

COMMISSIONING OF THE HEAD-TAIL MONITORING APPLICATION FOR THE TEVATRON *

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Abstract

A head-tail beam monitoring application has recently been developed for use in the Tevatron. With this application beam dynamics problems including head-tail instabilities can be monitored. In addition it can be used to perform chromaticity measurements using the head-tail technique developed at CERN. This application speeds up chromaticity measurements in the Tevatron especially during the acceleration ramp and low beta squeeze, which previously required three separate ramps using uncoalesced protons.

CHROMATICITY CALCULATIONS

The Chromaticity head-tail phase technique has been developed for use in the Tevatron using a head-tail monitoring application. This technique is based on the phase shift, which develops for particles of different energies within a single bunch. Since this phase shift is proportional to chromaticity, knowledge of the phase shift over a synchrotron period can allow extraction of the chromaticity. Currently the Tevatron uses a varying RF technique to measure chromaticity. So far the RF method cannot effectively measure chromaticity for coalesced proton bunches. The Head-Tail technique however seems to be capable of extracting chromaticity for coalesced protons even during acceleration. This application will greatly speed up chromaticity measurements especially during ramp and squeeze which currently require three separate ramps using uncoalesced protons. Under ideal circumstances a particle in an RF bucket will circulate in the bucket with the synchrotron frequency. Since chromaticity is a measure of the change in betatron tune vs. change in momentum, the betatron phase for a particle will depend on the chromaticity, the distance from the centre of the bunch and the synchrotron frequency. Thus the betatron equation for a particle undergoing synchrotron oscillations in a bucket will become,

$$Z(n) = A \cos[2\pi nQ + Q' \omega \tau \cos(2\pi nQ_s) - 1] / \eta] \quad (1).$$

Here $Z(n)$ is the transverse position at turn n since the beam was kicked, Q is the betatron tune, Q_s is the synchrotron tune, τ is the longitudinal position with respect to the centre of the bunch, Q' is the chromaticity, ω the revolution frequency and η the momentum compaction factor. If two longitudinal positions in the bunch are selected separated by $\Delta\tau$, the phase difference will become,

$$\Delta\Psi(n) = -Q' \omega \Delta\tau \eta / [\cos(2\pi nQ_s) - 1] \quad (2).$$

Thus we can solve for Q' to obtain,

$$Q' = -\eta \Delta\Psi(n) / \omega \Delta\tau [\cos(2\pi nQ_s) - 1] \quad (3).$$

HARDWARE AND SOFTWARE SET-UP

Using the 1-meter long strip line detector installed at F0 in the Tevatron the proton signal is captured using a Tektronics TDS7000 series oscilloscope. The A-B and A+B signals are measured with a resolution of 0.4 ns across 20 ns for 1049 turns. Since the recorded signal is the sum of the image current travelling with the beam and the reflected image of the beam from the downstream end we first de-convolute the single image by subtracting out the reflected image. This is accomplished digitally using knowledge of the length of strip line and the velocity of the beam. An example of the de-convoluted sum signal can be seen in Fig. 1.

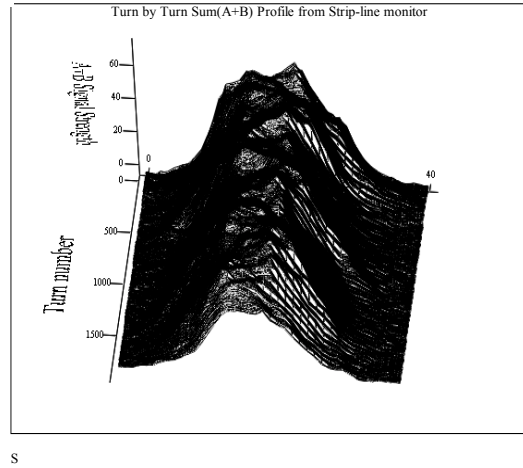


Figure 1: Using the vertical and horizontal strip-line detectors installed in the Tevatron at the F0 location we extract a profile of the transverse behaviour of the beam over a single longitudinal bunch.

After reconstruction of the signal the transverse position is then determined by taking the ratio of the sum and difference signal times a factor given by the geometry of the strip-line (27),

$$Z = 27x(A-B)/(A+B).$$

*Work supported by the URA., Inc., under contract DE-AC02-76CH03000 with the U.S. Dept. of Energy.

The A+B signal is then used to identify the bunch centre. We found that this was essential since for many data sets the bunch centre would oscillate with the synchrotron frequency Q_s . An example of this bunch oscillation can be seen in Fig.2. We selected two longitudinal positions around the bunch center separated by $\Delta\tau=0.8$ nsecs from each other. According to extensive simulation work done at CERN [1][2] this symmetrical location should mitigate any effects due to both non-linearities and acceleration.

The scope has an onboard processor with a running a Lab View application. This Lab View program is in turn controlled by a vax console program (C100) via a few acnet variables: T:CHROMO (the acquisition state i.e. single or multiple measurements, coalesced or uncoalesced protons) and T:CHRMCN which set the scope to acquire data. V:CHROM returns the current state

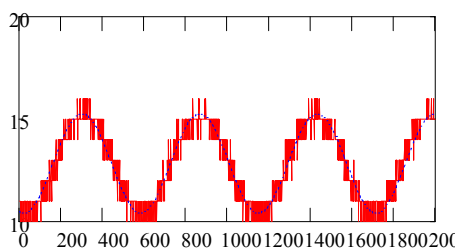


Figure 2: Bunch centre oscillations after horizontal kick.

of a given measurement (0-5), 2 = scope is armed 5= measurement complete. The scope is fed a series of event driven triggers I:F1N8C6 and I:F1N8C5. T:TBSDD0 defines the trigger timing (.195 Trev yields the P0 bunch) and T:RTBSMT the number of triggers.

The Lab View front end both controls the scope and pre-processes the waveforms generating transverse position turn-by-turn data for the vertical and horizontal head and tail slices of a given bunch. These four position arrays are then read into acnet array variables: T:CHRXT, XH,YT,YH.

The C100 vax console program controls the E17 vertical kicker and F17 horizontal injection kicker by setting the voltage of each kick and the timing as well as setting the events and delays. The E17 kicker uses a thyatron, which produced a half-sinusoid current pulse, with a base width of 10 μ secs. The F17 extraction kicker produces a square current pulse with a width of 1.8 μ secs. Since the timing of the E17 vertical kicker varied with voltage, a timing versus voltage table was built into the software using observed kicker response time. This table is graphed in Fig. 3. Since we have a history of burning out the E17 thyatron tubes any future replacement tubes

may require an adjustment of this voltage versus timing table. In addition the C100 program sets up the events and triggers for the scope (I:F1N8C6 , I:F1N8C5, T:TBSDD0 and T:RTBSMT) and controls the state of the Lab View program via T:CHROMO and T:CHRMCN.

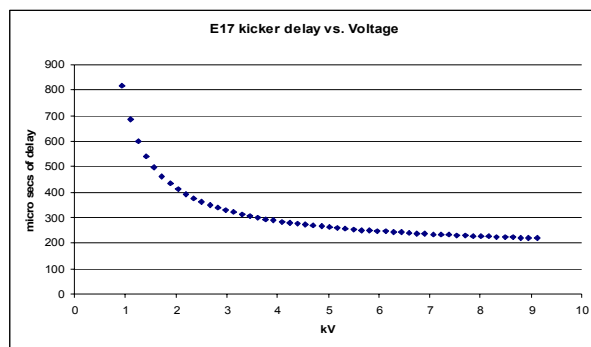


Figure 3: E17 kicker delay versus voltage.

RESULTS

On several occasions we acquired data at 150 GeV for a series of chromaticity settings with coalesced protons and

Difference in Head Tail Phase Evolution $Q'=7.49$

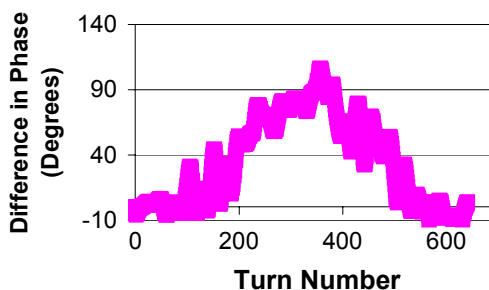


Figure 4: Evolution of $\Delta\Psi(n)$ over the first synchrotron period after horizontal kick.

later during the acceleration ramp. We typically used 1.5 mm (4.5π mm-mrad) kick. To extract the instantaneous phase for each turn for the selected two bunch slices a Hilbert transform was employed. This involves multiplying the signal $Z(n)$ by $2\cos(2\pi nQ)$ and $-2\sin(2\pi nQ)$ then filtering out the high frequency components $f < 2Q$ to obtain $y(n)$ and $x(n)$. From arctangent of $y(n)$ and $x(n)$ the phase as a function of turn number n can be found. We then can calculate $\Delta\Psi(n)$ using both slices. In Fig. 4 you can see an example of the evolution of $\Delta\Psi(n)$ over a single synchrotron period.

Solving for the chromaticity for each turn we select 40 points during the middle of the synchrotron period to average over. Since the calculation goes as $1/(\cos(2\pi n Q_s)-1)$ the error should be a minimum at the $1/2$ synchrotron period point.

In Fig. 5 we compare the head-tail technique to the standard RF technique currently in use. The measurements using the RF technique were carried out using an uncoalesced proton bunch. In the horizontal plane the same chromaticity set points were then used for coalesced bunches. Fig. 6 is an example of 10 points taken during the first 12 seconds of acceleration. These ten kicks caused at total of 50π mm-mrad growth in the emittance of both planes.

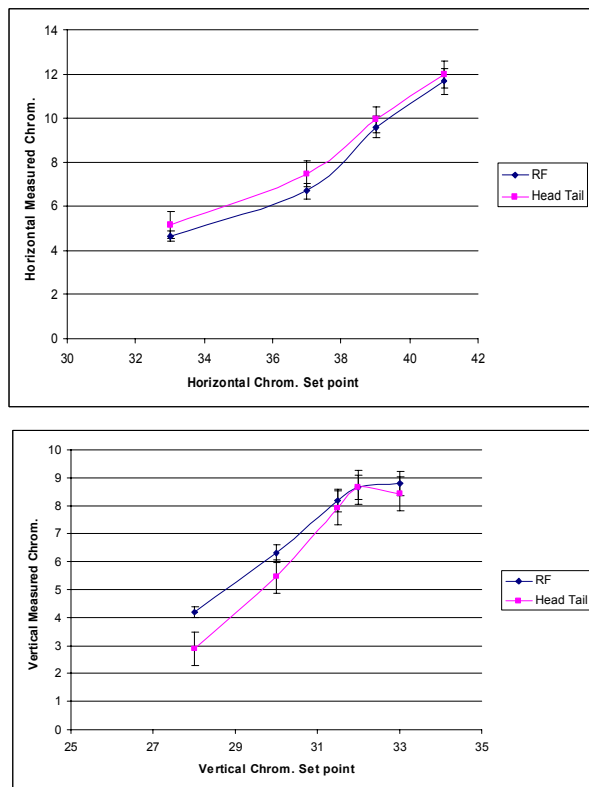


Figure 5: Horizontal (top) and Vertical (bottom) head-tail chromaticity measurement compared with RF chromaticity measurement at 150 GeV.

CONCLUSION

A head-tail monitoring system has been commissioned for the Tevatron, which can extract chromaticity during the acceleration ramp. The system currently can acquire a maximum of 20 points total per acquisition cycle. This limitation is due to the buffer memory size in the scope we are using. This system in addition can deliver tunes and linear coupling estimates as well as monitor head-tail instabilities by generating real-time transverse bunch amplitude profiles.

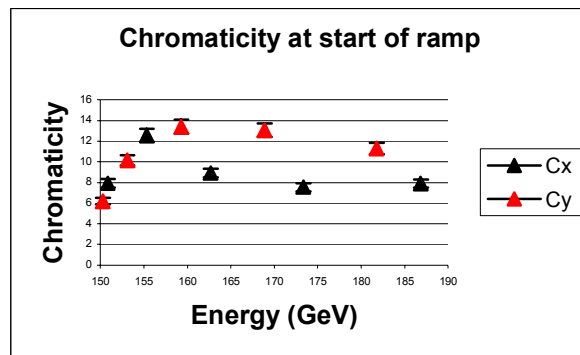


Figure 6: Horizontal (Cx) and Vertical (Cy) chromaticities during the first 12 sec of the ramp.

REFERENCES

- [1] D. Cocq, O. R. Jones, H. Schmickler, "The Measurement of Chromaticity Via a Head-Tail Phase Shift", 8th Beam Instrumentation Workshop (BIW'98), Stanford, CA, USA, May 1998.
- [2] S.Fartoukh and R. Jones, "Determination of Chromaticity by the Measurement of Head-Tail Phase Shifts: simulations, results from the SPS and a robustness study for the LHC", LHC Project Report 602 2002