Status Report of the Tevatron Alignment Task Force
and a
Report on Magnet Survey Activities During the
2003 Summer-Fall Shutdown

by the
Tevatron Alignment Task Force

Introduction:

The Tevatron Alignment Task Force was established in May 2003 to coordinate various tasks in the Tevatron dealing with magnet survey and alignment. The roles and responsibilities of the membership of the Task Force is given in Table 1.

Table 1: Roles and Responsibilities of the Tevatron Alignment Task Force

We report to Roger Dixon, head of the Accelerator Division.	Recommendations are reviewed and approved by Peter Garbincius and Vladimir Shiltsev.
The task force leader is Ray Stefanski	The shutdown coordinator is Jim Volk.
The Run II project leader is Jeff Spalding	Mike Syphers represents the Accelerator Integration Department.
PPD and TD Management is represented by John Cooper and Bob Kephardt.	Bob Bernstein, John Greenwood, Terry Sager, and George Wojcik represent the AMG
The Technical Division Representatives are Ray Hanft, Dave Harding, Jamie Blowers, Fred Nobrega, and John Tompkins.	The Accelerator Division representatives are Keith Gollwitzer, Norm Gelgand, Bruce Hanna, Todd Johnson, Mike McGee, Duane Plant, and Aimin Xiao
The PPD representatives are Alvin Tollestrup, Hans Jostlein and Jesse Guerra.	Consultants are Gerry Annala, Don Edwards, Craig Moore, and Jean Slaughter
Rob Roser and Rich Smith represent CDF and D0.	Outside Consultants are: Andrei Seryi (SLA C) and Andrey Chupyra (BINP)

The work of the Task Force is given in the mission statement:

I. The Task Force has two primary tasks to deal with:

1. Measure the Tevatron: Locate the Magnets relative to each other; Locate the cold mass relative to the magnet yokes for dipoles,
2. Monitor motion in the Tevatron.

II. The alignment work has the following components:

1. Develop a horizontal survey network for the Tevatron, to tie the tunnel into a global network. The network is called TevNet. Its installation was a primary goal of the 2003 summer shutdown.

2. Shorten the time it takes to make roll measurements so that these could be done in a few days and repeated periodically.

3. Set up a systematic study of Tevatron corrector magnet settings and BPM readings to monitor the occurrence of changes in the Tevatron.

III. The installation of motion detectors has the following components:

1. Continue to install inclinometers around the ring to locate any movement that might explain the fact that the Tevatron must be retuned every 10 days or so. In addition to the inclinometers, install hydrostatic level sensors (HLS) positioned in strategic parts of the tunnel to look for irregular motion.

2. Collect the HLS from MI-8, and the Aurora mine, and install them in Tevatron sector B to see how well they might work as long term elevation and tilt monitors.

3. Develop a modified HLS at BINP for simultaneous measurements of elevation and tilt. Andrey Chupyra has a rough idea of what we're looking for, and may be able to deliver a prototype this year.

In preparation for the summer shutdown the Task Force concentrated on completion of the issues outlined in the mission statement. This document represents a report on the status of meeting the goals given in the mission statement and providing an outline of work to be done.

The bulk of the work done in the summer and fall of 2003 came during the scheduled shutdown that took place between September 8 and November 15, 2003. However, two unscheduled shutdowns of significant duration occurred that gave us additional time to complete roll corrections, realignment and surveys[1]. These occurred between December 8 to December 15, caused by a conning tower failure, and December 19 and December 29 initiated by a six house quench.

In addition to the issues addressed in the mission statement, alignment tasks at CDF (to bring the IR into the detector's acceptance) D0 (to correct an aperture restriction) A0 kickers (to correct an aperture restriction) and F0 Lambertson magnets (to study the interface between beam transfer fromthe Main Injector to the Tevatron) were addressed and are reported in this document.

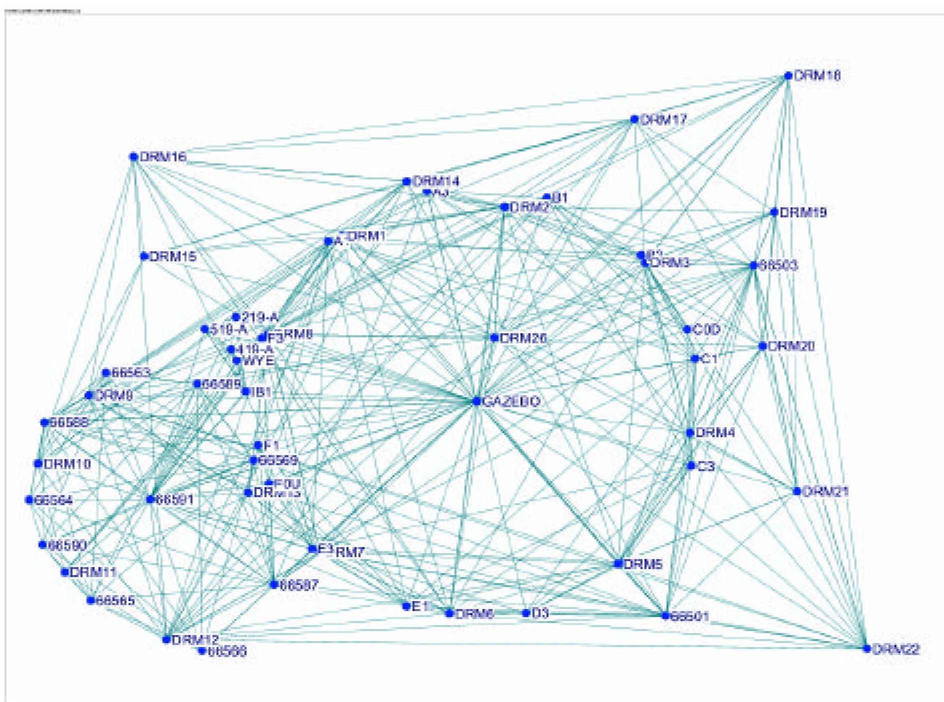

Figure 1: TevNet as it is laid out on the surface of the site.

---

[1] *Falstaff.* What wind blew you hither, Pistol?
Pistol. Not the ill wind which blows no man to good.
William Shakespeare: *Henry IV. act v. sc. 3.*

Physical Alignment of the Tevatron:

TevNet

The physical alignment of the Tevatron was the main task undertaken by the Alignment and Metrology Group (AMG) during the summer shutdown. It consisted of installation of an alignment network in the Tevatron tunnel, and simultaneously measuring horizontal and vertical positions of Tevatron magnets. Combining these tasks provided the most efficient way to measure magnet positions, while installing TevNet. Most of the effort comes in setting up the instruments. The actual measurements take little time. As a result the AMG was able to provide a complete measurement of horizontal magnet offsets from the Murphy line, and a set of relative vertical data for all of the yoke magnets in the Tevatron, during the installation of TevNet. The results of these measurements are discussed in later sections.

TevNet is a system of alignment monuments located on the surface of the site, and within the accelerator tunnels. The surface configuration of TevNet is shown in Figure 1. The Main Injector and Tevatron rings are clearly visible. TevNet consists of 1,736 stations in the control network. 28,612 observations using GPS, Mekometers, laser trackers, and traverse were used to make measurement (observations) of station positions. A Least Squares fitting method was used to find the optimal positions that minimized the overall errors.. For example, the distance between stations directly across the Tevatron ring, which has a one kilometer radius, was determined to a precision of about 2.5 mm; or about one part in a million, using the surface stations. For measurements in the tunnel, which will be more tightly constrained, relative measurements across the ring are good to about 1 mm.

The TevNet is also part of the National Geodetic Survey (NGS). This property isn't used in our work in the Tevatron, but is important for NuMI and other potential long baseline neutrino experiments.

The survey stations in the Tevatron tunnel are related to the site risers in TevNet with a precision of about 0.25 mm. Because the installation of TevNet involved tying this surface network into alignment stations within the tunnel, vertical site-risers were needed to provide an optical connection between the surface and tunnel. We were fortunate to find air ventilation ducts located around the ring that could be used as site risers. Twelve of these ducts, plus two other existing site risers, were used to install TevNet.

Figure 2 shows the ducts and towers used for this work:

a) A photograph of an air duct that is not in use. These are found at all of the 2 and 3 numbered houses around the ring.
b) A photograph of a ventilation unit sitting atop an air-duct. These are seen at the 1 and 4 numbered houses around the ring.
c) At the bottom of each of the 24 air ducts sits a cable tray that obstruct a clear view into the alcove. A special device was designed by Mike McGee to bring the line-of-sight around the cable tray.
d) A photo of the alcove at the bottom of the air ducts, showing also a cable tray. The AMG used twelve air ducts for the installation of TevNet. Those used were located at the 1 and 3 houses.
e) A photograph of one of twelve towers constructed above the air-shafts, this one at C3. From the top of the tower, which extends above the surrounding structures, readings taken at the surface can be transmitted down the sight-riser, nee air-duct.

As an example of the work already done, measurements made in the tunnel by a Laser Tracker can be evaluated for quality by considering the precision achieved in redundant distance measurements. Over 69,000 measurements were made in the Tevatron using the 1,688 measuring stations. Over 63,000 of these measurements were redundant, so that the precision of the observations could be calculated. The precision measurements are used as weights in the Least Squares fitting process. Figure 3 shows the results of these measurements. The vast majority have a standard error smaller than 50 microns. Measurements that have a standard error greater than 1/2 mm are considered erroneous, and are studied to determine the cause of the error. These are ultimately eliminated from the data set, because they might severely distort the network.

In Figure 4, the set of error ellipses is shown based on the observations made in the tuunel and tied into TevNet. If the location of one station is fixed, the position of all of the remaining stations in the tunnel can be computed with an associated error ellipse. The largest error would be associated with the station directly across the ring from the fixed station, and would have a transverse error on 9 mm. When all 14 stations are used the largest transverse error is about 1 mm.

The work involved in understanding the network is continuing. When complete, an independent confirmation of the location of the Murphy line will be possible. The horizontal positions of elements in the Tevatron tunnel will have been measured better then ever before. Magnet elevations and rolls will also be available at better precision. Repeated measurements will be done more quickly than would be possible with traditional methods. Being able to locate the position of elements in the tunnel and to periodically check for changes is an important part of establishing a system of configuration control in the Tevatron.

Figure 2: Photographs of air ducts, and towers used during the installation of TevNet.

Standard Errors	Number of Observation	Percent
>2.0	1	0.0016%
>1.0	18	0.03%
>0.5	327	0.51%
>0.2	1363	2.15%
>0.1	5796	9.13%
>0.05	13250	20.86%
>0.0	63516	100.00%

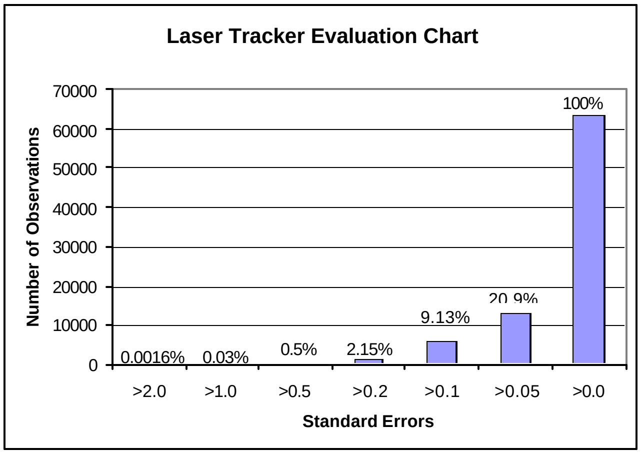

Figure 3: A laser tracker evaluation chart.

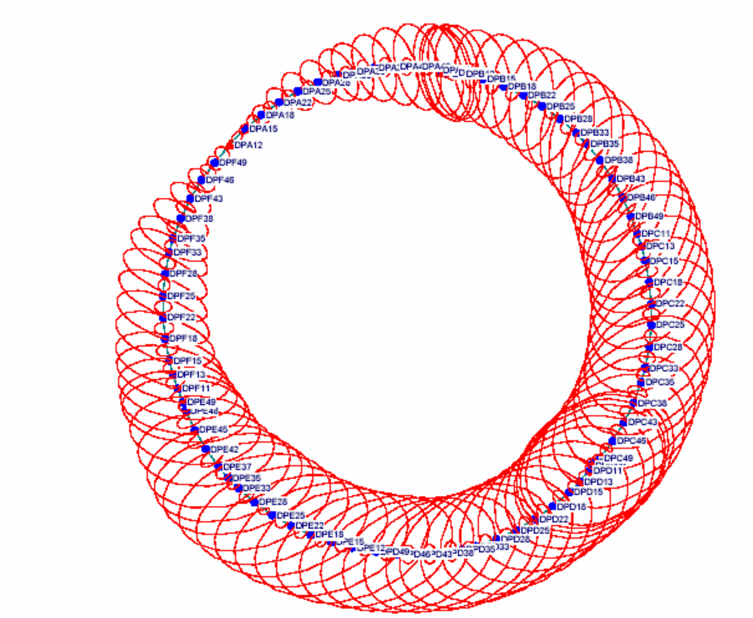

Figure 4: From the observations taken in the tunnel, an error ellipse can be formed for the location of any station relative to any other station. In this Figure, we plot the error ellipses of each station relative to station A12. The largest error is on the opposite side of the ring at D13, where the ellipse has a semi-major axis of 18mm. When all 14 constraints are used, the error tightens up to about 1 mm.

Magnet Roll Measurements and Corrections

In addition to the survey measurements done by the AMG, an independent effort took place to measure magnet rolls along the entire Tevatron. In particular, a substantial effort was made to shorten the time involved in making these measurements. This was done by improving the measurement fixture used, and incorporating direct readout of the measurements into a laptop. Two fixtures were actually used: The first was similar to the fixture used in the January shutdown. This fixture proved problematic, in that calibration issues arose during its use. We finally settled on a less precise, off-the-shelf protractor that was much easier to use. Measurements from both fixtures were read directly into a laptop. The measurements were done by experimenters from CDF and D0, and Keith Gollwitzer analyzed of the data.

Improvements in magnet roll during the shutdowns were striking. Figures 5a and 5b show a comparison of roll measurements before and after adjustment during the shutdown and the beam-off periods that followed. Many of the most troubling sections were corrected. A comparison of magnets with substantial rolls before the shutdowns and after is given in Table 2. In particular, all of the magnet rolls greater than 4 mrad have been eliminated. There are now 58 magnets with rolls greater than one mrad that should be corrected, compared to 151 before the shutdowns. The biggest remaining rolls are in A and E Sector. This work had an immediate impact on vertical corrector magnet settings, which had previously run close to capacity. Corrector currents are now running at much more reasonable levels as can be seen in Figures 6a and 6b.

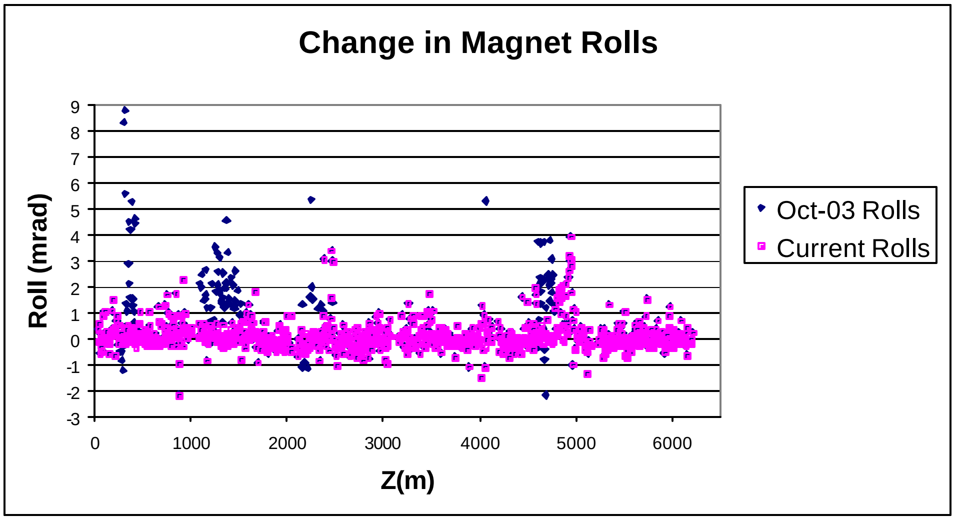

Figure 5a: Comparison of magnet rolls (Dipoles and Quadrupoles) around the entire Tevatron before and after the summer shutdown and the two December shutdowns. Current rolls are in purple, the corrected Oct-03 rolls are in dark blue. The origin is at A0.

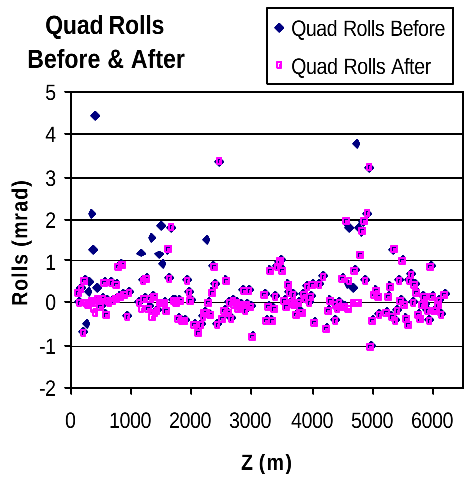

Figure 5b: Comparison of quadrupole rolls around the entire Tevatron before and after the summer shutdown and the two December shutdowns. Current rolls are in purple, the corrected Oct-03 rolls are in dark blue. The origin is at A0.

Table 2: Comparison of magnet rolls before and after the summer shutdown. (#before, #after)

House	Roll Angle	>N mrad					
	>1	>2	>3	>4	>5	>6	>7
A-1	(3,3)						
A-2	(20,2)	(10,0)	(8,0)	(8,0)	(4,0)	(2,0)	(2,0)
A-3	(4,4)						
A-4	(2,2)	(1,1)					
B-1	(20,0)	(9,0)	(3,0)				
B-2	(19,0)	(7,0)	(2,0)	(1,0)			
B-3	(2,2)						
B-4							
C-1	(11,0)	(1,0)	(1,0)	(1,0)	(1,0)		
C-2	(5,4)	(3,3)	(2,2)				
C-3							
C-4							
D-1	(1,1)						
D-2	(4,4)						
D-3							
D-4	(2,1)	(1,0)	(1,0)	(1,0)	(1,0)		
E-1	(1,1)						
E-2	(17,4)	(10,0)	(3,0)				
E-3	(23,17)	(13,8)	(5,3)				
E-4	(2,2)						
F-1	(1,1)						
F-2	(2,2)						
F-3	(1,1)						
F-4							
Total>N	(141,51)	(55,12)	(25,5)	(11,0)	(6,0)	(2,0)	(2,0)

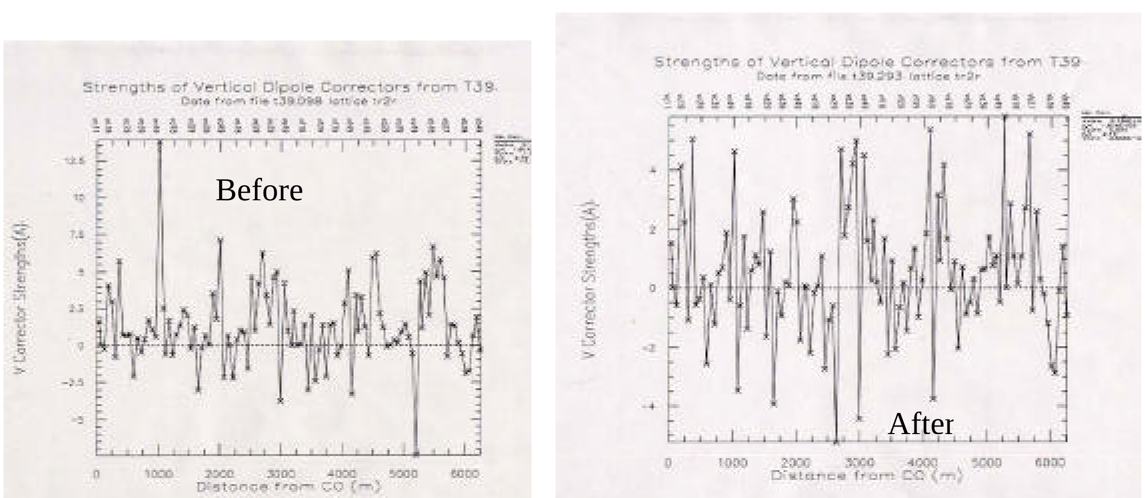

Figure 6a: Comparison of vertical corrector magnet currents before and after the shutdowns. The origin is at C0. The vertical scale changes from (-6 to 13 amp) before to (-5 to 6 amps) after.

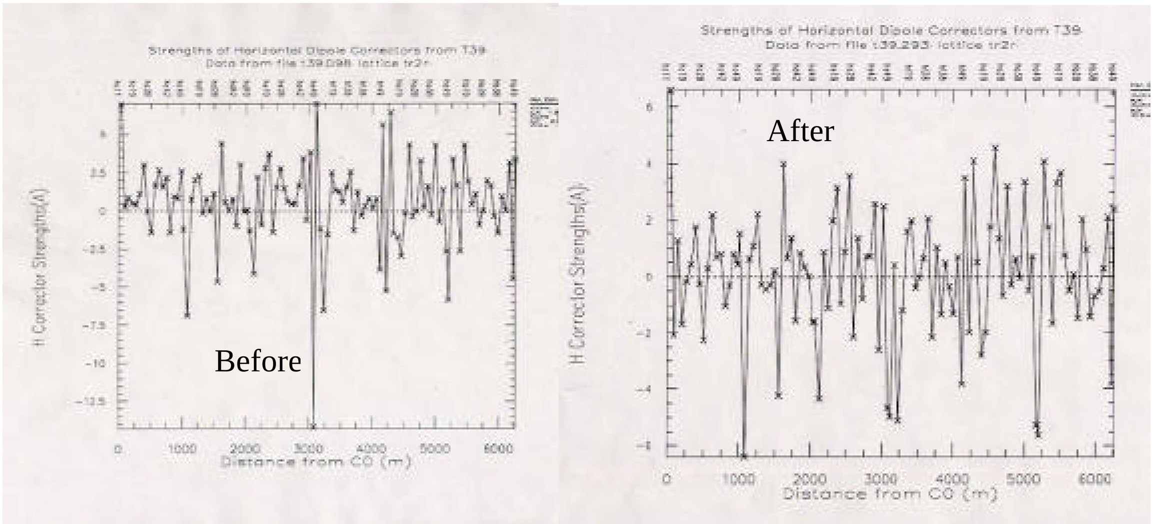

Figure 6b: Comparison of horizontal corrector magnet currents before and after the shutdowns. The origin is at C0. The vertical scale changes from (-13 to 6.5 amp) before to (-6 to 6.5 amps) after.

Horizontal Offsets

As part of the TevNet installation process, the AMG made measurements of horizontal offsets to the Murphy line for quadrupole and dipole magnets. This took relatively little added time, since most of the effort was involved in setting up the instrumentation for the TevNet installation. Relative magnet elevations were also measured; these will be discussed in the next section.

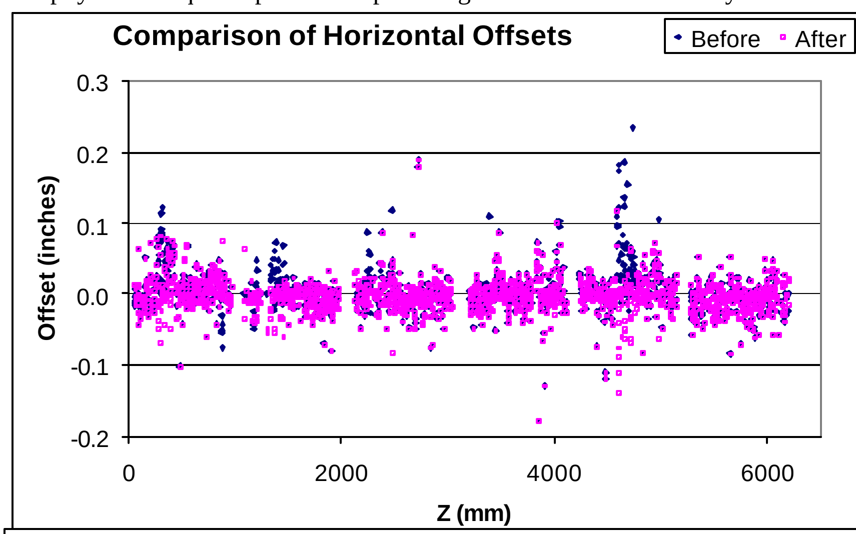

Figure 7: A comparison of horizontal offsets relative to the Murphy line. The blue points are measured offsets at the start of the shutdown, later corrected. The purple points are current offsets, including those corrected during the shutdown. The origin is at A0.

The results of the measurements are given in Figure 7. These data represent the first comprehensive measurements of horizontal offsets in the Tevatron since the initial installation. The results indicate that the magnets were relatively stable horizontally over the years. Only two quadrupoles were sufficiently out-of tolerance that a specific effort was made to correct their offsets. The improvement in horizontal offsets evident in Figure 7 came about by systematically correcting the horizontals whenever any other work was done on a magnet, such as a roll correction or magnet stand replacement.

Elevations

Part of the process of correcting magnet rolls, installing new magnet stands, or correcting horizontal offsets includes local corrections to magnet elevations. These corrections were aimed at smoothing local variations, so that magnets sit on a common line within several cells. A before-after comparison is shown in Figure 8. Some improvement in global variations around the ring is seen in this plot, but because the corrections are local, the curves appear very similar.

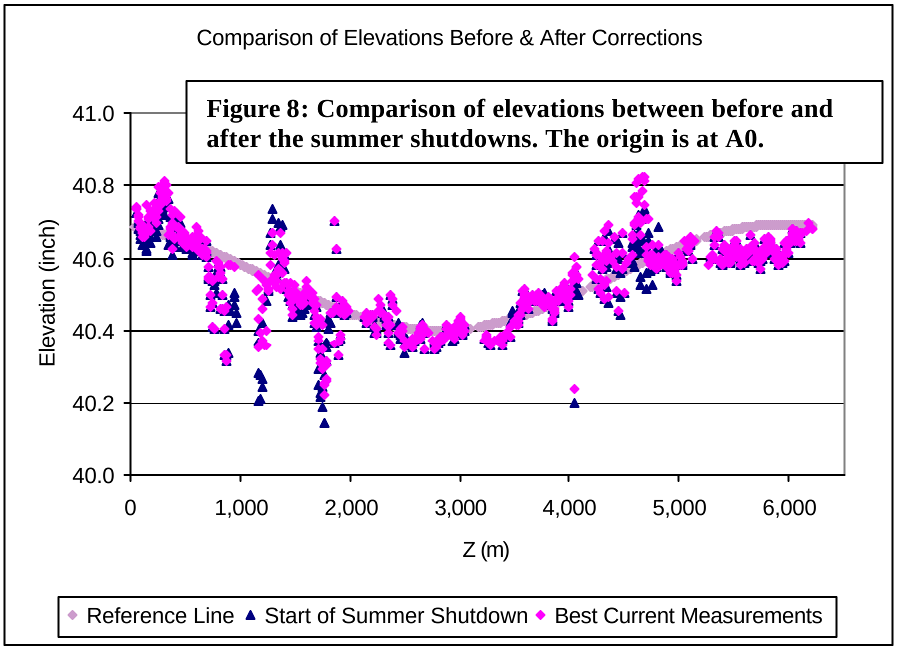

Figure 8: Comparison of elevations between before and after the summer shutdowns. The origin is at A0.

Global elevation corrections will not be carried out until the TevNet results are available and orbit simulations are done to determine the sensitivity of the Tevatron orbit to variations in magnet elevations. Based on operating experience since the shutdown, we might suspect that magnet elevations have a large tolerance and that more effort should be devoted to roll corrections and spool piece alignment.

Where do we go from here?

The original specification for horizontal and vertical alignment of the Tevatron was 10 mils for quads and 30 mils for dipoles with respect to the monument system. The total error budget also included measuring the magnetic center of the elements, setting the reference lugs on the outside with respect to the magnetic center, and the error on analyzing and installing the monument system. We will shoot for nothing less 20 years later, especially since TevNet will give us better information about the monument system.

The experience of the summer shutdown pointed to the importance of spool piece alignment. These were not considered in this year's plan. Measurements made during the shutdown have shown that the spools may be significantly out of alignment in some parts of the ring.

Correction to the skew-quadrupole component in Tevatron dipoles

The horizontal and vertical betatron oscillations in the Tevatron were strongly coupled, requiring the skew-quadrupole correction circuits to run at about 60% of the maximum current. Don Edwards and Mike Syphers reported beam measurements that showed the source of the coupling to be distributed fairly uniformly around the ring, rather than concentrated in one or a few locations. Their analysis of several different measurements concluded that the strength of the coupling was consistent with a skew-quadrupole component in each dipole of approximately one "unit" (parts in 10^4 at one inch). A measurement that was also confirmed by the Technical Division, in that one unit of skew-quadrupole component could be attributed to a settling of the cryostat over time.

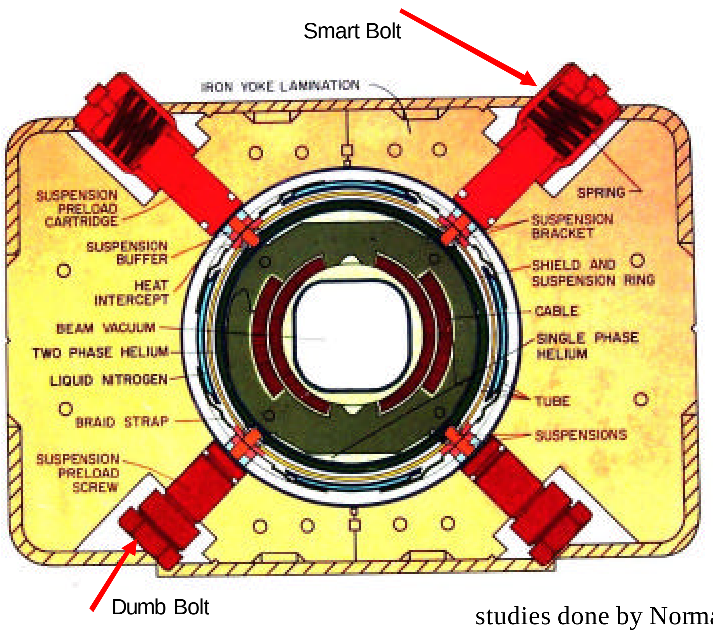

Figure 9: A cross-sectional view of a Tevatron dipole. The smart bolts are located at the upper corners and are spring loaded. Dumb bolts are located at the lower corners and are not spring-loaded. Three mil shimswere placed at the dumb bolt ends to correct for the vertical settling of the cryostat

The coupling is corrected globally, but the removal in 1991 of spools with skew-quad correctors on each side of each IR, to make room for new low-beta insertion components, left the coupling uncorrected locally through these two sensitive regions. Tracking studies done by Norman Gelfand showed that the skew-quad component in the dipoles leads to, among other things, a vertical dispersion of 0.5 meters, with the majority coming from the intersection regions. To correct for the skew-quad component in the dipoles, the cryostats had to be shimmed to raise them to the original positions. Figure 9 illustrates how the process took place. This Figure shows a cross-sectional view of a Tevatron dipole and the location of the bolts that hold the cryostat in place; the so-called smart and dumb bolts. For each of the 106 magnets that were corrected in the Tevatron, three mils shims were added at the dumb bolt ends on each of the nine locations along the magnet length. Figure 10 shows some of the cold lift measurements made during the January shutdown, the first indication of a problem in cryostat elevation within the dipole yoke.

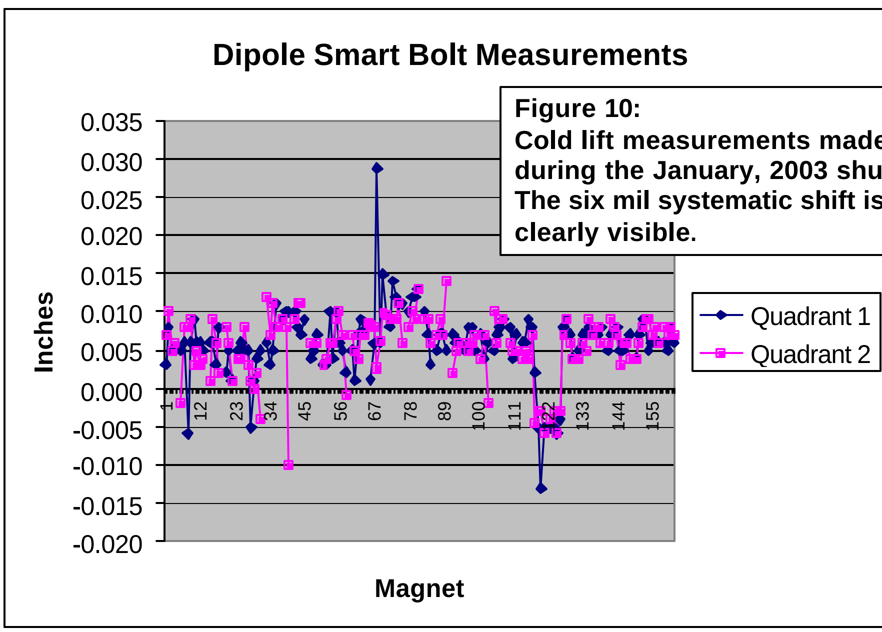

Figure 10: Cold lift measurements made during the January, 2003 shutdow The six mil systematic shift is clearly visible.

During the shutdown, 106 dipoles were re-shimmed to remove the skew-quad component of magnetic field. The corrected dipoles corrected are distributed on either side of the intersection regions, namely from A44-2 through B19-5 and from A44-2 through D19-5. The end points on these lists are half way between the last remaining skew quad corrector and the first missing skew quad-corrector. By Norman Gelfand's calculation, this would reduce the vertical dispersion from 0.5 m to 0.15 m, and Tevatron operation since the shutdown seems to confirm that the machine is now much more easily tuned.

In addition, measurements made during the shutdown by technicians from the Technical Division suggest that there may be a problem with the cryostat anchor inside the yoke of many dipoles in the ring. The extent to which this defect is present in the Tevatron is being studied. The effect on magnetic field quality and stability is also under study by the Technical Division.

Installation of Real-Time Motion-Sensors:

Beam properties in the change on a time scale of roughly ten days. These changes are sufficient to require a complete retune of the machine. Magnet motion or tunnel movement may be the cause of some of these periodic. Tilt monitors have been used in the Tevatron to detect magnet motion at the IR's and some of the arcs. Based on the data available, significant changes may be taking place. The estimates, given in Table 3, are based on observation taken over five to seven month periods. Extrapolating thye data to one year time periods suggests that magnet rolls of about ½ mrad per year may be taking place. We'll continue to make these observations to try to confirm these results.

Table 3: Tevatron tilt-meter studies in 2003: Eight tilt-meters were in place from May 1 through September 1, 2003. The A16 tilt-meter was in place from March 1 through September 1. (Data taken by Todd Johnson.)

Location	Average Roll/Time	Estimated Annual Roll
	μrad/day	μrad/year
A15-1 Quad	1.10	400
A16-3 Dipole	0.58	210
A21-1 Quad	0.21	77
B17-5 Dipole	1.52	555
B24-1 Quad	0.22	80
C24-1 Quad	1.30	474
E29-1 Quad	1.07	390
E32-1 Quad	1.77	646
E39-1 Quad	1.18	430

Figure 11b shows two measurements made by tilt monitors set on top of quadrupoles in the arcs. After a quench, one magnet is seen to recover back to its original position, while the other does not. Such changes may account, at least in part, for changes that occur in machine operation after a quench. We need to understand the cause of magnet motion during a quench.

During the shutdown, twenty-six hydrostatic level sensors (HLS) were installed in the tunnel, primarily in B-Sector. These were previously used in MI-8 and the Aurora mine for liner-collider ground-motion studies. They were placed in Sector-B, because this sector seems to be one of the most troublesome in the ring. Tilt monitors were also placed in sector B to cross-calibrate with the HLS. Figures 11a shows a some of the data available from the HLS in B-sector.

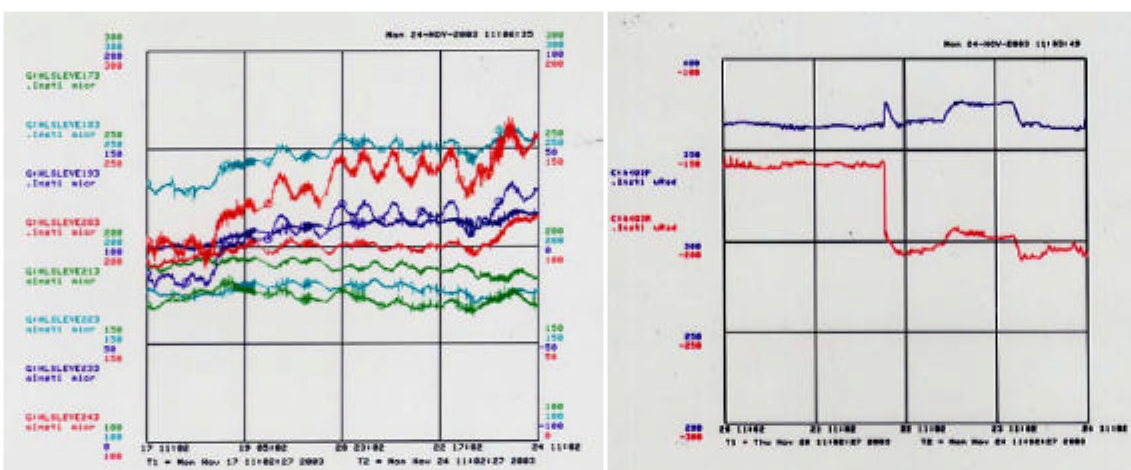

Figure 11a (left) and 11b (right): Examples of HLS and tilt-meter data taken after installation of these devices in the summer shutdown. Figure 11a shows the response of the HLS in different parts of B-Sector in a one-week period Figure 11b shows one of the tilt monitors responding to a local disturbance probably a magnet-quench.

These measurements are suggestive but not conclusive. Additional HLS and tilt-monitors placed around the ring would provide a more complete picture of changes that take place. Do seasonal variations take place in parts of the ring, but not others; How do variations in mounting fixtures affect the way that magnets respond to quenches and other disturbances; What affects can be attributed to the magnet ramp, and are the effects uniform around the ring? Our goal is to measure real time motion in the entire ring to look for these correlations, and to compare them to accelerator simulations. Perhaps we'll be able to eliminate short term changes that occur in the Tevatron and the subsequent the need for retune of the Tevatron after brief periods of operation.

Magnet Stand Replacement:

Magnet stands have suffered corrosion in areas where water accumulated during floods, or because of seepage through cracks in the tunnel concrete. The occurrence of the water in the tunnel has since been greatly reduced, but the affected stands are still in place. An example of a corroded stand is shown in Figure 12.

Sixty-one dipoles had new stands installed during the shutdown, in areas where the greatest damage was observed. A summary of magnet stand replacement by Tevatron location is given in Table 4. During the next shutdown, additional dipoles stands will be replaced, as well as affected quadrupole and spool-piece stands.

Figure 12: An example corrosion affecting a magnet stand in the Tevatron.

Table 4: Distribution of magnet stand replacements in the Tevatron.

Section or House	Stands replaced	Section or House	Stands replaced
A-1	2	D-1	0
A-2	15	D-2	0
A-3	0	D-3	0
A-4	0	D-4	2
A-Sector	17	D-Sector	2
B-1	15	E-1	0
B-2	5	E-2	12
B-3	0	E-3	5
B-4	0	E-4	1
B-Sector	20	E-Sector	18
a-1	1	F-1	0
a-2	1	F-2	0
a-3	2	F-3	0
a-4	0	F-4	0
a-Sector	4	F-Sector	0

Changes at B0 and D0:

An accident that occurred several years ago involving the D0 LBQ girder caused a 0.25 inch horizontal displacement at one end of the girder. Recent aperture scans revealed a serious restriction at D0, making it imperative to correct the situation. In Figure13a, we show the survey data of the LBQ before the shutdown (as-found) and after (as-set). It may be that this single ¼ inch correction did the most to open up the Tevatron aperture for this run. Craig Moore led the effort for this work.

The month of December had many machine down days. We took the opportunity to adjust the vertical position of the IR at B0. The IR was about 6mm high at CDF, nearly falling off the edge of the detector acceptance. The solution was developed by a team lead by Vladimir Shiltsev, including Mike Syphers, Valery Lebedev, Norm Gelfand and Mike Martens. The correction involved moving the LBQ down by about 50 mils. This adequately satisfied CDF's requirements. The alignment changes are shown in Figure 13b.

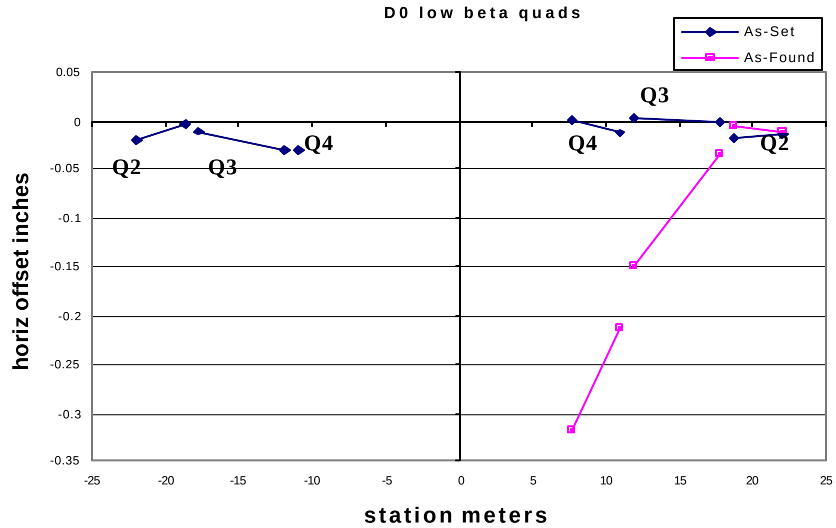

Figure 13a: A ¼ inch horizontal correction was carried out at D0 on the upstream side of Q4. Initial (as-found) positions are shown compared to the corrected (as-set) positions.

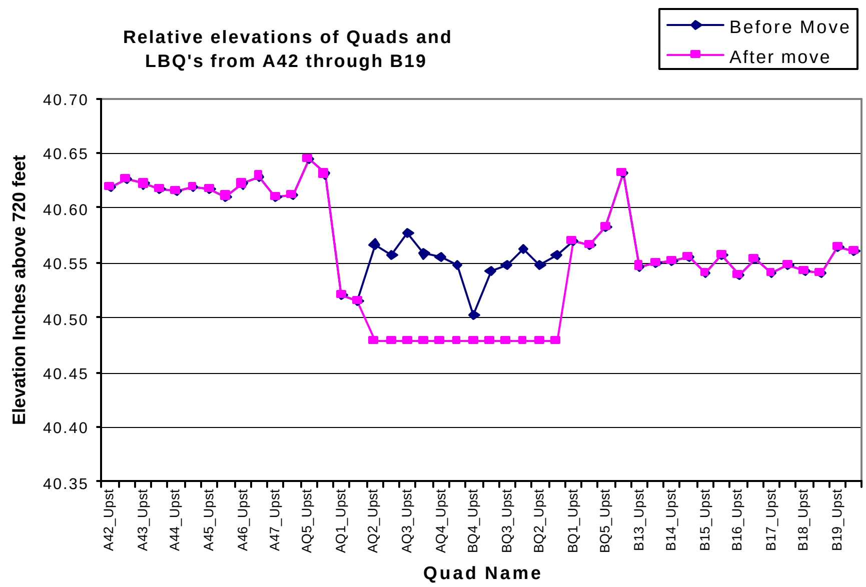

Figure 13b: Vertical changes carried out at B0 to shift the IR down by about 5 mm, and back within the CDF acceptance.

Tevatron Lambertson Liners

Head-tail instabilities, caused by the interaction between the proton and p-bar beams, were observed and studied prior to the summer shutdown. This instability arose because the iron in the injection Lambertson magnets sustained long-latency for beam images. The latency is caused by the impedance of the iron. To reduce the impedance, and thereby reduce the head-tail instability, low resistivity liners were fabricated and installed in the field free region of the four Lambertson magnets at F0. Petr Ivanov of the Tevatron Department developed the concept, and Alex Chen of the Mechanical Support Department did the mechanical design.

The design constraints required that the liner be thin (1mm) to retain as much aperture as possible, have low resistance to dissipate charge, and be ridged to allow for insertion in the field free region. In addition, the liner required perforations so that trapped gas did not spoil the vacuum. A 98% copper 2% beryllium alloy was chosen as the fabrication material. The basic shape chosen was a five sided "dog house" shape. The circulating beam resides near the peak in the liner. The base of the liner was designed to provide spring loading, forcing the peak into the field free region. This spring action forces the magnet aperture to be as large as possible.

To install the liners the center two of the four F0 Lambertson magnets were removed from the beam line. The liners were then inserted into each of the four 3 meter long magnets. A spring loaded pull through target was developed as a tool to help AMG measure the fit of the liner in the magnet aperture. The measurement provided a check that the liner was pushed against the peak of the aperture as much as possible, and that there were no obstructions in the field free region to degrade the circulating beam. The target carried a corner reflector that was used by the Laser Tracker system. The target was both pulled and pushed through the Lambertson magnets before and after liner insertion. These data were compared to assure that there was no restriction in the aperture. Figure 14 shows a typical aperture scan with before and after data.

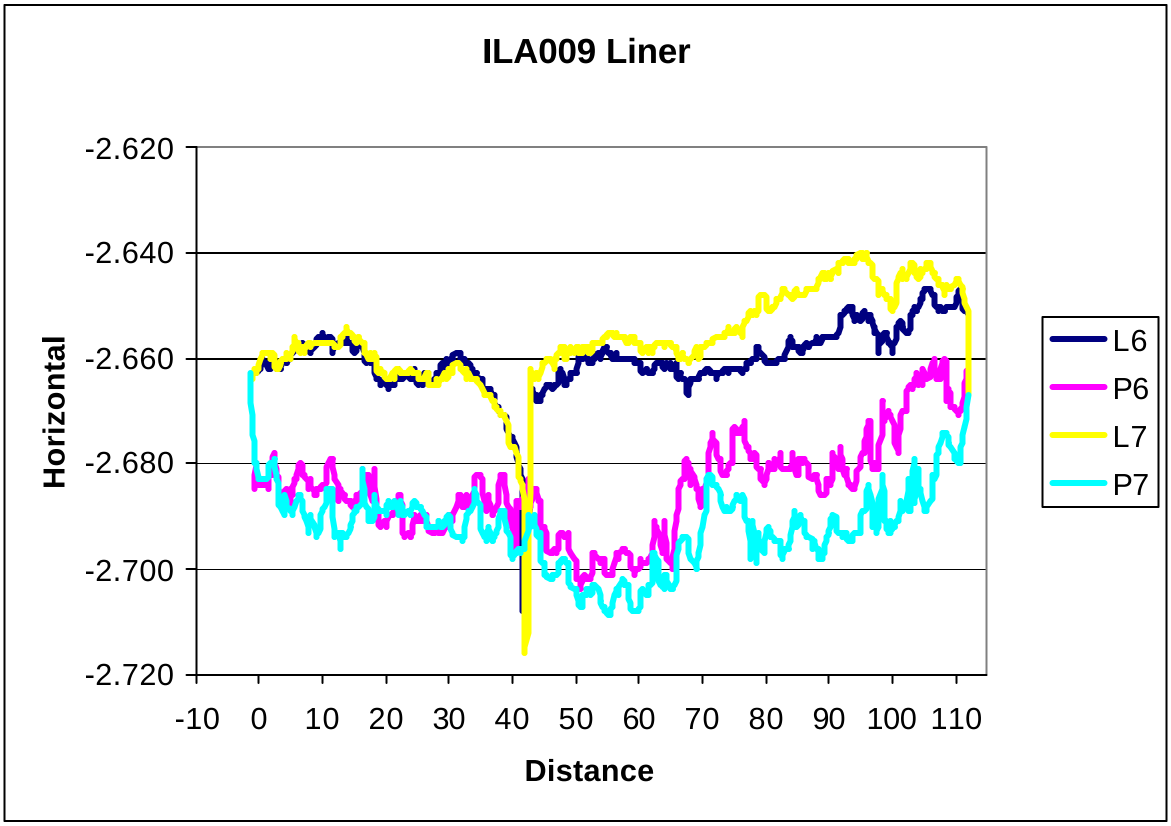

Figure 14: Survey data taken by the AMG of the liner position within one of the Lambertson magnets. P are the before liner measurements and L are measurements with with the liner. The number represents the sixth and seventh attempts on this magnet.

After completing the liner insertion, the two central Lambertsons were replaced on the movable stands and optically surveyed back to the as-found position. In addition to new liner insertions, improvements were made to the vacuum and instrumentation on both the upstream and downstream ends of the magnets. Improved stands and mountings were installed for the BPMs and strip line detectors. Differential pumping was added to improve the vacuum in this region of the Tevatron. In the process of reassembly a mismatch or misalignment of about 6mm (0.25 inch) was discovered between the Tevatron and Main Injector. Given the size of the beam pipe, the aperture of the magnets and that the history of successful beam transport in this part of the Tevatron, no attempt was made to correct this misalignment during the summer shutdown. More work will be needed to understand the source of the misalignment, further beam studies will be done, with the goal of correcting this problem at the next opportunity.

A0 Kicker Realignment

During the first part of Run II, aperture scans near A0 showed a restriction in the vicinity of the anti proton kickers. An optical survey revealed that the anti proton kickers were misaligned in the horizontal plane at the upstream end by 15 mm (0.6 inches). Figure 15 shows the deviation of the kicker alignment form an ideal horizontal line.

A study of survey data taken in 2000 and 2001 did not reveal this large discrepancy. All five kickers are mounted on a bedplate that was designed to move during the change from 800 GeV fixed target operations to colliding beam operations. Adjacent and to the radial inside were the bedplates for the fixed target extraction Lambertson magnets. Both systems were designed for easy movement during change over between these two running modes. It appears that sometime between March 2001 and October 2003 the bedplates for the Lambertson magnets were pushed into the bedplate for the kickers causing the offset.

The bed plates for the Lambertson magnets were jacked up and placed on cribbing to immobilize them. The kicker girder was pushed back into the proper alignment and optical survey was used to realign each kicker on the correct position. Aperture scans in A0 indicate that the restriction has been successfully removed.

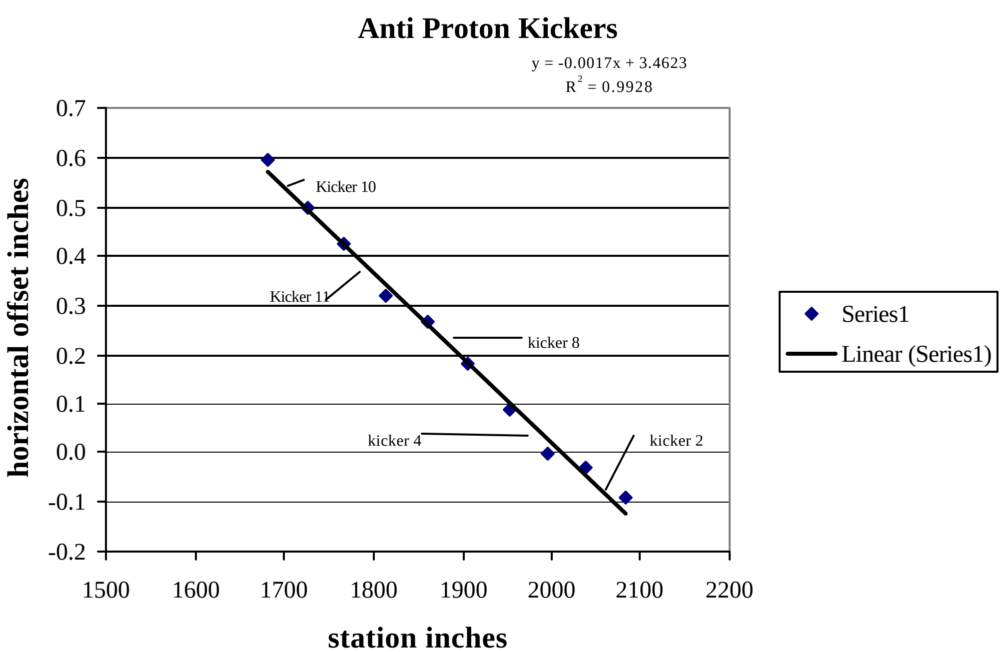

Figure 15: Deviation of A0 kickers relative to an ideal horizontal line.

Conclusion

A great deal was accomplished during 2003. Complete measurements of magnet roll, horizontal offsets, and relative elevations were completed in the Tevatron tunnel. Most of the bad rolls were corrected, and further corrections will be done as access to the tunnel becomes available. TevNet was installed, and data processing is currently taking place. When complete, these measurements will provide a guide to future realignment in the Tevatron. A set of motion detectors was installed in B-sector an in B0 and D0. These provide a test-bed for discovery of what moves in the Tevatron tunnel, and provides an opportunity to measure long term stability and reliability of these devices. The effects of the smart bolt corrections require some dedicated beam study time, but early indications are that coupling is greatly improved in the Tevatron, and that vertical dispersion is reduced. Work in measuring magnet rolls will continue in the future. We will soon eliminate all major magnet rolls, and future measurements will be made on a regular basis to check magnet stability.

In 2004, TevNet information will become available. A proposal will be prepared to align the Tevatron to within original specifications: As Tevatron beam intensity increases, the need to minimize beam losses requires maximum aperture, which can only be achieved with good magnet alignment. Furthermore, an inventory of all elements in the Tevatron will be done to make certain that the alignment standard is met. In the recent past, many of the biggest alignment errors were discovered in elements that were forgotten, or not often used. There will also be an effort to understand short term motion in the Tevatron tunnel. The effects of magnet quenches, and ground motion have been seen at the 100 micron level. Whether the effects are cumulative, and whether they constitute an issue for Tevatron optics is to be understood. Considerable effort will also be given to better coordinate data available from instrumentation with alignment information. Efforts to develop an appropriate database are in process. Studies of cryostat changes in Tevatron magnets will continue in the Technical Division, hoping to address potential problems before they occur.