



Survey and Alignment of the Fermilab Booster Accelerator

*Babatunde O'Sheg Oshinowo
John Kyle
Alignment and Metrology
Fermi National Accelerator Laboratory
Batavia, IL 60510*

ABSTRACT

The Fermilab Booster is a fast-cycling synchrotron which accelerates protons from 400 MeV to 8 GeV of kinetic energy for injection into the Main Injector and for use by all of the Lab's physics programs. The Booster was originally built in 1970. In 2004, as part of the Booster upgrade, a decision was made to upgrade the Booster survey network by densification with monuments and to survey the main Booster components using modern survey and alignment instruments. This paper discusses the survey and alignment methodology employed for the Booster Accelerator upgrade.

1. INTRODUCTION

The Fermilab Booster [1] is a fast-cycling synchrotron which accepts the 400 MeV protons from the Fermilab Linac and accelerates them to 8 GeV for injection into the Main Injector and for use by all of the Lab's physics programs (Figure 1). The Booster accelerator is the lowest energy level synchrotron at Fermilab (Figures 2). Currently the Booster provides protons for MiniBoone and NuMI (Figures 3). Fermilab Linac is a negative hydrogen ion, 400 MeV accelerator. The Booster is a circular accelerator of about 474 meters in circumference and is 1/7 the size of the Main Injector. The Booster ring is located in a concrete tunnel 8ft. high and 10 ft. wide, which is covered with 15 ft. of earth shielding. The last network survey of the Booster Ring, which was originally built in 1970, was done in 1993. In 2004, as part of the Booster upgrade, a decision was made to upgrade the Booster survey network by densification with monuments and to survey the main Booster components using modern survey and alignment instruments. The survey and alignment of Booster Accelerator was completed in December of 2004.

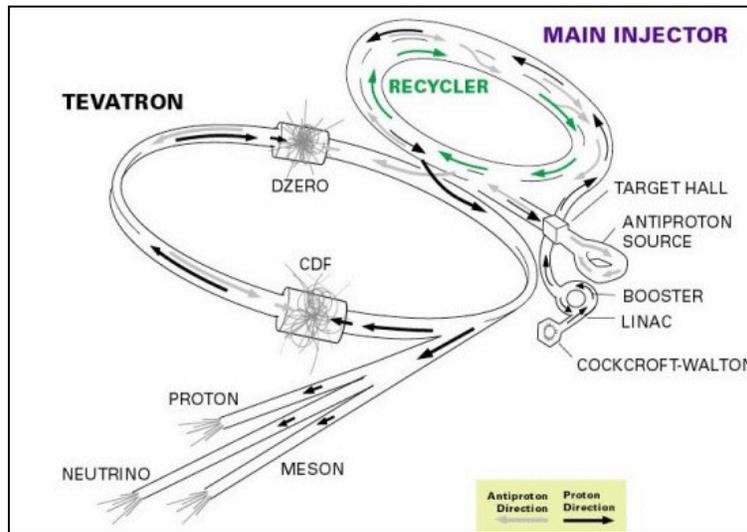


Figure 1. Fermilab's Accelerator Chain



Figure 2. Booster Ring

2. BOOSTER ACCELERATOR

The Fermilab Booster is an alternating-gradient synchrotron with a radius of 75.47 m. The magnet ring contains 96 10-foot long combined-function magnets, which both focus the beam and bend it around the circular orbit.

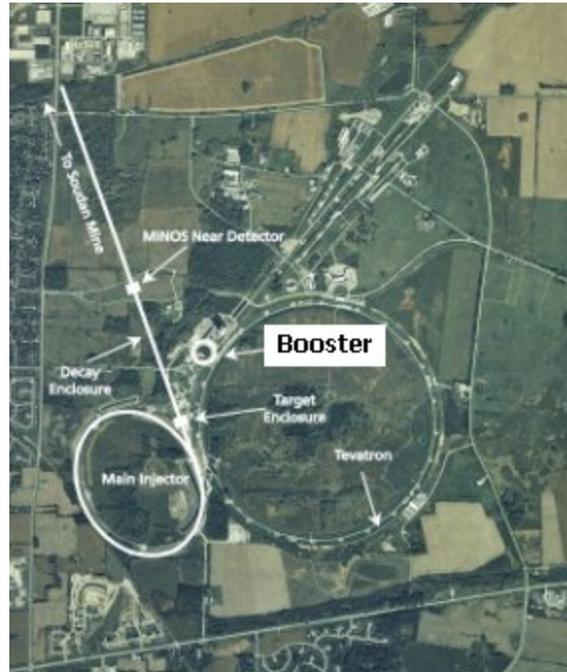


Figure 3. Booster Accelerator Location

2.1 Booster Lattice

The Booster lattice is divided into 24 identical periods from P1, P2, P3, ... P23 to P24 (Figure 4). Each period contains a 6-meter long straight section and a 1.2-meter short straight drift section, along with four combined function magnets, two horizontally focusing (F magnet) and two horizontally defocusing (D magnet). This Booster lattice is expressed schematically by FOFDOOD. This represents a focusing magnet (F), a short drift space (O), another focusing magnet (F), a defocusing magnet (D), a long drift space (OO), and another defocusing magnet (D). DOODFOF would also be correct [2].

The Booster magnet system consists of 48 modules in the ring. Each of these modules consists of a support girder which carries one D magnet, one F magnet, a choke, a capacitor bank, a correction element package, a beam position detector, and an ion pump (Figure 5). Two of these modules, two magnet girders, form one period of the Booster lattice. The long straights are used for injection and extraction areas, RF (Radio Frequency) acceleration cavities, and special correction magnets and beam diagnostics. The lattice periods are numbered from 1 through 24 in the direction of the beam as L1, S1, L2, S2, ..., L24, and S24, where "L" is for long straight and "S" is for short straight. There are 24 long and 24 short straight sections in Booster for a total of 96 gradient magnets in the ring. The standard cell length is 19.76 meters.

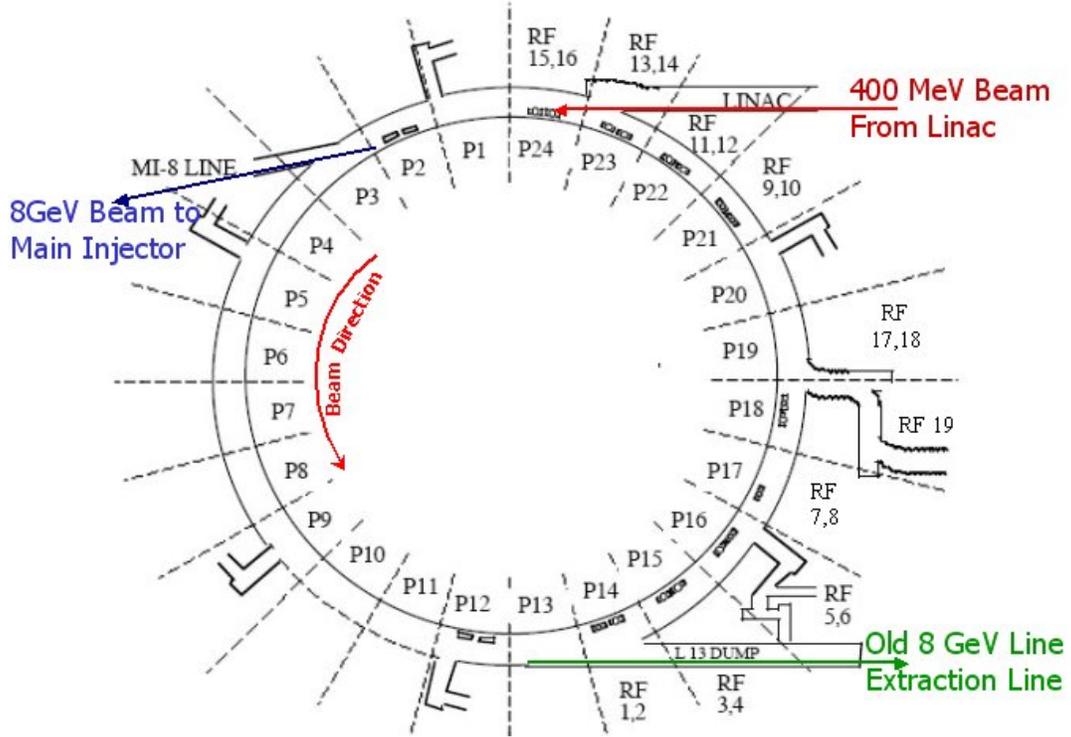
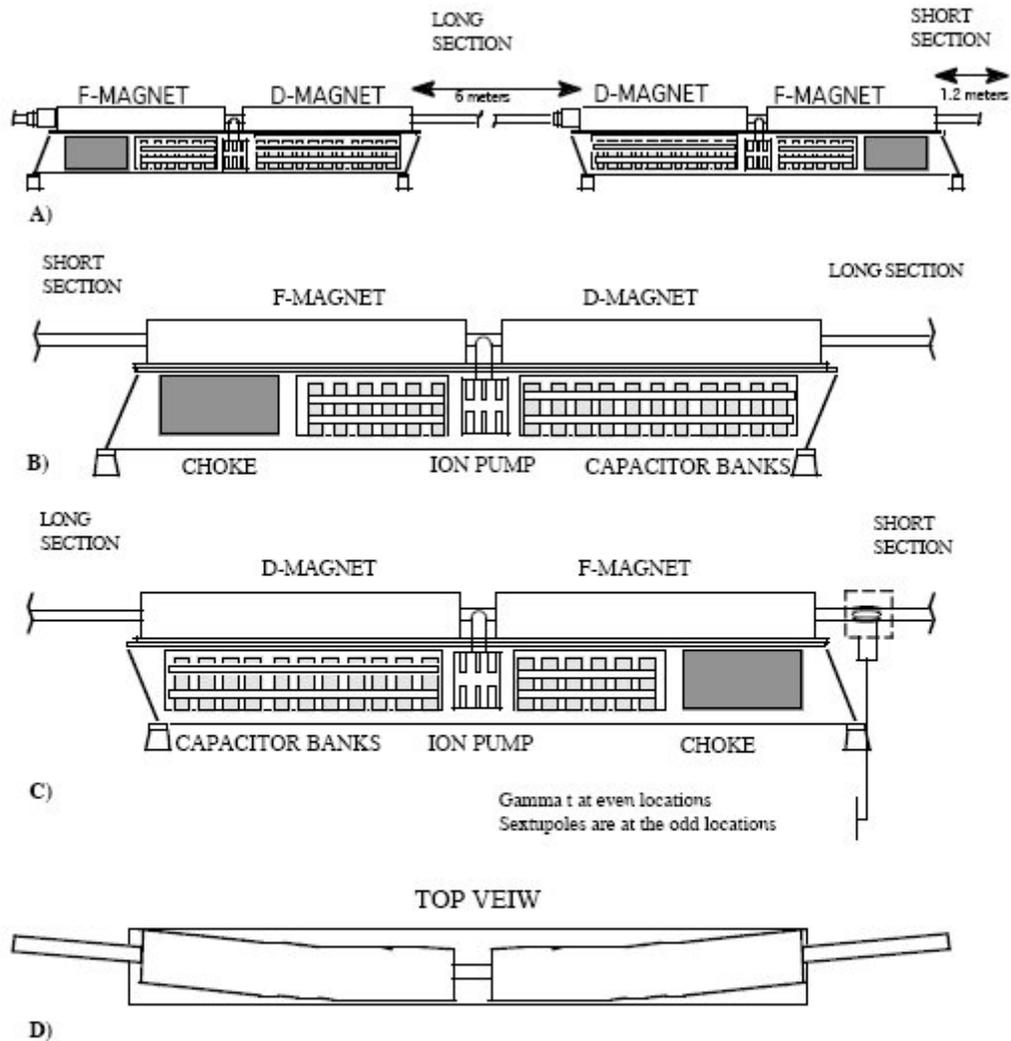


Figure 4. Booster Periods

2.2 Booster Components

Booster magnets are combined function magnets. Each magnet bends the beam (a dipole magnet function) and focuses the beam either horizontally or vertically (a quadrupole function). There are 96 10-foot long combined-function magnets in the Booster (Figure 6). Each magnet is built by stacking some 4400 silicon steel laminations (0.025" thick) together inside a stainless steel vacuum container. The laminations are stacked in such a way that magnets have the curvature of the beam path. The completed magnet has a cross section of 13 inches by 18 inches and is 10 feet long. The magnet assembly weighs approximately 5 tons.



- A) Typical lattice cell starting with focusing magnet and ending with short straight section (FDOODFO).
- B) Upstream section of the cell showing girder elements.
- C) Downstream section of Cell.
- D) Top view showing relative curvature.

Figure 5. Booster Magnets [2]

The Booster Beam Position Monitors (BPMs) measure both vertical and horizontal beam positions as well as beam intensity. The BPM detector is an impedance matched stripline device consisting of four striplines contained in a single cylindrical housing which allows measurements in both planes at a single location (Figure 7). There are 48 BPMs located in the Booster ring, one at every short and long straight section.

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The application of RF energy accelerates the Booster beam. The beam is accelerated by 19 ferrite-tuned cavity resonators located around the Booster ring. The 19 RF cavities are located in nine of the long straight sections of the Booster lattice and they are grouped in pairs (Figure 8). Each pair is mounted on a girder in one of the 6-m long straight sections in the Booster magnet lattice. At long straight 18 there is only one cavity.

There are other components in the Booster ring, such as the septum magnets and dogleg magnets, which will not be described in this paper.

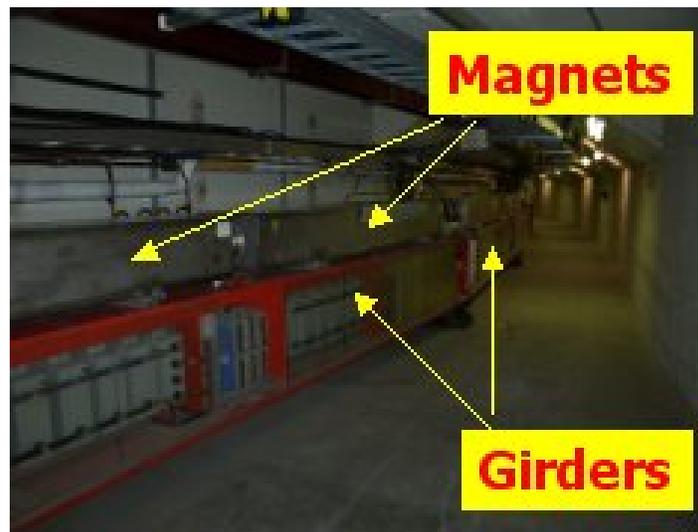


Figure 6. Booster Magnets and Girder

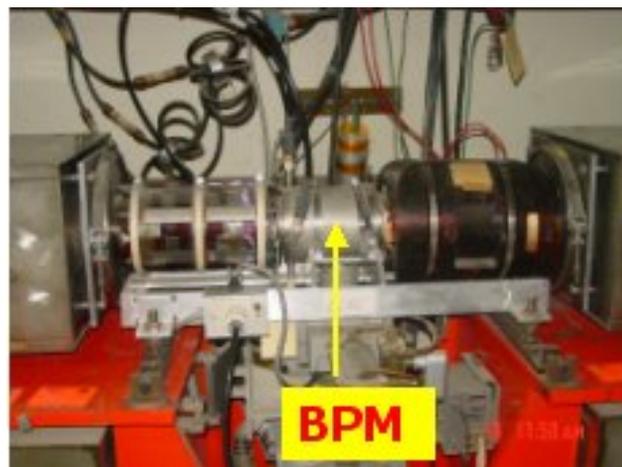


Figure 7. Booster BPM

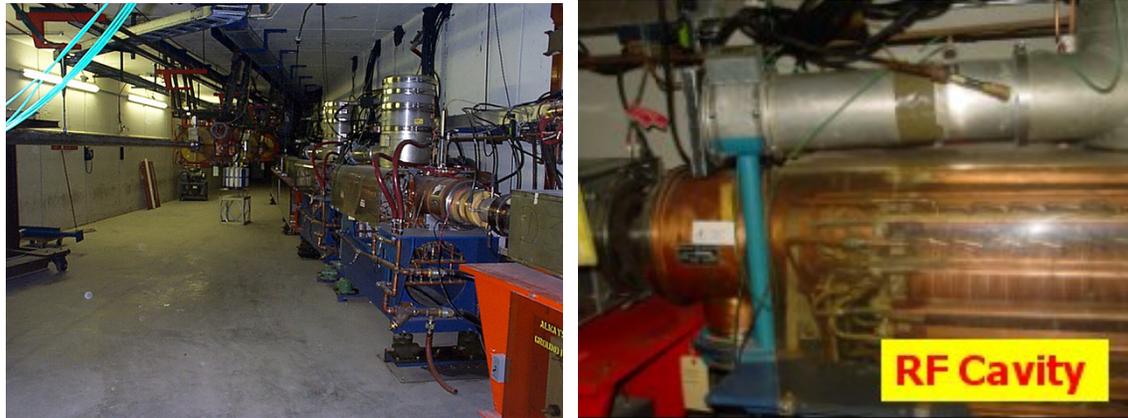


Figure 8. Booster RF-Cavity

3. SURVEY AND ALIGNMENT OF THE BOOSTER ACCELERATOR

The purpose of the current survey was to establish a precision control network for positioning Booster beamline components in the Fermilab Site Coordinate System (FSCS) [3]. In addition to network measurements, since the components were installed in the 1970s, the goal was to

- i) measure (as-found) all magnet fiducials, BPMs and RF Cavities with special fixtures in the Booster ring;
- ii) measure (as-found) all dipole and quadrupole magnet fiducials in the Linac 400 MeV line;
- iii) determine the upstream and downstream coordinates of each beamline component along with corresponding, azimuth, pitch, roll and twist; and
- iv) generate a beamsheet to document component fiducial locations

3.1 Fermilab Site Coordinate System (FSCS)

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3.1.1 FSCS:XYZ

The FSCS:XYZ coordinate system corresponds to the lattice version of the FSCS. This coordinate system was developed for the beamlines extracting from the Tevatron at A0. It is a right-handed Cartesian coordinate system defined as follows:

- Origin - A0
- Y-axis - NORTH axis rotated by Geodetic Azimuth α from the Geodetic North. Positive along the extraction line towards the Neutrino Area
- X-axis - EAST axis. Positive to the right and perpendicular to the Y-axis
- Z-axis - Positive up and perpendicular to both X- and Y-axis. It is aligned with the direction of the normal to the ellipsoid at A0.

The parameters that define the FSCS:XYZ coordinate system origin at A0 are defined in [3].

3.1.2 FSCS:XYH

FSCS:XYH is a right-handed Cartesian coordinate system based on a Double Stereographic Projection [3]. The (XYH) coordinates in this system are identical to the (XYZ) coordinates in the FSCS:XYZ system at the origin, where H is the orthometric height (elevation).

3.2 Survey and Alignment Methodology

The Booster accelerator network of 1993 was based on the Fermilab Site Coordinate System (FSCS:XYH). In order to precisely survey and align the Booster accelerator beam line components in the FSCS system, a precise tunnel control network was established in December 2004 and tied to the existing 1993 Booster accelerator network. Components were aligned and surveyed to these control points. The survey instrumentation used for the Booster accelerator network was as follows:

- i) SMX 4500 Laser Tracker and its associated Insight™ software were used for measuring control points, and for the survey and alignment of components. The Laser Tracker is a device that makes three-dimensional measurements. It uses a laser distance meter, two precision angle encoders and proprietary software to calculate, store and display real-time three-dimensional position of a mirrored target positioned on the desired point or feature. The mirrored target is a spherically mounted retroreflector (SMR). Table 1 shows the Laser Tracker 4500 specifications.

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ii) Digital level (Leica NA3003; precision = 0.4mm/km) was used for elevations. Brunson optical tooling instruments were used for making offset measurements from the components to the control points.

Category		Radial	Transverse
Resolution		0.5 microns	0.25 arcseconds
Repeatability	Near	7 microns	3 microns
	Far	1 micron/meter	1 micron/meter
Accuracy	Near \pm	20 microns	12 microns
	Far \pm	1.1 micron/meter	5 micron/meter
Working Range		0 to 34 meters	270° horizontal 120° vertical

Table 1. Laser Tracker 4500 Specifications

3.3 Booster Control Network (BooNet)

The Booster tunnel control network is a system of braced quadrilaterals between the floor monuments, wall monuments, pass points, and tie-rods in the tunnel. The tunnel network consisted of both horizontal and vertical networks.

3.3.1 Booster 1993 Control Network

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A Booster tunnel control network was established in July of 1993. The Booster network consisted of a total of 48 floor monuments and 26 tie-rods on the wall. The floor monuments consisted of 24 stainless steel plugs with punched “+” marks. Figure 9 shows the schematic of stainless steel plugs locations. Each point is located under a Kern base “force centered” wall mount (Figure 10). The remaining floor monuments were 24 Brass plugs with punched “.” (Figure 12a). The tie-rods included 24 tie-rods in the Booster ring, one in each period. Tie-rods were primarily used as vertical benchmarks.

Distance measurements were made with a Mekometer 5000 (precision = $0.2 \text{ mm} \pm 0.2 \text{ ppm}$) and angles were observed with a Kern E2 (precision = 0.3 arcsecond).

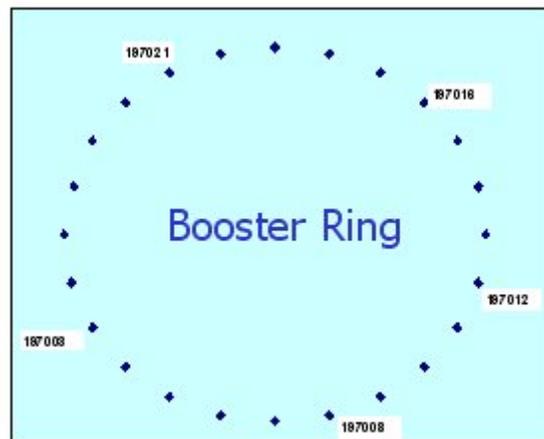


Figure 9. 1993 Booster Control Network:
Schematic of Stainless Steel Plugs Locations

3.3.2 Upgraded 2004 Booster Control Network

The 1993 Booster control network was upgraded in December of 2004 using the Laser Tracker by densifying the existing monumentation inside the Booster ring with new monuments. The new 2004 control network was tied to the existing 1993 Booster network. The upgraded 2004 Booster network consisted of a total of 59 new floor monuments, 125 new pass points, 48 existing floor monuments and 26 tie-rods (Figure 11). The new floor monuments included 48 monuments close to the girders, two in each period. The new pass points include 96 points epoxied on the girders, four in each period. The pass points also included 24 pass points epoxied on the outer Booster ring wall, one in each period (Figure 10).

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Survey measurements were made with the SMX 4500 Laser Tracker. Leica NA3003 digital level was used for elevation measurements.

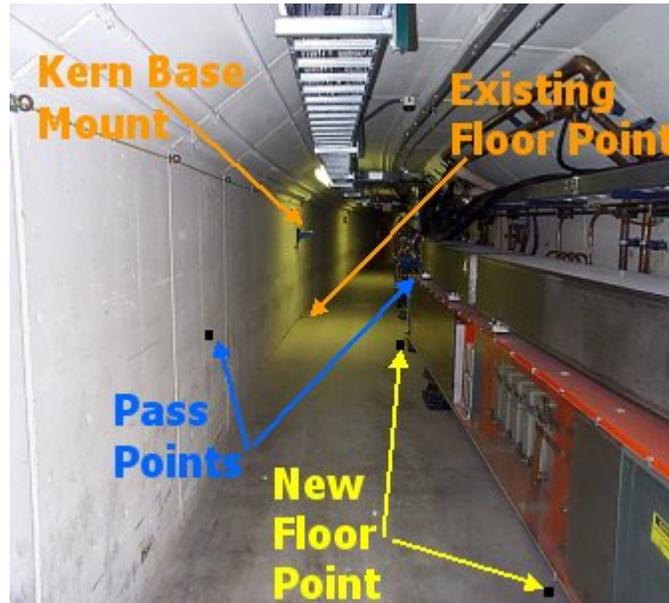


Figure 10. Booster Network Monuments

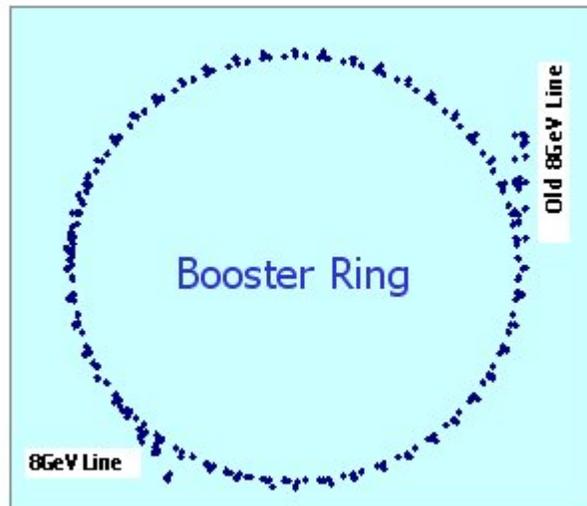


Figure 11. Densified 2004 Booster Control Network

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The stainless steel and brass plugs were measured with the SMX RetroProbe (Figure 12b). A RetroProbe with a pointed tip measures recessed features. It can quickly measure small pockets, holes, corners, punch marks, contours, crosshairs, scribed lines and other hard-to-reach features with high accuracy and repeatability.



Figure 12a. Brass Plug



Figure 12b. A RetroProbe with a pointed tip

The new monuments used for the control points were dead bolts (“Dijak bolt”) with 0.250-inch holes (Figure 13a). The dead bolt is a modified $\frac{3}{4}$ x 10-inch

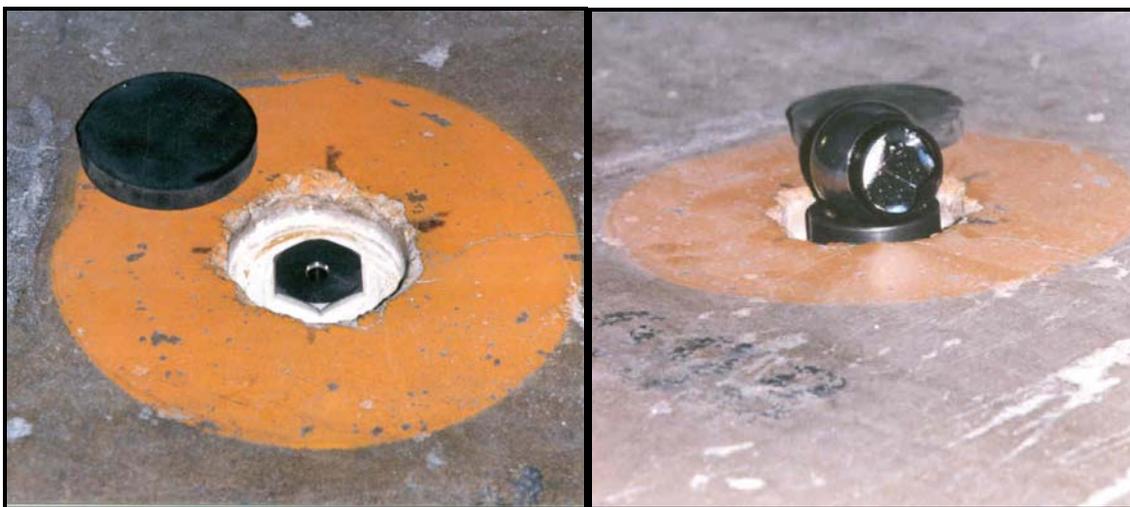


Figure 13a. Exposed Dead Bolt.

Figure 13b. Dead Bolt with Nest and SMR

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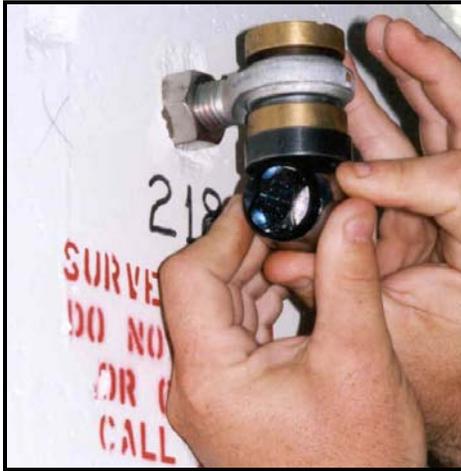


Figure 14a. Nest, Adapter and SMR on Tie-rod. Figure 14b. Stick-Mic Adapter and Nest on Dead Bolt

steel hex head bolt, machined to provide a high accuracy repeatable point. It is used as a sub-surface, corrosion resistant, low cost, horizontal and vertical control monument, which is easily installed. The 0.250-inch hole provides a receptacle for Laser Tracker and optical tooling fixtures (Figures 13b and 14b). Figure 14a shows a tie-rod used for vertical control and the tie-rod adaptor used for measurements. The new pass points were 2 x 2.5-inch construction plates with 0.250-inch holes epoxied on the girders and the Booster ring wall.

The horizontal control network was measured with the SMX 4500 Laser Tracker. Figure 15 shows the resulting standardized observation residuals for the network. Figure 16 shows the resulting absolute error ellipses at the 95% confidence level, which were all less than 0.30 mm. These results show that the network was very good. The vertical control network was measured using the Leica NA3003 level instrument. It should be noted that the vertical control network measurements had been performed several times in the past ten years.

A deformation analysis was performed after the network adjustment. Results revealed deformations in and around the areas where construction had taken place in the past ten years. Figure 17 shows the horizontal deformations between the December 2004 and the July 1993 horizontal networks. Figure 18 shows the vertical deformations between the September 2004, February 2004, January 2003, and July 1998 vertical networks.

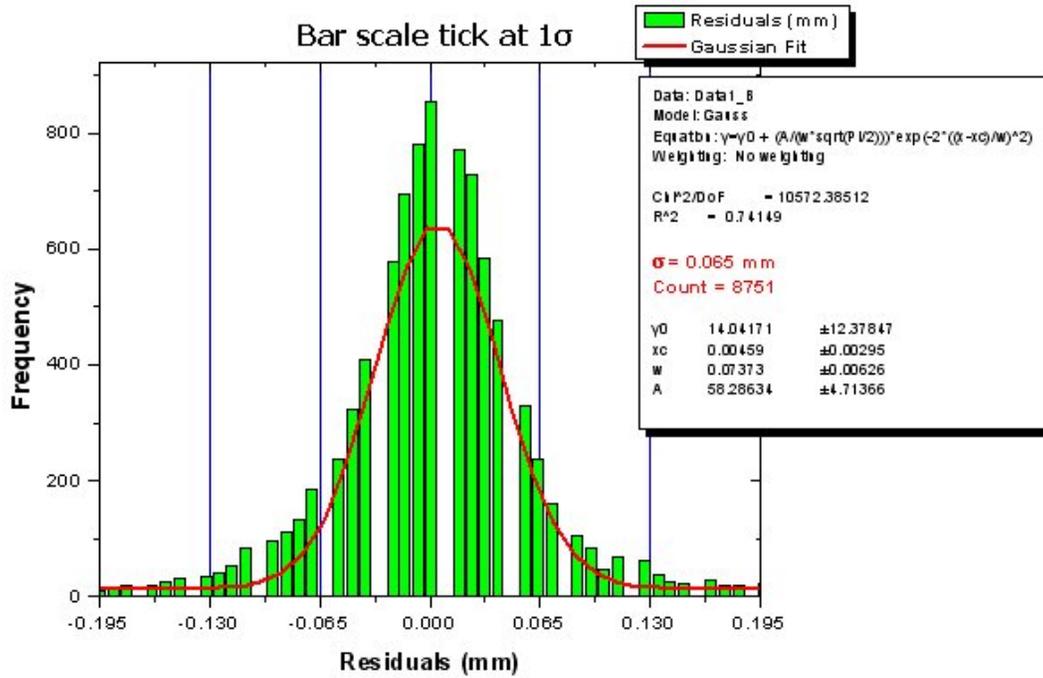


Figure 15. Booster Control Network: Histogram of Standardized Observation Residuals.

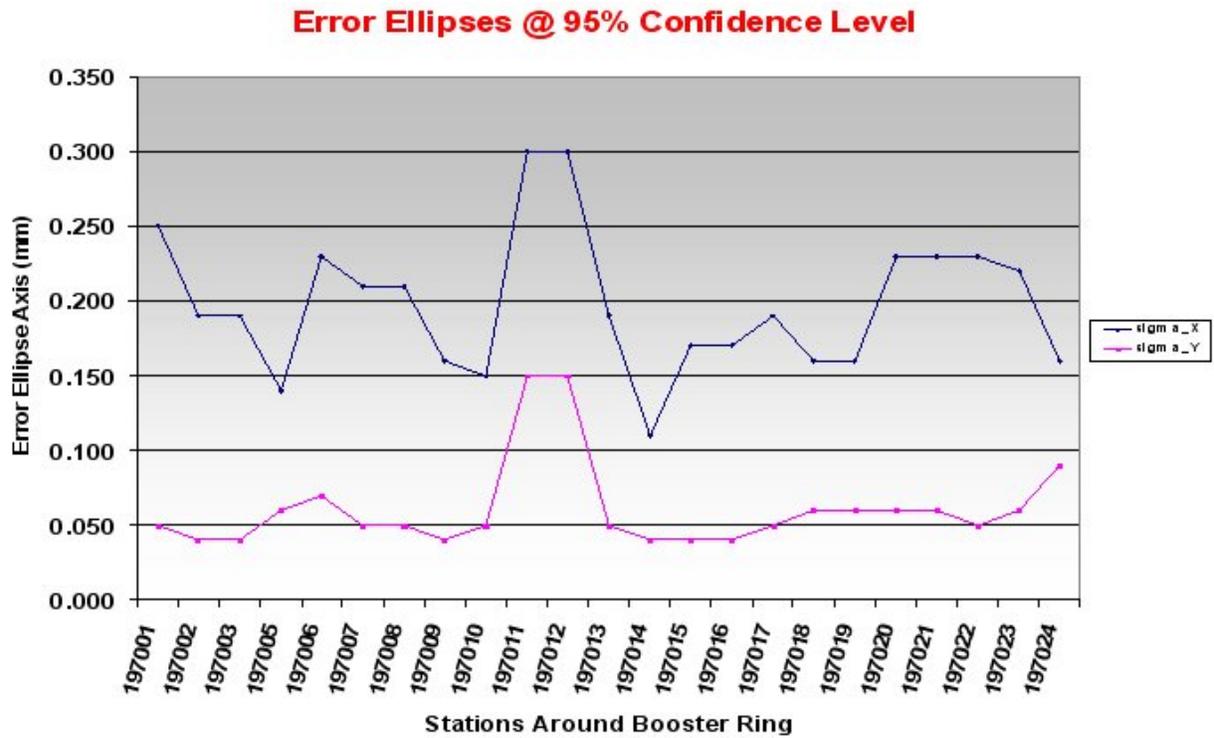


Figure 16. Booster Control Network: Error Ellipses (95% Confidence Level)



Horizontal Deformation Dec2004 - Jul1993

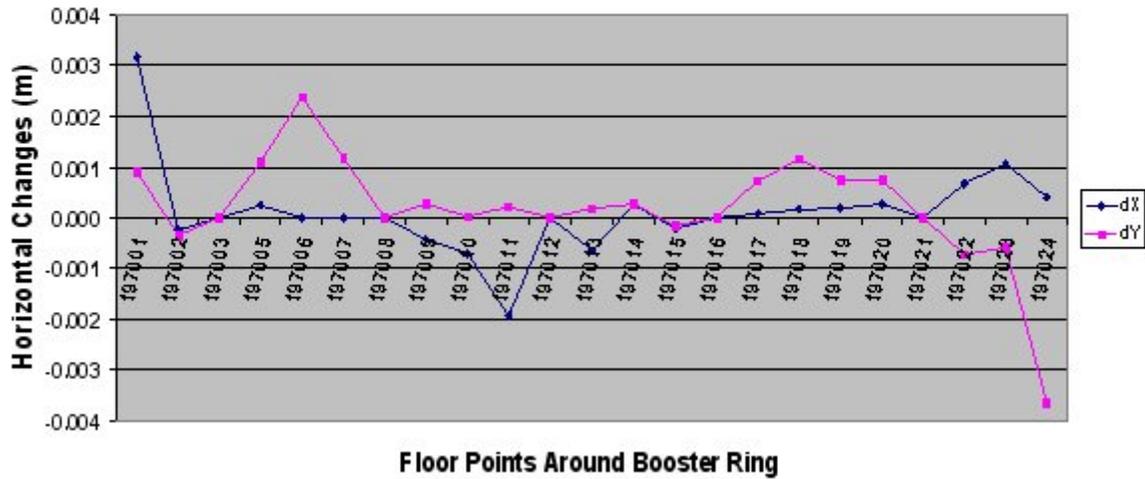


Figure 17. Booster Control Network: Horizontal Deformations – Floor points

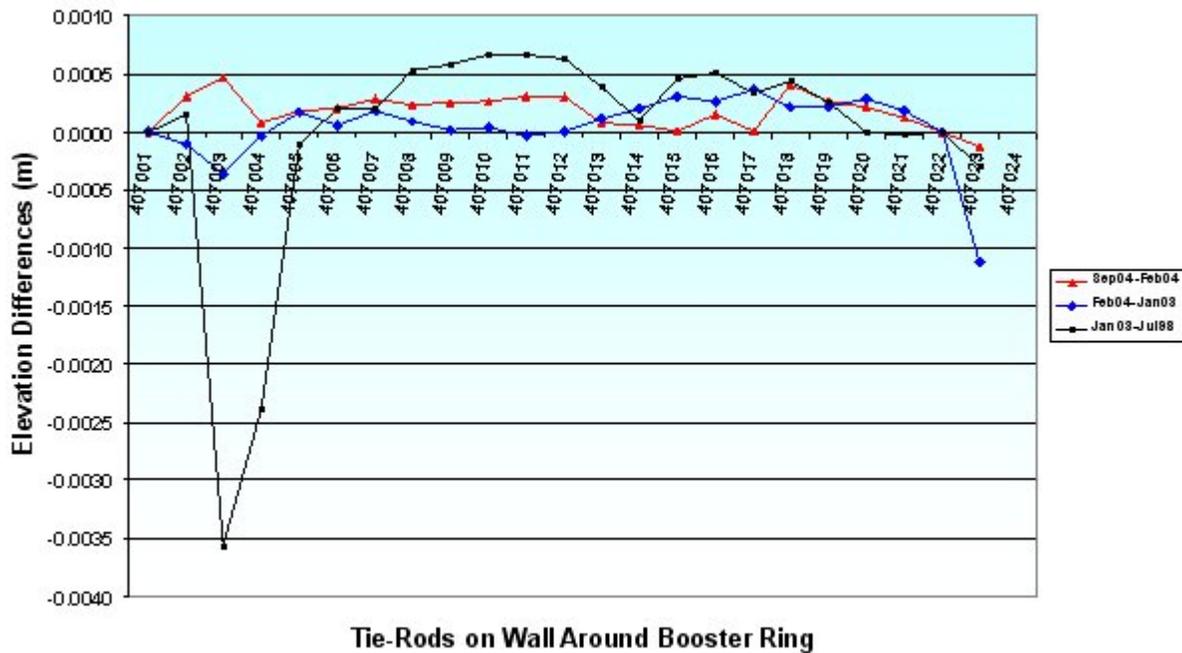


Figure 18. Booster Vertical Control Network: Vertical Deformations - Tie-rods

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3.4 Beamline Component Survey

In addition to the “as-found” measurements of the Booster beamline components, “as-found” measurements were made of all the Linac 400 MeV line in the Booster ring (Figure 19). Analysis of the 400 MeV line measurements will not be discussed in this paper.



Figure 19. Booster and Linac 400 MeV Line

3.4.1 Component Fiducialization

The goal of the component fiducialization is to relate its physical or magnetic center to the survey fiducials mounted on the component. Several survey fiducial points are mounted at suitable locations on each component. At the center of each fiducial is a 0.250-inch (6.0-mm) hole that precisely fits a Laser Tracker SMR pin nest. The center of this hole defines the location of the fiducial point. Usually each component is referenced in a local component coordinate system, defined such that its origin is at the physical center. Software is written to transform the local fiducial coordinates to the beam lattice coordinate system.

All Booster magnets were fiducialized in the 1970s as shown in Figure 20. The terms “upstream” and “downstream” refer to the direction of beam motion. Beam always travels from upstream to downstream. There was no evidence or record of any magnet being referenced. The Booster magnet fiducials were 0.4375 inch in diameter. Therefore, a special fixture was built for use with the Laser Tracker SMR pin nest (Figure 22). There were two types of magnet fiducials for the Booster magnets:

- i) Magnet fiducials with a recessed insert (Figure 21a); and
- ii) Magnet fiducials with a raised insert (Figure 21b).

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The BPMs had no fiducials but had two notches, one on the top and the other on the aisle side, to hold a specially built fixture for measurement purposes. The RF cavities had no fiducials, and thus the beam pipe locations at the upstream and downstream ends were used to determine the entrance and exit coordinates.



Figure 20. Booster Magnet Fiducials: US = Upstream; DS = Downstream



Figure 21. (a) Booster Magnet Fiducials with Recessed Insert
(b) Booster Magnet Fiducials with Raised Insert

3.4.2 Fiducial Fixtures

In the past, an 8-inch long pin had been used for the magnet fiducials in order to use optical tooling instruments. Special fixtures were built for the magnet fiducials for use with the Laser Tracker. The new fixture consists of a bushing with a 0.250-inch hole. The bushing is 1.25 inches long and 0.434 inch in diameter. A 0.875-inch SMR and the pin nest sit on top of the bushing (Figures 23 and 24). When placed in the fiducial hole, the bushing sits on a point whose distance is known to the beam centerline (Figure 25). The dimension from the center of the SMR is known to the beam centerline.

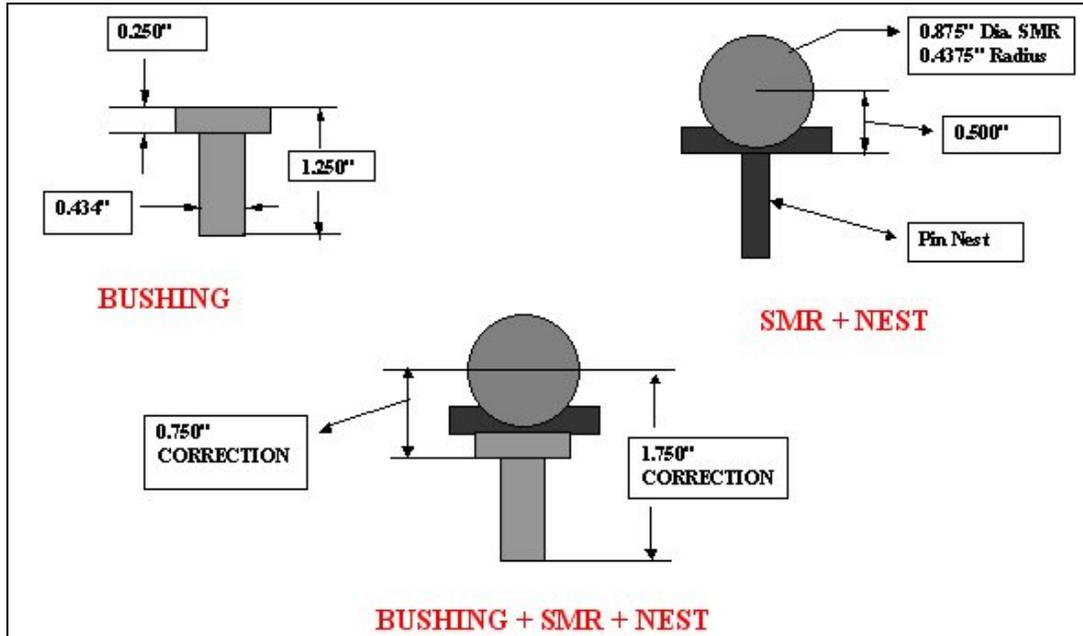
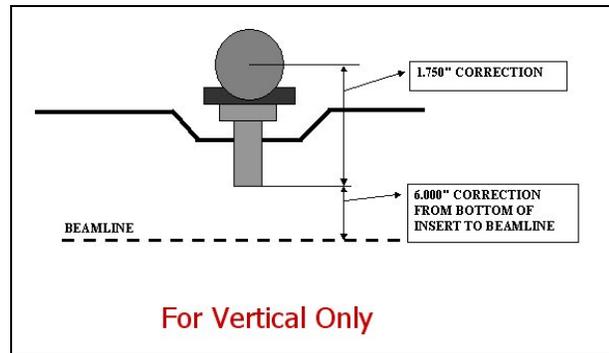
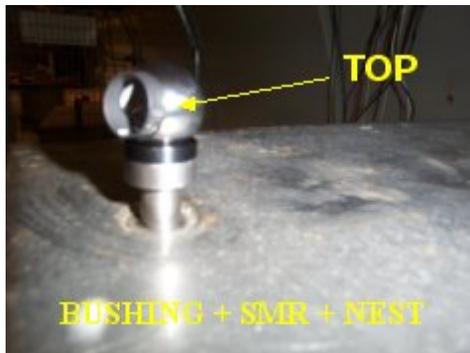
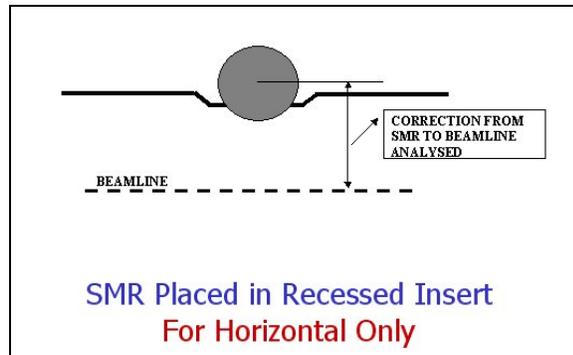


Figure 22. Booster Magnet Fiducial Fixture



(a)



(b)

Figure 23. Booster Magnet Fiducials with Recessed Insert

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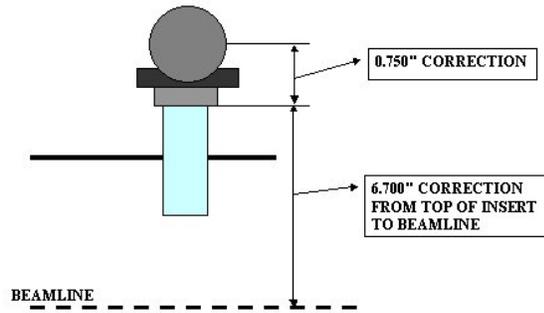
Since the BPMs had no fiducials but had two notches, an L-shaped fixture was built to latch on to the top notch for measurement. A Y-shaped fixture (radius rod) was built to measure the RF cavities which had no fiducials. One end of the fixture was placed on the beam pipe and the other end contained a nest for a SMR. Figure 26 shows the BPM and RF cavity fixtures.

3.4.3 Fiducial Measurements

The SMX 4500 Laser Tracker and its Insight™ software were used to survey all components using the floor control points, pass points and tie-rods. First, the ideal coordinates of all the Booster control points were imported into the Insight™ software. Second, after the normal calibration, the Laser Tracker was positioned at a point near the control points to be measured. Third, the Laser Tracker was oriented into the beamline Tunnel Control Network by best-fitting to several floor control points, pass points and tie-rods. From this setup, measurements were made to the fiducials on the components - magnets, BPMs, and RF cavities.

For the recessed insert, the components were measured twice at each fiducial - TOP and BOT measurements. TOP was measurement with the SMR sitting on the extended fixture in the fiducial (Figures 23a and 24a) and BOT was measurement with the SMR sitting on the fiducial without the fixture (Figures 23b and 24b). For the raised insert, the components were measured once at each fiducial – TOP measurement. The BOT measurements were more stable and were used to determine the horizontal (X, Y) coordinates of the fiducials. The vertical (H) part for the BOT measurement was not used because of unknown vertical correction. Therefore, the TOP measurements were used to determine the vertical (H) coordinates of the fiducials. The TOP measurements were reduced to the beam centerline (Figure 25).

All corrections from the SMR to the beam centerline were known with the exception of the BOT measurements when the SMR was sitting on the fiducial without the fixture. Part of this task was to determine a correction number to use for future surveys.



For Horizontal and Vertical

(a)



(b)

Figure 24. Booster Magnet Fiducials with Raised Insert

Holding the BPM fixture on the BPM, measurements were made on the top and side planes of the fixture as shown in Figure 26b at the upstream and downstream end of the BPM. Plane fits were performed from measurements on both the top and side planes at the upstream and downstream ends. Using the plane-plane intersection function of the software and applying the constant offsets, the entrance (upstream) and exit (downstream) coordinates of the BPM on the beamline were computed. Holding the RF cavity fixture on the RF cavity, beam pipe measurements were made while moving the fixture rod at intervals around the object. Circle and cylinder fits were performed on the measurements. The entrance (upstream) and exit (downstream) coordinates of the RF cavities on the beamline were computed.

Some of the RF cavities were removed and re-aligned. In addition, two Septum magnets and four Dogleg magnets were installed and aligned at Long Straight 13. Survey and alignment of the beam line components were completed in December 2004.

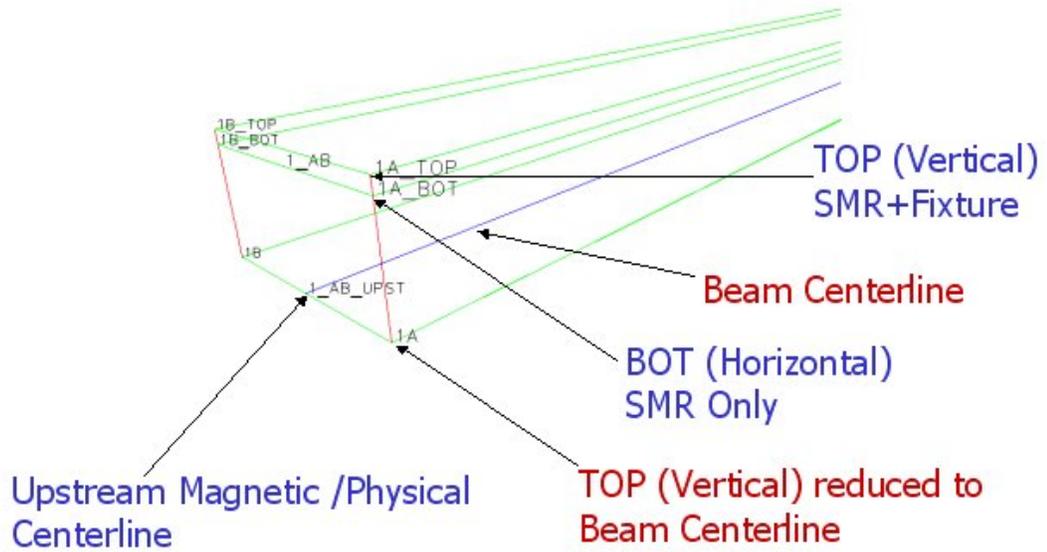
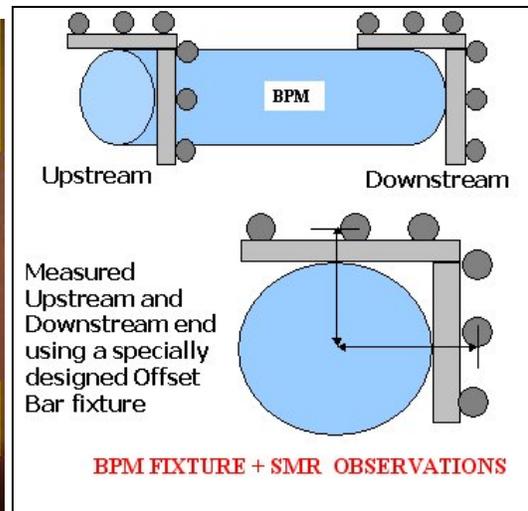
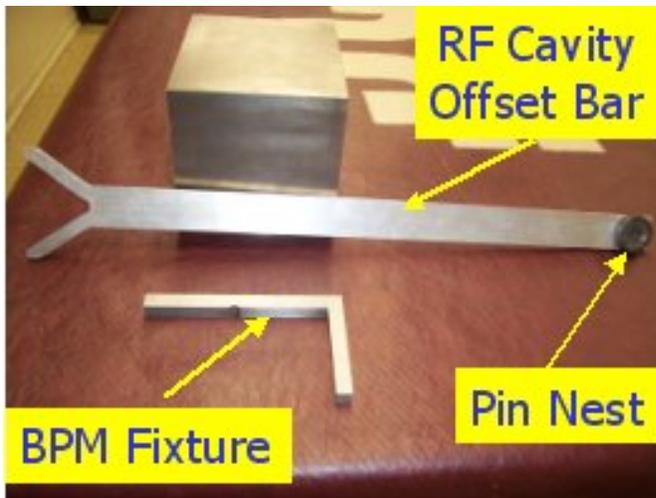


Figure 25. Booster Magnet Fiducials



(a)

(b)

Figure 26. (a) BPM and RF Cavity Fixtures
(b) BPM Observation Method with Fixture

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3.4.4 Magnet Fiducial Analysis

The purpose was to determine the following:

- i) blunders and noisy measurements;
- ii) average height difference between the BOT fiducial and the beam centerline;
- iii) compare Tracker vertical data with optical measurements;
- iv) beam heights from the TOP measurements with known offsets;
- v) ideal fiducial coordinates for future alignment using the Laser Tracker

All fiducial analyses were done in unit of inches because the fixtures were designed in inches. The ideal design distance between fiducials A and B and fiducials C and D is 15.016 inches (Figures 27 and 28). The measured distances for AB and DC were computed from measured coordinates as:

$$\text{Distance (AB)} = \sqrt{[(X_B - X_A)^2 + (Y_B - Y_A)^2]}$$

$$\text{Distance (CD)} = \sqrt{[(X_D - X_C)^2 + (Y_D - Y_C)^2]}$$

In order to identify blunders and noisy measurements, comparisons were made between the TOP and BOT measurements (Figure 29). Comparisons were also made between the designed and measured distances (Figures 30 and 31). All measurements with the differences larger than 0.020 inch (0.5mm) were flagged and tagged with "To Be Checked." Height differences between the BOT measurements and the beam centerline were computed and analyzed as shown in Figure 32. The average height difference was 6.870 inches. This number will be used in the future for reducing the BOT measurements to the beam centerline.

Laser Tracker derived elevations were compared with hard elevations, which were determined with optical levels (Figure 33). Most of the differences were larger than 0.020 inch (0.5mm). However, the hard elevations were considered more reliable and were used for the beamsheet generation.

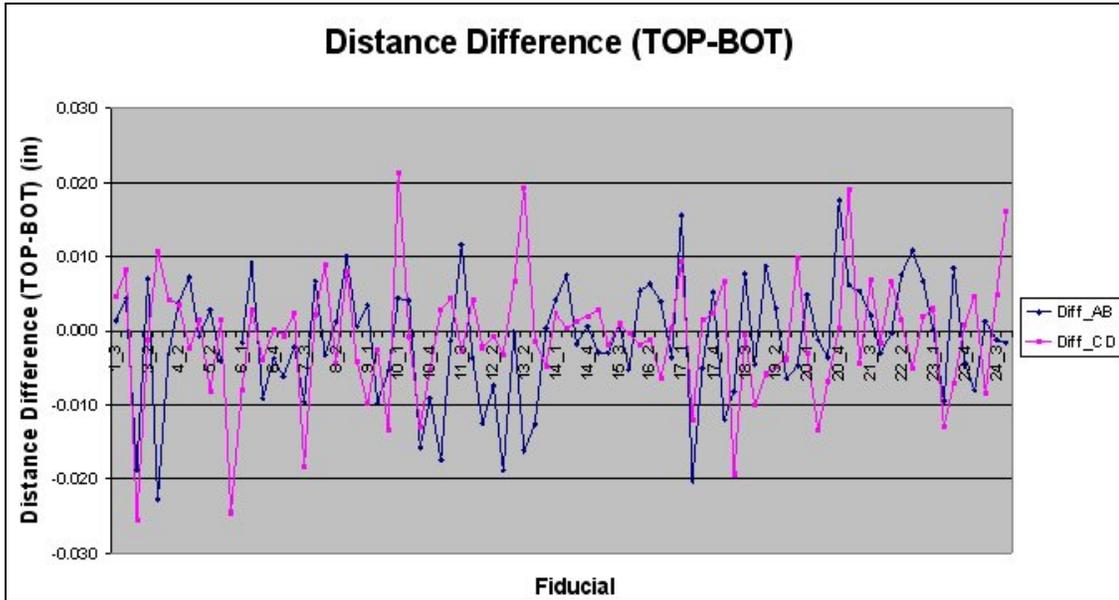


Figure 29. Fiducial Distance Difference (TOP-BOT)

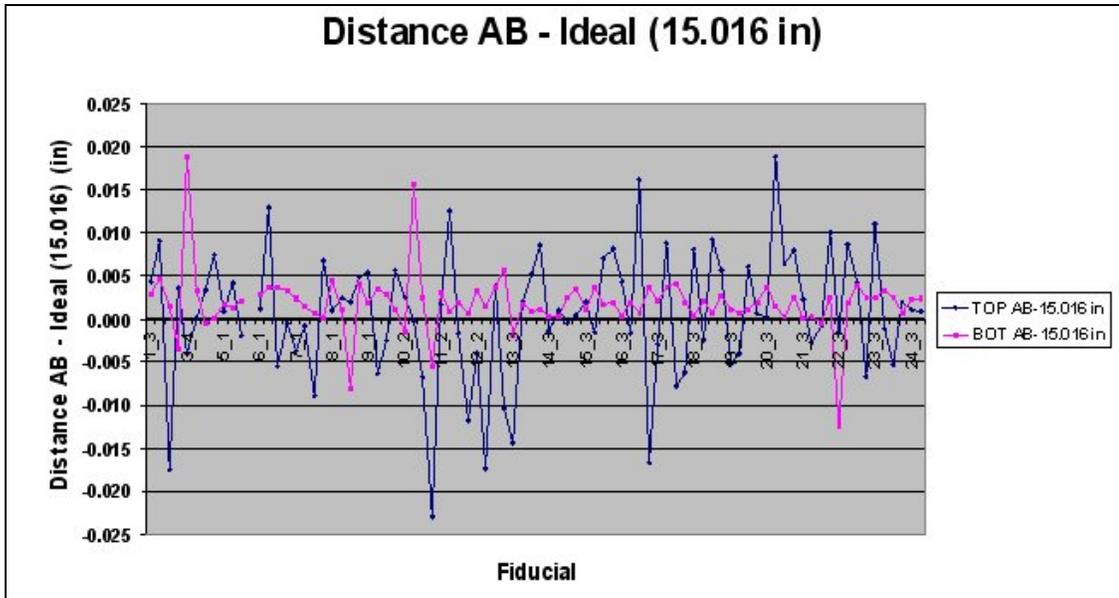


Figure 30. Fiducial Distance Difference (Measured AB - Ideal)



Distance CD - Ideal (15.016 in)

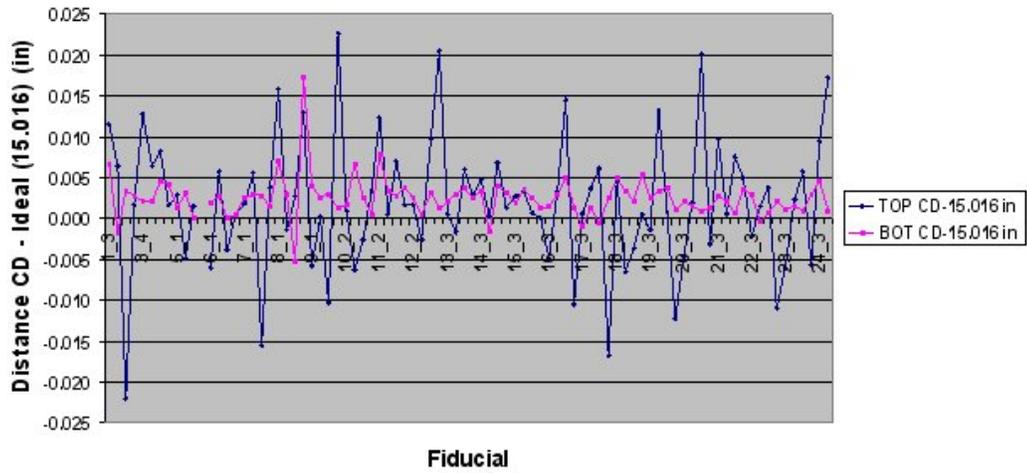


Figure 31. Fiducial Distance Difference (Measured CD - Ideal)

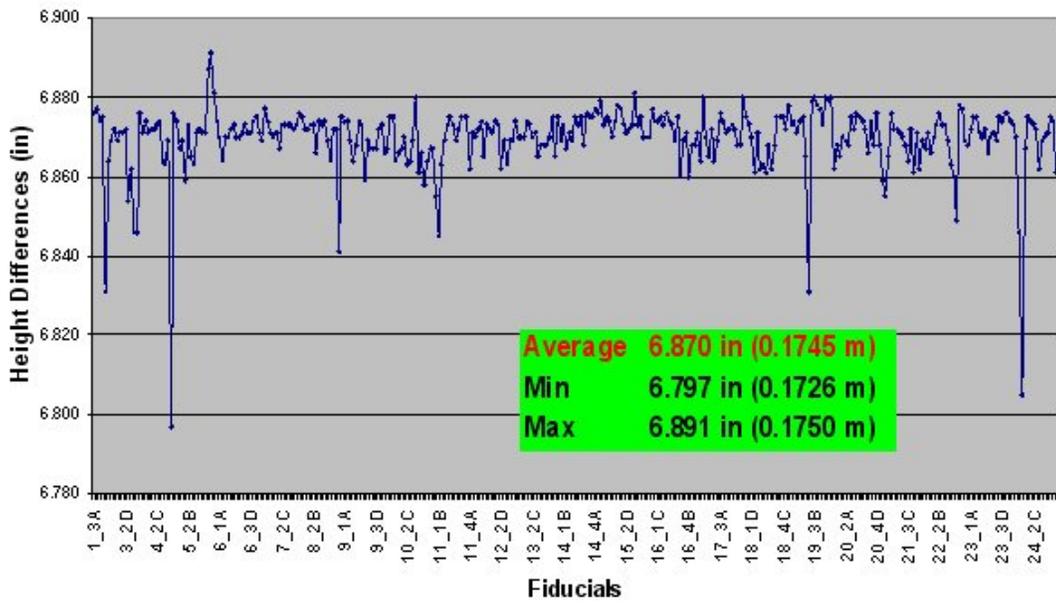


Figure 32. Height differences between the BOT fiducial and the Beam Centerline

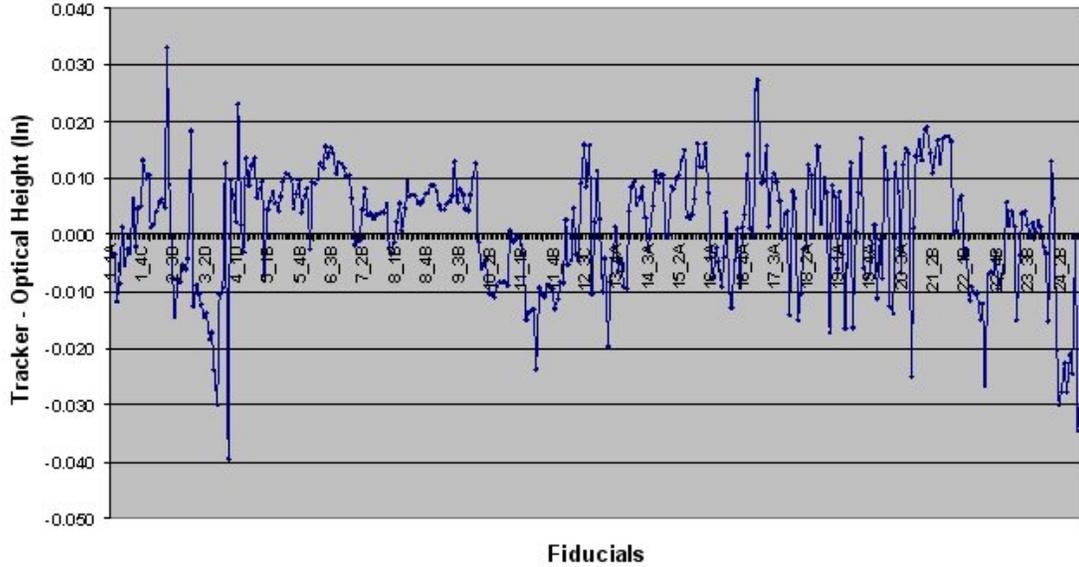


Figure 33. Height Differences (Laser Tracker - Optical Heights)

3.5 Booster Beamsheet

The 3-D coordinates of the entrance (upstream) and exit (downstream) coordinates of the magnets on the beamline were computed, with the physical centerline corrected for magnetic offset at Beam Center, as follows:

$$X_{US} = (X_A + X_B)/2 \pm dX_{AB-OFFSET}$$

$$Y_{US} = (Y_A + Y_B)/2 \pm dY_{AB-OFFSET}$$

$$X_{DS} = (X_C + X_D)/2 \pm dX_{CD-OFFSET}$$

$$Y_{DS} = (Y_C + Y_D)/2 \pm dY_{CD-OFFSET}$$

where $dX_{AB-OFFSET} = MM_{OFFSET} \times \sin(\text{Azimuth}(AB))$

$$dY_{AB-OFFSET} = MM_{OFFSET} \times \cos(\text{Azimuth}(AB))$$

$$dX_{CD-OFFSET} = MM_{OFFSET} \times \sin(\text{Azimuth}(CD))$$

$$dY_{CD-OFFSET} = MM_{OFFSET} \times \cos(\text{Azimuth}(CD))$$

MM_{OFFSET} = Magnet Move offset, the offset between the physical and magnetic centerline (Figures 27 and 28). The offset values are defined by [4] as:

$$MM_{OFFSET} = 0.053 \text{ inch radially in for magnet type D}$$

$$MM_{OFFSET} = 0.042 \text{ inch radially out for magnet type F.}$$

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Azimuth, pitch, roll and twist were computed for each magnet. From the corrected coordinates, a Booster beamsheet (Beamsheet_07Apr05) was generated and stored in Worksheet No. 1 in the Excel file Booster Beamsheet_07Apr05.xls. It consisted of the following (Figure 34):

- Device/Fiducial name
- Magnet Type
- Station
- Easting (X) coordinate (US, DS)
- Northing (Y) coordinate (US, DS)
- Elevation (H) (US, DS)
- Azimuth (degree)
- Pitch (milliradian)
- Roll (milliradian)
- Twist (milliradian)

The measured fiducial coordinates (Fiducials_07Apr05) were placed in Worksheet No. 2. It consisted of the following (Figure 35):

- Device/Fiducial name
- Magnet Type
- Easting (X) coordinate
- Northing (Y) coordinate
- Fiducial Elevation (H)
- Beamline Elevation (H)

4. CONCLUSION

The Booster accelerator has been surveyed and aligned and the results have been presented. The 1993 Booster control network has been upgraded with the 2004 Booster network. The existing survey monuments were densified with new monuments. These monuments were surveyed and tied to 1993 survey in the Fermilab Site Coordinate System. All magnet fiducials, BPMs and RF cavities were measured with special fixtures in the Booster ring. Dipole and quadrupole magnet fiducials were also measured in the Linac 400 MeV line in the Booster ring. A beamsheet was generated to document the location of all the components. The alignment methodology used has also been presented.



Site Coordinates for Booster Beamsheet ddm mmyy.xls Date: April 07, 2005

NOTES: Coordinates are given for the entrance and exit of the device in Site coordinate system.
 Site X-axis (EAST); Site Y-axis (NORTH); Site Z-axis (ELEVATION)
 Azimuth is CCW wrt site EAST.
 Roll = (Rd + Ru)/2, where Rd = downstream roll, Ru = upstream roll Unit = milliradian
 Roll is -VE implies magnetic rolled CCW from the UPST view (rolled radially toward center of Booster)
 Pitch is the vertical angle about the x-y plane. Unit = milliradian
 Twist = Rd - Ru, where Rd = downstream roll, Ru = upstream roll Unit = milliradian

Booster Beamsheet generated by Babalunde O'Sheg Oshinowo on February 11, 2005

Modifications:

Device	Type	DISTANCE	EAST(X) [m]	NORTH(Y) [m]	ELEVATION(H) [m]	Azimuth [deg]	Pitch [mrad]	Roll [mrad]	Twist [mrad]
1_1U	D8	0.000000	30321.52102	30303.53321	221.432208	271.72737	0.08140	-0.19926	0.12565
1_1D	D8	2.311387	30321.60878	30300.62315	221.432445				
1_2U	F2	3.387277	30321.63790	30300.14815	221.432662	275.49376	0.20693	-0.53486	0.23597
1_2D	F2	6.301292	30321.91688	30297.24752	221.433265				
BPM_11U		6.775070	30321.97712	30296.77759	221.432520	277.50372	2.55055	1.68546	4.08171
BPM_11D		6.968365	30322.00236	30296.58595	221.433010				
1_3U	F3	7.476211	30322.07120	30296.08278	221.433445	279.56712	-0.15338	-0.70790	-0.42999
1_3D	F3	10.390541	30322.55557	30293.20899	221.432998				
1_4U	D1	10.863700	30322.65060	30292.74547	221.433916	283.32544	-0.34323	-2.02671	0.00000
1_4D	D1	13.777224	30323.32211	30289.91039	221.432145				
2_1U	D11	19.758281	30324.87160	30284.13353	221.432816	286.71463	-0.15560	-1.41188	-0.17042
2_1D	D11	22.672780	30325.70983	30281.34217	221.432363				
2_2U	F8	23.147005	30325.85920	30280.89208	221.432492	290.47183	-0.17113	-0.04326	-0.38541
2_2D	F8	26.059915	30326.87799	30278.16314	221.431993				
BPM_21U		26.542869	30327.05723	30277.71468	221.431970	292.73973	12.08505	8.21031	-7.62645

Figure 34. Booster Beamsheet - Worksheet No. 1

Site for Booster Beamsheet: Booster Beamsheet.xls Date: April 07, 2005

Coordinates are given for the dipole fiducial in Site coordinate system.

Beamsheet generated by Babalunde O'Sheg Oshinowo on February 11, 2005

Type	EAST(X) [m]	NORTH(Y) [m]	Fiducial ELEVATION(H) [m]	Beamsheet Elevation(H) [m]	Comments
D8	30321.93176	30303.52757	221.62149	221.432298	
D8	30321.71297	30303.53894	221.62139	221.432198	
D8	30321.80074	30300.62878	221.62165	221.432419	
D8	30321.41951	30300.61760	221.62170	221.432471	
F2	30321.44700	30300.12968	221.62202	221.432787	
F2	30321.82667	30300.16642	221.62177	221.432538	
F2	30322.10567	30297.26576	221.62242	221.433186	
F2	30321.72596	30297.22908	221.62287	221.433345	
F3	30321.88207	30296.05084	221.60819	221.433536	
F3	30322.25822	30296.11437	221.60803	221.433351	
F3	30322.74268	30293.24037	221.60743	221.432822	
F3	30322.36635	30293.17725	221.60780	221.433174	
D1	30322.46658	30292.70174	221.63623	221.434903	
D1	30322.83724	30292.78982	221.63546	221.433530	
D1	30323.50909	30289.95442	221.63446	221.432530	
D1	30323.13776	30289.86697	221.63007	221.428148	??? - (221.433303) TOP To be checked
D11	30324.69000	30284.07949	221.61595	221.433069	
D11	30325.05579	30284.18833	221.61544	221.432563	
D11	30325.89385	30281.39679	221.61496	221.432077	
D11	30325.52839	30281.28831	221.61553	221.432648	
F8	30325.67942	30280.82518	221.61534	221.432463	
F8	30326.03699	30280.95824	221.61540	221.432520	

Figure 35. Booster Beamsheet - Worksheet No. 2

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5. ACKNOWLEDGMENT

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6. REFERENCES

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