SURVEY AND ALIGNMENT OVERVIEW: FERMILAB MAIN INJECTOR RING

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1. INTRODUCTION

The purpose of the Fermilab Main Injector Ring (FMI) is to replace and improve upon the performance of the existing Main Ring by simultaneously enhancing both the Fermilab collider and fixed target programs. The FMI is situated in the southwest area of the Fermilab site, interacting with the Tevatron (TeV) near the F-O straight section (Fig 1). The FMI will perform all the duties currently required of the existing Main Ring. Thus, operation of the Main Ring will cease following commissioning of the FMI, with a concurrent reduction in the background rates seen in the colliding beam detectors. The performance of the FMI, as measured in terms of protons per second delivered to the antiproton production target or total protons delivered to the Tevatron, is expected to exceed that of the Main Ring by a factor of two to three. In addition the FMI will provide high duty factor 120 GeV beam to the experimental areas during the collider operation, a capability that does not presently exist in the Main Ring (Fig. 2) [1].

2. FMI DESIGN GEOMETRY

The FMI consists of an irregularly shaped oval with a circumference of 3319.419m. The MI-60 straight section of the FMI is parallel to the Tevatron at F-O straight section, separated from it by 11.823m horizontally and 2.3253m vertically. The reference point defining the plane containing the Main Injector design orbit lies at the intersection of a line from the center of the Tevatron ring and passing 13.222m downstream of TeV F-O normal to the F-O straight section, and a line parallel to the MI-60 straight section and equidistant from the MI-60 and MI-30 straight sections. Gravity at this point defines the normal to the plane. The plane containing the Main Injector orbit dips at an angle of 0.231 milliradians toward the southwest corner (project coordinates) [1].

3. ALIGNMENT TOLERANCES

In order to achieve a smooth and successful startup, the FMI design committee has defined the desired absolute and relative alignment tolerances for the 208 quadrupole and 344 dipole magnets. In addition to these tolerances, future long range experiments that may result from the flexibility of the FMI, demand global considerations as well.

3.1 Global tolerances

To provide for the continued development of long range experiments at the conceptual design level, the initial global tolerance of the FMI must meet the Third Order, Class II Horizontal Survey Accuracy Classifications in the current North American Datum of 1983 (NAD 83) and Second

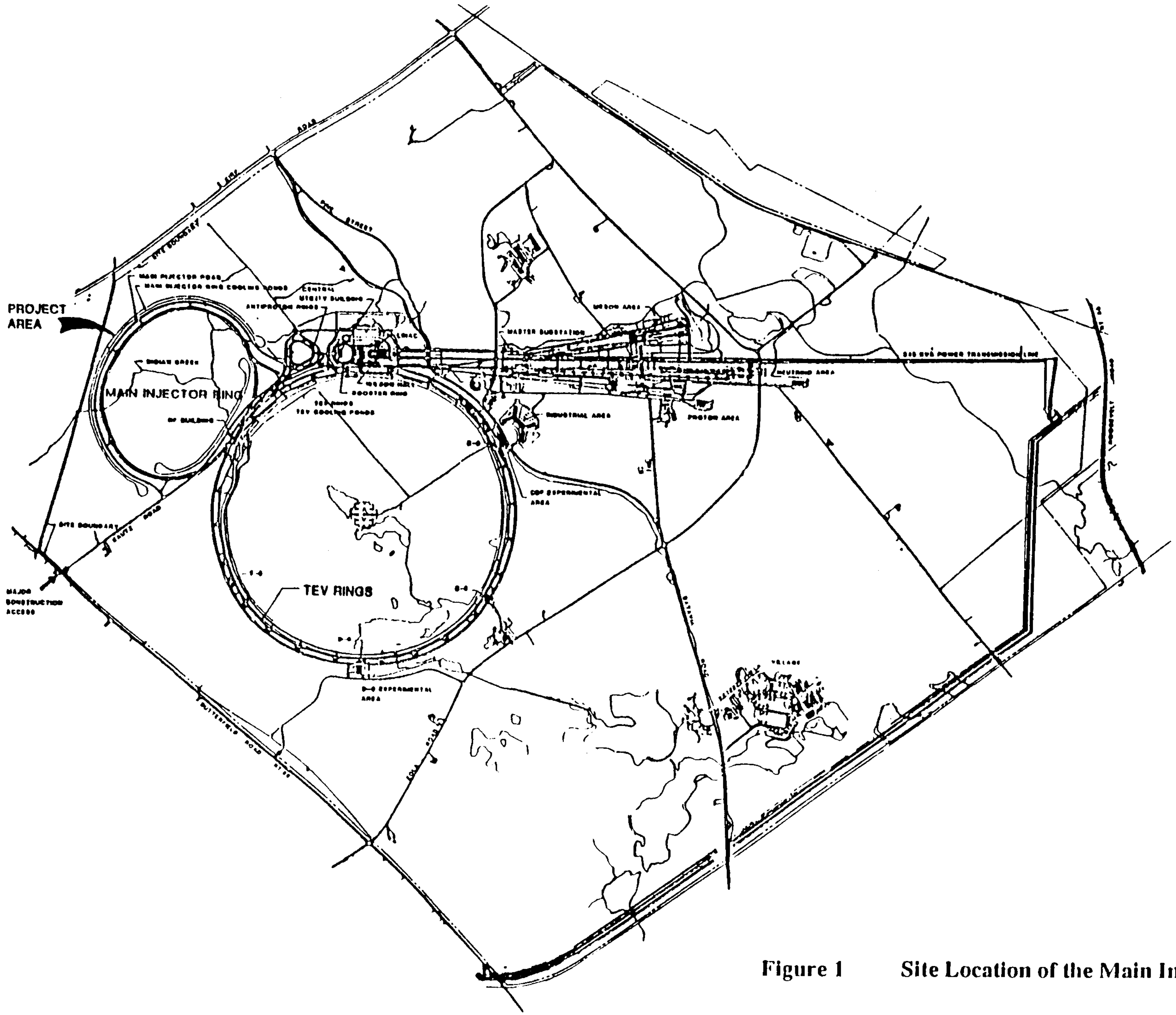


Figure 1 Site Location of the Main Injector.

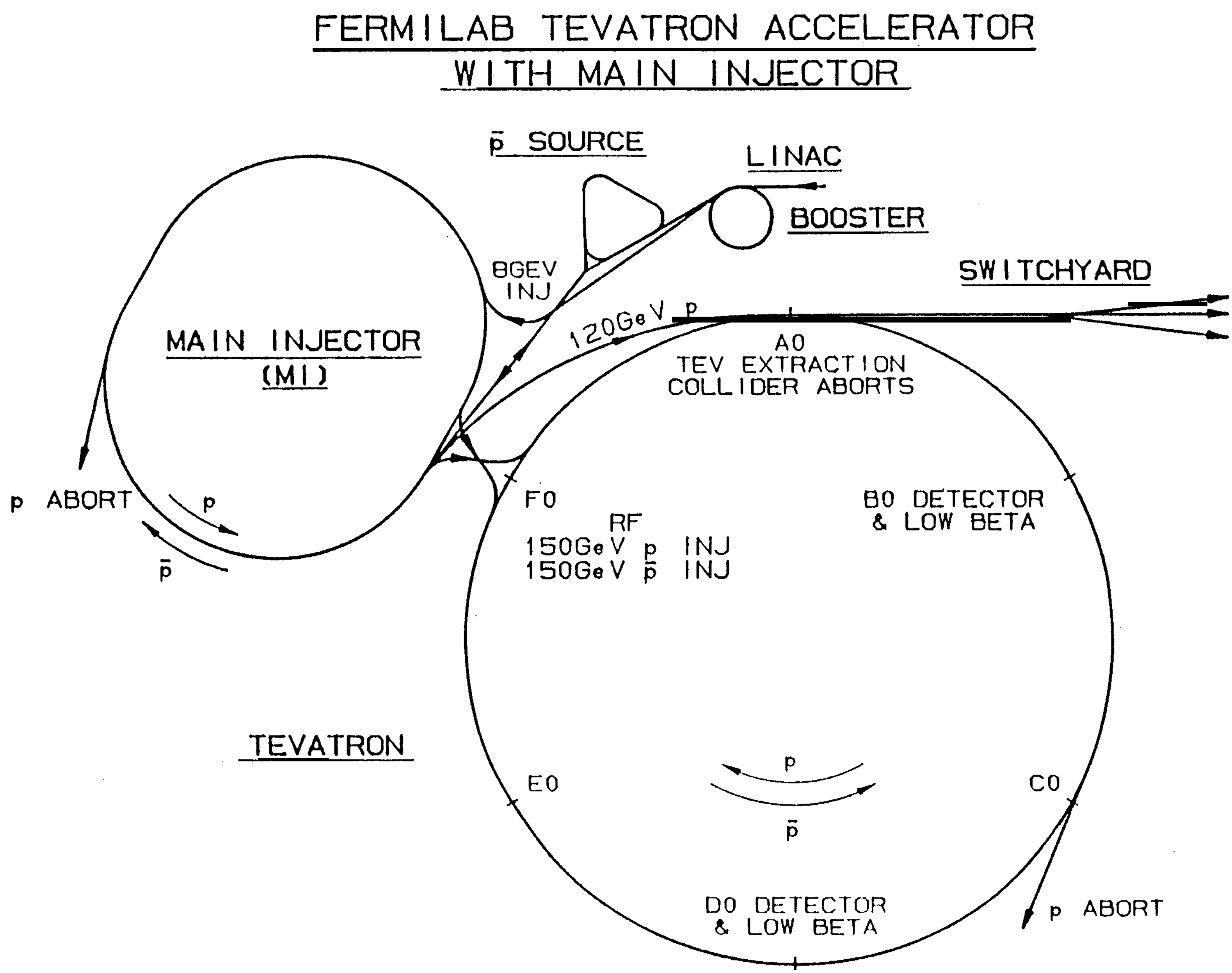


Figure 2. Schematic View of the Main Injector Connections to the Booster, Antiproton Source, Tevatron and Switchyard.

Order, Class II Geodetic Leveling Accuracy Classifications in the current North American Vertical Datum 1988 (NAVD 88) as defined by the Federal Geodetic Control Subcommittee [2].

3.2. Absolute tolerances

The absolute placement tolerances require the positioning of each beam component on the local projection around the FMI ring within a horizontal and vertical envelope of +/- 2mm of the ideal position [3].

The circumference tolerance is defined as +/- 5mm. This tolerance, being at the very limit of current measurement technology to control it, is still in negotiation and can possibly be redefined to +/- 10mm with little or no effect on the performance of the machine.

3.3 Relative tolerances

Table 1 defines the relative alignment tolerances of the quadrupoles and dipoles to adjacent components [3].

Table 1

Component type	Horizontal/Vertical	In Beam Direction	Roll Angle
Quadrupoles	+/- 0.25mm	+/- 3mm	+/- 0.5mrad
Dipoles	+/- 0.25mm	+/- 3mm	+/- 0.5mrad

4. GEODETIC SURFACE CONTROL NETWORK

Ten concrete pillar type monuments with forced centering devices constitute the framework for the surface control network. Nine of these monuments surround ten vertical sight riser shafts or drop points to the tunnel. The tenth concrete monument is installed near the center of the FMI ring, forming a strong polygon (Fig. 3). To date, three precise control surveys have been accomplished; the first, in the spring of 1992, transferred the relative position of the Tevatron F-0 point and F-0 straight section azimuth to the surface control to lay out the MI-60 initial point and azimuth. The second, completed in the fall of 1993, defined the relative position of six of the ten concrete monuments to the 1992 survey. The third, completed in the spring of 1995, defined the relative position of all ten monuments to the original F-0 survey and repeated the 1993 survey. This strategy yielded data for deformation analysis on the common monuments over a two to three year period. Results of the deformation analysis showed no detectable movement within the network adjusted error ellipses of +/- 1mm [4].

A fourth precise survey is scheduled for 1996 at which time all ten concrete monuments and ten sight riser drop points will be incorporated into a network to provide absolute positioning for tunnel control system constraints at the +/- 1mm level. Astronomic observations will be performed as required.

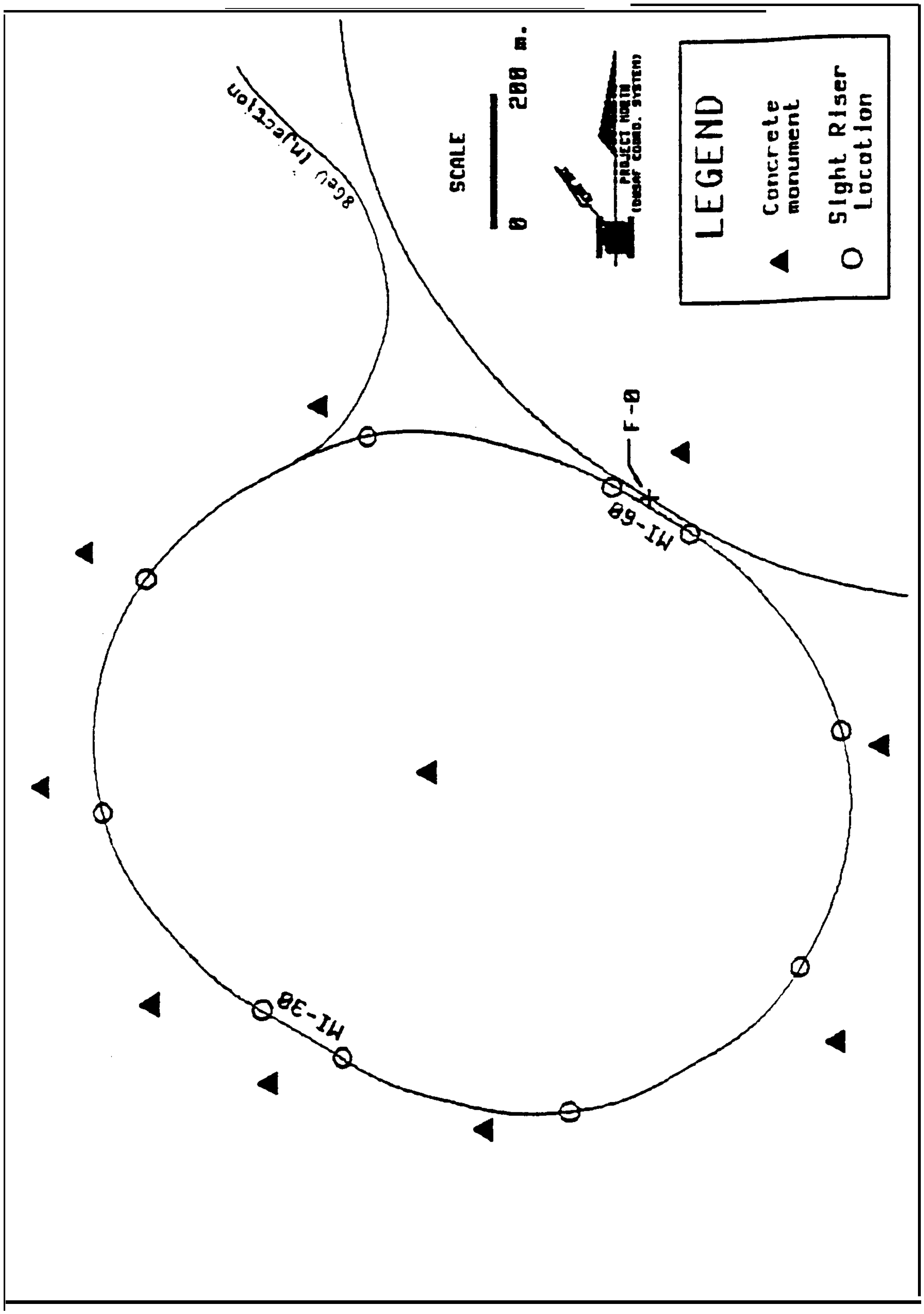


Figure 3 Surface Control

5. TUNNEL CONTROL SYSTEM

5.1 Geodetic considerations

For underground surveying purposes a double stereographic projection was chosen to map the GRS 80 ellipsoid coordinates onto a conformal mapping plane at the elevation of the tunnel. All underground surveying and alignment activities will take place near the perimeter of this projection. Special care was taken not only to minimize and standardize the scale distortions, but also to correct for the effect of variation in ellipsoidal height around the ring [5].

5.2 Monumentation

Considering the dynamic nature of the tunnel control system due to deformation, thermal conditions, other environmental factors and especially the ability to detect these small movements with today's instrumentation, a strategy was adopted using inexpensive yet durable monuments. The ~200 floor monuments will consist of a stainless steel bolt with a precision hole in the machined top to receive a standard Hubbs 1 1/2 inch laser tracker nest. Repeatability tests show no significant errors develop using this technique. The cost for hardware and labor for installation are reduced by nearly 5 times. Monuments are placed at intervals of ~17m around the ring. Elevation bench marks are placed on the inner wall between every second monument. Adapters enable the use of the bench mark as a pass point in the final laser tracker network thereby effecting a gravity referenced system for the laser tracker.

5.3 Secondary tunnel constraint network

To provide additional constraints for the final tunnel control network, a ME-5000 and Kern E-2 precision traverse will be performed and adjusted between adjacent sight riser drop points. This survey will utilize the longest sight lines possible, taking no more than five stations to close between any two sight risers. Azimuth control will be provided using a gyro-theodolite.

5.4 Tunnel control network

The final control network will utilize a system of braced quadrilaterals enveloping the volume of the tunnel between the constraint points and incorporating all floor monuments and bench marks. Since alignment of magnets will begin before the entire tunnel control network is measured with laser tracker instrumentation, the constraint points are necessary to control the immediate region for initial alignment of the components. Once the entire tunnel control network has been measured a block adjustment will be performed.

6. MAGNET FIDUCIALIZATION AND ALIGNMENT

6.1 Methodology

The method of magnet fiducialization and alignment procedures adopted for the FMI project was chosen for its ability to apply the latest most accurate measurement instrumentation and computer technology, while still maintaining optical tooling alignment capabilities for quick magnet change-outs to minimize down time. Three major factors led to the acceptance of a method termed the One Fixed - Four Random (1F4R) system. First, the physical centerline of the steel laminations define the magnetic centerline of each magnet. Second, the magnets are constructed to published tolerances, the mean values being +/- 0.002 inches radially and +/- 0.003 inches vertically. Third, since the 1F4R system references each magnet as it is being aligned into its slot in real time, the costs associated with hardware, labor for installation and referencing are not necessary, representing a major savings in dollars.

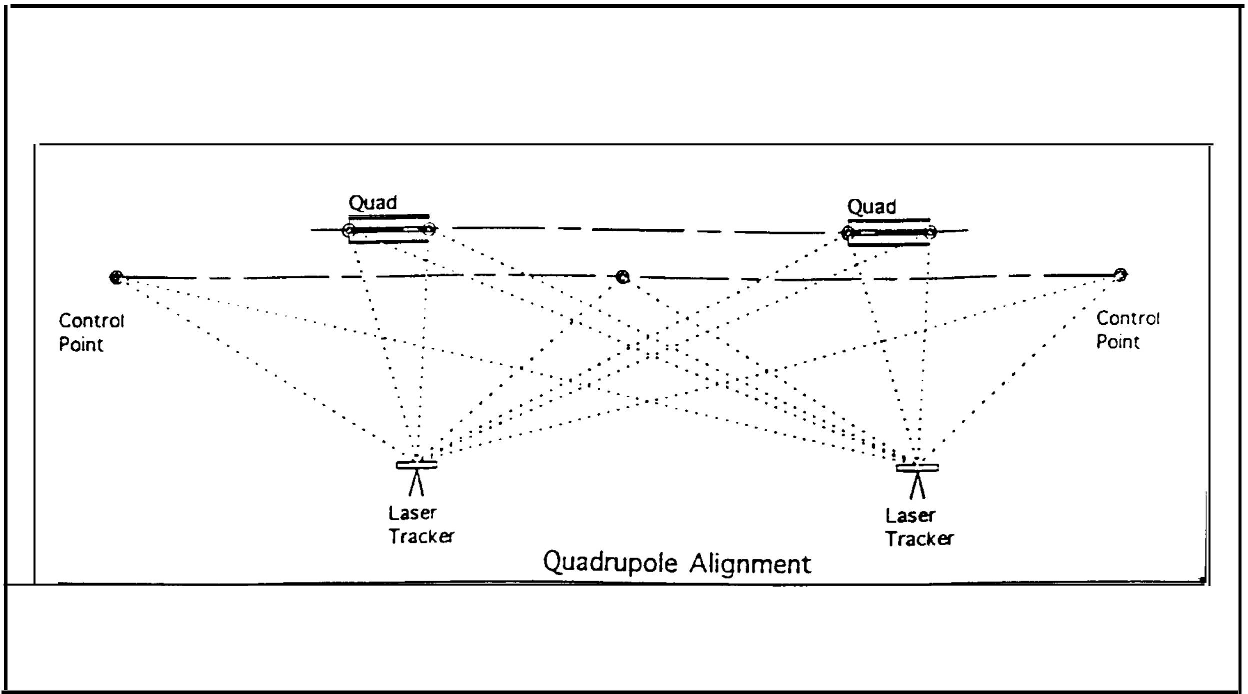
6.2 Theory

The success of the 1F4R system will be dependent upon a computer database containing the entire FMI spacial parameters, ideal magnet models and the beam lattice. This database will interact in real time with application software (now under development) containing the necessary algorithms to actually align each magnet into its proper slot. The one fixed point that is required for this system to work is placed at the longitudinal centerline of each magnet to an accuracy of one lamination or ~1.5mm. This fixed point is not required to be located accurately in the radial direction. The four random points (mobile fixtures accepting a standard laser tracker nest) will determine each magnets radial alignment.

6.3 Alignment procedure

Fixtures will be placed on each of the eight dipoles and three quadrupoles that make up one observation session or laser tracker setup. One fixture on each magnet will be placed on the fixed (1F) point and four fixtures will be placed on each magnet at four random (4R) points at or nearly at a position directly above the support stands [6].

The laser tracker will be positioned and oriented into the tunnel control system (TCS) at a point nearly perpendicular to a quadrupole magnet. This allows the strongest measurement to take place at the most critical component using optimum geometry. From this setup all 55 fiducials comprising this observing session will be measured. The software will compute each magnets geometry, compare it to the ideal magnet model in the database to alert the operator of any misplaced fixtures or other spacial problems and compute the offsets required to place each magnet into its slotted position according to the beam lattice. All eight dipoles and three quadrupoles will be rough aligned from this setup. However, only the quadrupole nearest the setup and the two adjacent dipoles will be final aligned. For redundancy, each quadrupole and dipole will be observed from three independent setups, each setup being adjacent to a quadrupole (Fig. 4). The redundant measurements provided from multiple observations will be used in the final smoothing process.



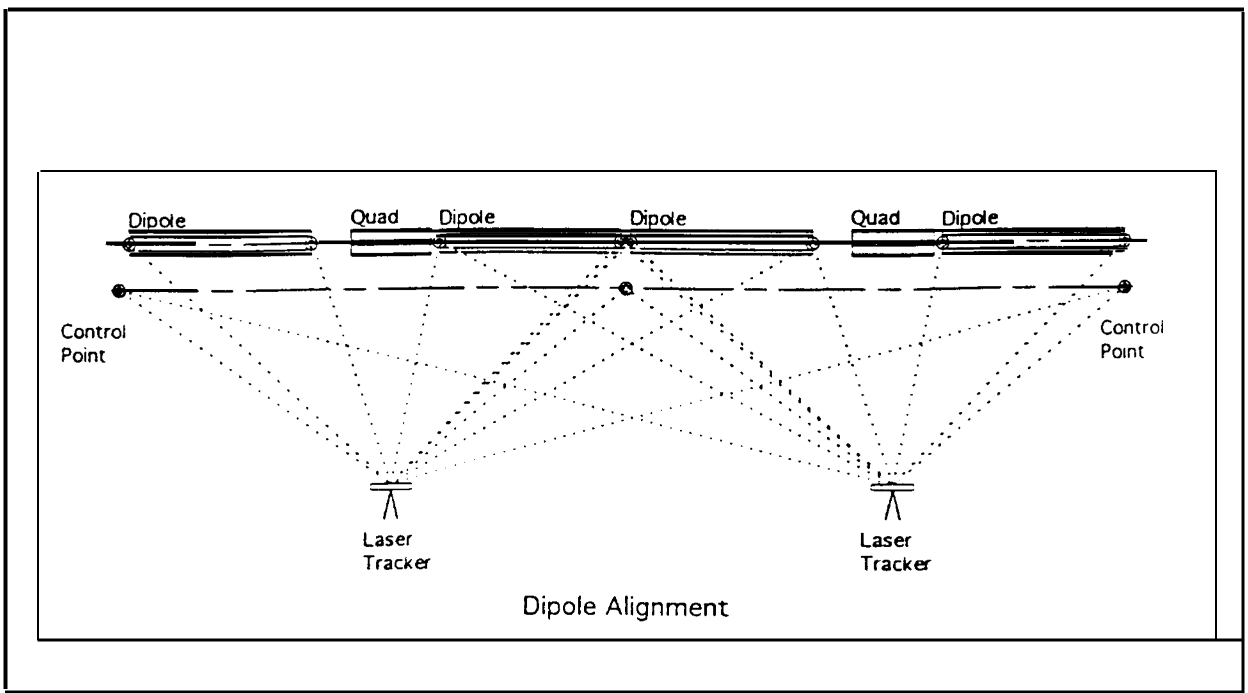


Figure 4 Magnet Alignment

7. QUALITY CONTROL

A total database management system, quality control - quality assurance, and deformation monitoring procedures are now being developed.

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