Operational Experience with the Tevatron Collider using Separated Orbits

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Abstract

This paper will discuss the operation of the Tevatron for the 1992 collider run. Operation and commissioning of electrostatic separators, new low beta insertions, a new abort system, feeddown sextupoles, and new features of the control system will be discussed.

I. INTRODUCTION

During the 1989 collider run there was a single major experiment at B0. Six proton bunches and six antiproton bunches traveled on the same closed orbit, giving rise to 12 beam crossings per turn. The beam-beam tune shift caused the antiprotons to fill the available tune space of .025 units with proton intensities of 80 E9 given a transverse emittance of 25 π mm mrad. The proton emmittances were intentionally blown up to this level to allow for the survival of the antiprotons. Separating the beams everywhere but at the two interaction points allows a factor of six higher proton densities while the beams are colliding. The beams are separated everywhere at injection.

Adding a second major interaction point required the addition of second low beta insertion. The insertion used in the 1989 run was not matched to the lattice, so two identical new insertions were installed.

Table 1 shows relevant parameters to compare the 1989 run with the goals for collider run 1A.

	1989	run 1A
Protons per bunch	7.0E 10	1.2E 11
Pbars per bunch	2.9E 10	3.6E 10
Proton emittance	25π mm-mrad	16 π mm-mrad
Pbar emittance	18 π mm-mrad	16 π mm-mrad
Pbar tune spread	.025	.011
Proton tune spread	.014	.003
Luminosity	1.6E 30	5.37E 30

Table 1.

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

II. IMPACT ON THE TEVATRON

The arrangement of electrostatic separators chosen called for vertical separator to be placed where the antiproton abort kicker used to reside. Because of this, a new abort system was designed and installed elsewhere in the accelerator (A0 straight section).

Separating the beams requires that the particles go off center through devices with nonlinear fields. This gives rise to a differential tune shift of the two beams. To compensate for this, a distribution of sextupoles (feeddown sextupoles) were installed to differentially control the tunes and coupling.

The feeddown sextupoles were installed in pairs with opposite polarity to leave the chromaticity unchanged. The entire system consisted of 46 sextupoles of which 38 were already installed in the Tevatron. 8 spool pieces needed to be changed to a type containing skew sextupoles. 28 power supplies were added to run the feeddown system.

The low beta insertion called for special quadrupoles to extend back 600 feet into the arcs. 24 spool pieces had to be replaced by new low beta spools. The upstream correction packages in the spools, consisting of a steering dipole, a tune quadrupole, and a chromaticity sextupole, remained, but the secondary correction packages were replaced by a low beta quadrupole. Six skew quadrupoles and a single octupole (used only for fixed target) were only active elements eliminated. In addition to the spool replacement, 8 low beta quadrupoles were removed from the old insertion at B0 and 10 new quadrupoles were installed at both B0 and D0.

The process of putting a new store into the Tevatron is done in many distinct sequences. This is an operationally complex process, so much of the Tevatron control system was upgraded [1]. In the past, the fill sequence was halted in several places to reload waveforms needed for the next step. The Tevatron front end for the Camac link and the control console computers were PDP-11s. It was difficult to write and maintain the large application programs needed to run the collider. To solve these problems, a new waveform generator was designed to allow all the necessary waveforms to be preloaded and then triggered on event. The control consoles were upgraded to VAX work stations and many of the application programs were written to take advantage of these upgrades. The front end computer was changed to a Multi-bus II multiprocessor system to improve performance.

III. IMPLEMENTATION

A. Separators

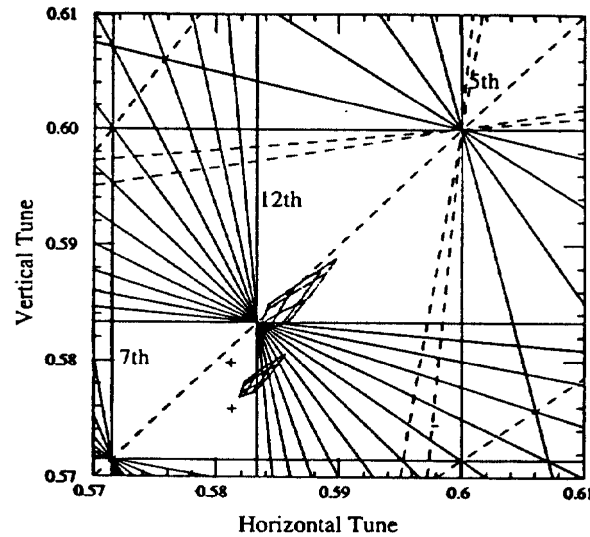
The nominal design separation of the beams was 5 transverse beam sigma's. This corresponded to about 100 KV for some of the separator modules. There was a problem with the physical aperture near the new abort dump early in the run, so the system was initially turned on to 60% of nominal separation. This separation was adequate for the beginning of the run as the antiproton lifetime was several hours at injection. As the proton intensities increased, the antiproton lifetime began to suffer during the injection front porch. The separators were eventually turned up to 115 % of their design value at 150 GEV to improve the beam lifetimes.

The performance of the separators has been excellent. There is one separator module that sparks at lower a voltage when its polarity is reverse. This is only a problem when attempting to run protons on the antiproton orbit by reversing the separator polarities. This is an activity during studies and the problem is handled by increasing the voltage on one electrode, and decreasing the voltage on the electrode susceptible to sparking. At this point in time, only one separator spark has been observed during normal operation and it had little impact on the quality of the store.

B. Feeddown Sextupoles

The feeddown sextupoles have been powered at low energies where the physical separation is large. At higher energy, the actual separation becomes smaller and the differential tune shift is small enough to fit inside the working space. These sextupoles have been adjusted during stores to study the effect on luminosity lifetime and background rates but they normally run at zero current during physics runs. Figure 1 shows the where in tune space where the beams actually exist with both the differential tune shift (.002 units vertically) and the tune spread caused by beam-beam forces.

The horizontal proton tune sits on the 7/12 resonance, but this is not destructive to the low amplitude particles. The high amplitude particles are affected by this high order resonance, but they are tune shifted less and stay below the resonance. The antiprotons are shifted above the protons, so they can reside between the 3/5 and the 7/12 resonances. The vertical tunes for both the protons and antiprotons fit between the 7/12 and the 4/7 resonances. Details of beam-beam interactions around this working space can be found in reference [2] If the uncentered orbit does not go through the center of these sextupoles, tuning these circuits will cause the base tune to change. The normal tune quadrupoles can be adjusted in concert with the feeddown sextupoles, but since the separated tunes can result in acceptable lifetimes and background rates, the feeddowns are normally brought to zero during a store.



Three transverse beam sigma shown in this figure.
Proton intensity 1.2 E11 - Emittance 20 π mm-mrad
Antiproton intensity 5 E10 - Emittance 16 π mm-mrad
$\sigma p/p$ of .0001 at 900 GEV.

figure 1

C. Low Beta Insertions

The installation of the new low beta inserts brought with it new quench protection systems and a larger burden on the cryogenic system. These complications have been managed successfully. It has been found however, that the magnet to magnet variation in transfer constants have introduced beta errors in the Tevatron of significant magnitude [3]. These errors have had many minor impacts on the operation of the collider. One adverse effect is that the maximum luminous point for the D0 experiment is not in the center of their detector. The collision point cannot be moved longitudinally to maximize the interaction rate at both experiments simultaneously. Trim power supplies are being added to quadrupoles within electrical circuits to be able to correct for the gradient errors.

The design beta * for collider run 1A is 1/2 meter. The quadrupoles and power supplies will allow further reduction of beta *, but the beta errors have made this difficult. A small number of stores have been run at 1/4 meter beta *, but these were run with only a partial set of trim power supplies for the low beta quads.

D. A0 Abort System

The new abort system installed at A0 has operated with great success. The system was timed in and commissioned in a couple shifts and to date there has been only one prefire that ended a store. By comparison, the old abort system was responsible for ending 31 stores in the 1989 run because of kicker prefires. During the early weeks of run 1A, there were many quenches of the low beta quadrupoles caused by beam loss when the new abort system fired. It was found however that this was not caused by the abort system, but by an RF operation done in the Main Ring before beam was injected into the Tevatron. During bunch coalescing, small amounts of beam would actually be captured in buckets in the Tevatron abort gap.

E. Controls Improvements

The new waveform generator used by the collider is a Camac 465 card built in house. This card is driven by clock events and are loaded asynchronous with the operation of the collider. The 465 sums a time dependent waveform and a pair of machine parameter dependent waveforms. The operational code has been upgraded several times with only a change of proms. The flexibility of this card has proven itself throughout the run.

Three major application programs were written specifically to control the upgraded Tevatron collider. The waveform generator and loader fills all of the 465s and does complex manipulations of ramp tables during special operations[4]. The orbit smoothing program was written to take care of all steering dipole corrections needed. This program has worked very successfully to globally correct the Tevatron orbit. The third program that was written was the Sequencer. This is used to orchestrate the operations needed for collider operation. The sequencer was written so the user can interactively change the sequence of operations performed, but still contain enough structure to allow for reliable execution of the fill sequence. Each of these three programs replaced programs that were limited by the old controls hardware.

IV. CONCLUSIONS

The upgrade to the Tevatron has allowed the collider to operate at Luminosities above the goal. Table 2 shows the goals next to the actual performance of the accelerator. The ACHIEVED column are the best done during the run. The only entry that falls short of the goal is the proton emittance. 16 π mm-mrad protons have been achieved, but not with proton intensities as high as shown in table 2.

The improvements in the controls system permitted the Tevatron collider to be turned on with a minimum of difficulty. Improvements in the other accelerators have allowed higher intensity beams to be injected into the Tevatron. The Tevatron upgrade to separated orbits has made it possible to turn this increased intensity into increased luminosity.

	RUN 1A GOALS	ACHIEVED
Protons per bunch	1.2E 11	1.5E 11
Pbars per bunch	3.6E 10	8.0E 10
Proton emittance	16 π mm-mrad	20 π mm-mrad
Pbar emittance	16 π mm-mrad	16 π mm-mrad
Weekly integrated Luminosity	1000 nb^{-1}	2300 nb^{-1}
Total integrated Luminosity	25 pb^{-1}	30^{-1}
Luminosity	5.37E 30	8.97E 30

Table 2

IV. REFERENCES

[1] P. Lucas, "Updated Overview of the Tevatron Control System", Proc. of the 1987 conference on Control Systems for Experimental Physics, Villars-sur-Ollon, Switzerland, Cern 90-08.

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[4] D. Johnson, G. Goderre, B. Hendricks, R. Johnson, and R. Joshel, "Control of the Time and Energy Dependent Parameters of the Upgraded Tevatron Collider", Proc. of the 1991 Particle Accelerator Conference, IEEE 91CH3038-7