: This figure shows the block diagram of the autozero circuit.

Digital Notch Filter

The digital notch filter consists of two digital delay lines when summed together produces notches at the revolution harmonics. Its response is given by

$$R_{\text{notch}}(\omega) = 1 - e^{-i\omega NT} \tag{3}$$

where T is the revolution period and N is the number of revolution periods in the delay.

Uniform Triggers

In order for the digital delays to work they have to be triggered. The triggers which we use are uniform in time and they trigger in places even when the beam is not present. The reason will become apparent later in the discussion. At present, in Tevatron operation, there are three

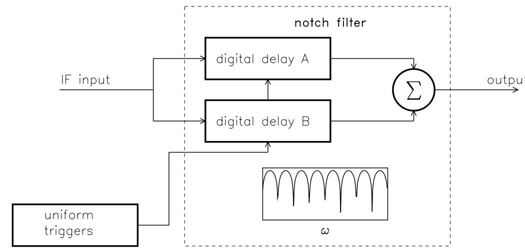

Figure 3: The digital notch filter.

trains of 12 bunches each. In each train, the bunches are spaced 21 buckets apart. The spaces between the trains are the abort gaps and they take up 140 buckets each.

Notice that all bucket spacings are divisible by 7. Therefore, if we have triggers which are spaced exactly 7 buckets apart, the digital delays will sample all the bunches as well as alot of empty space. The reason for having more triggers than necessary is to allow us to use reasonable cable delays to fine tune the system delay to ensure that the correct buckets are kicked. In the worst case scenario for this trigger pattern, the cable length will be 7 buckets$/2 \approx 70$ ns for correctly hitting the right bucket. While for triggers where there are bunches only, the worst case scenario will be 140 buckets$/2 \approx 1.3\ \mu$s of cable! (Recall that 1 ns is about 1 foot of cable.)

RESULTS

We measured the open loop response of the damper system by breaking the loop as shown in Figure 4. The Tevatron is filled with 36 bunches of protons in the pattern discussed in *Uniform Triggers*. After we add in 17 μs of delay, the frequency response becomes nice and symmetric about half the revolution frequency $f_r/2$ as shown in Figure 5

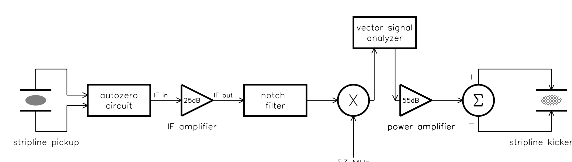

Figure 4: The loop is broken just downstream w.r.t. mixer and a vector signal analyzer (VSA) is connected there.

Closing the Loop

Finally, we can close the loop and damp. We injected 36 bunches into the Tevatron and sat at 150 GeV for this set of experiments. Figure 6 shows the effect of closing the loop. The red curve is the noise spectrum measured at A of

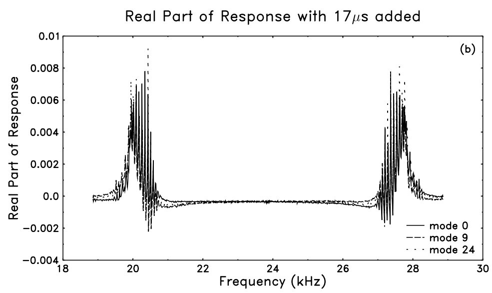

Figure 5: This graph shows real part of the response after adding 17 μs to the digital delay. To get the real part of the response to be negative, we have to multiply by -1 in the electronics. We have superimposed three graphs on top of each other by shifting the frequency of mode 9 by $-9f_r$ and mode 24 by $-24f_r$.

Figure 1 with the power amplifier off. The power amplifier is turned on, thus closing the loop, and we see that there is a suppression at the horizontal tune sidebands of about 6 dB (the purple curve). The noise floor is increased by about 2 dB in the middle of the spectrum. The closed loop gain of the damper is 6 dB at the horizontal tune. The full width at half min (fwhm) of the absorption line gives the damping time of the damper for the 361.6 kHz tune line which is 0.55 ms ≈ 26 turns in the Tevatron.

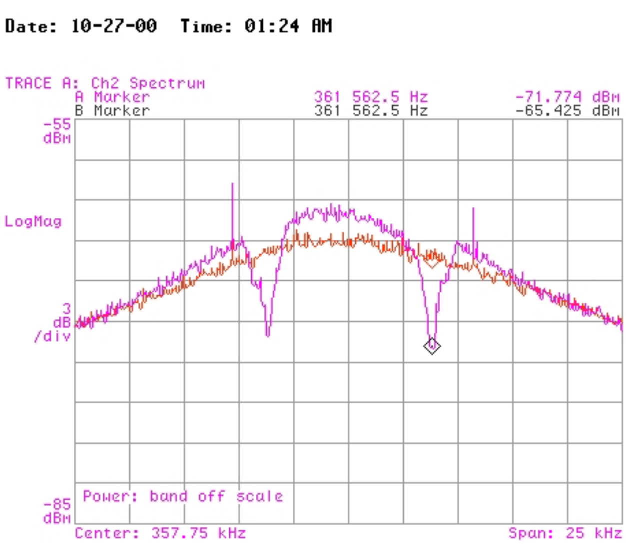

Figure 6: The suppression of the horizontal tune sidebands (purple curve) when the loop is closed compared to the red curve when it is open.

Operations

In operations, we lower the horizontal chromaticity by about 6 units and vertical chromaticity by about 4 units from their nominals of 8 units for both planes on the central orbit and 12 units for the horizontal and 8 units for the vertical on the proton helix. For store #1868 shown in Figure 7 which had the horizontal chromaticity lowered by 5 units and vertical lowered by 2 units, the effect of the lower chromaticity is dramatic. Before the dampers are turned on, beam lifetime T:IBEAM (total beam current) and C:FBIPNG (proton beam current) is poor. The $1/e$ time is about 1 hr for C:FBIPNG at this time. When the dampers are turned on for pbar injection and chromaticities lowered, we see that the C:FBIPNG $1/e$ lifetime is improved by a factor of 3 to 3 hr. At the completion of pbar injection, just before we ramp, the dampers are turned off and chromaticities restored to nominal. Again, we see that the T:IBEAM and C:FBIPNG lifetime reverts back to being poor again.

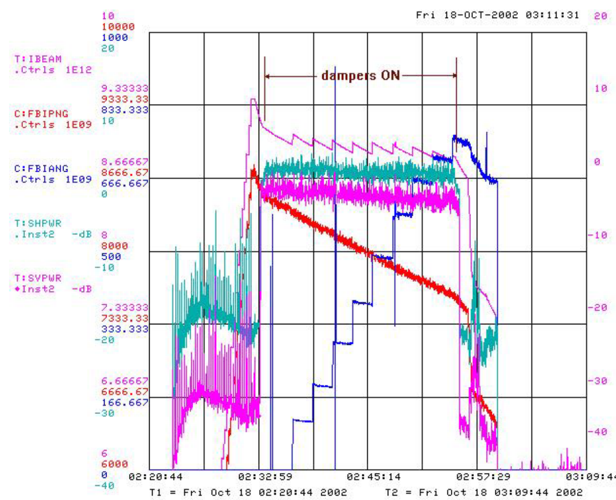

Figure 7: This plot shows the damper in action. Total beam current is T:IBEAM (the sawtooth shape comes from pbars being injected). C:FBIANG shows the increase in pbar current as they are being injected. C:FBIPNG is the proton beam current only. T:SHPWR and T:SVPWR are the horizontal and vertical Schottky powers which rise up by about 30 dB when the dampers are turned on.

CONCLUSION

The transverse dampers have been used in high energy physics operations and enough data have been gathered to show that the dampers do no harm to the protons or pbars at 150 GeV. With low chromaticity the lifetime of the pbars is always improved, although the proton lifetime is improved some of the time on the helix. Thus the value of the dampers for high energy operations is mainly for keeping pbars in the Tevatron during injection.

REFERENCES

[1] C.Y. Tan, J. Steimel, “The Tevatron Transverse Dampers” (unabridged), Fermilab Technical Memo, TM-2204.

[2] Y. Alexahin,*et al*, “2002 Tevatron Log Book”, 2002.