POLAR COORDINATE ALIGNMENT OF THE MAGNET STANDS IN THE BO OVERPASS REGION OF THE FERMILAB MAIN RING.

C. D. Moore and T. A. Topolski
Fermi National Accelerator Laboratory
P.O. Box 500
Batavia, Illinois 60510

Abstract

We describe the three-dimensional alignment of the magnet stands in the nonplanar region of the Fermilab Main Ring near BO. Polar coordinate measuring from a single set-up utilizes two angles and a distance to locate a point in space. We discuss the procedures and equipment utilized, as well as the accuracy and effectiveness of this style of alignment.

Introduction

In order to accommodate large detectors for pbar-p physics in the Tevatron, the Main Ring has been modified to be nonplanar. A 1700-foot long portion of the ring has been reworked to create an overpass at BO, which displaces the beam orbit upwards by 19 feet and radially inward by two feet. A large fraction of this overpass is in a newly constructed tunnel.

Based upon our experience with the smaller overpass at DO, we knew that the placement of the stands (including the cups, Fig. 1) was a crucial ingredient for the smooth installation of the magnetic elements. A swift installation was necessary to meet schedules due to the amount of time spent waiting for the tunnel to stop settling from the massive civil construction.

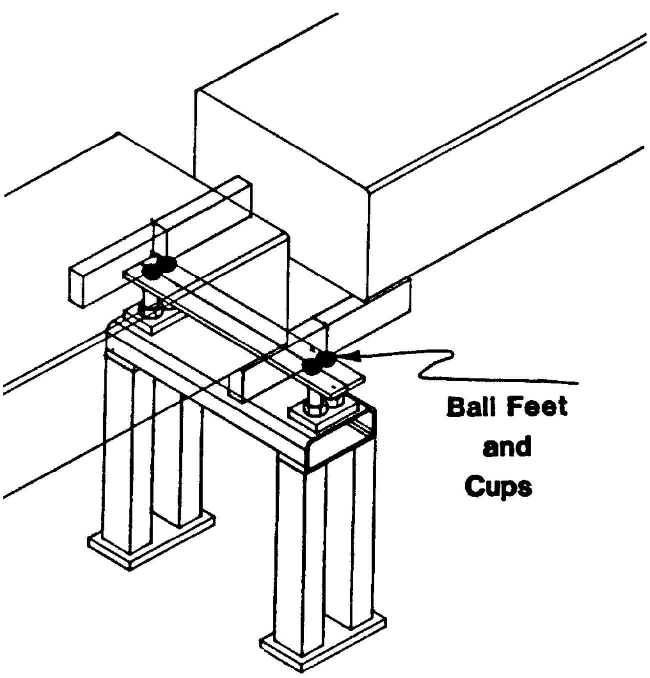

Fig. 1 Magnet stand schematic

Coordinate system

Every element in the tunnel is referenced to the same sets of benchmarks (radial, vertical). The radial benchmarks are, in fact, at the bend centers of the Tevatron (Fig. 2). However, to lessen the chance for confusion, the Main Ring is referenced to the same monuments. The overpass does not follow the same pattern as the rest of the Main Ring, and thus, it is not an extra problem to use a reference system which is not based upon the Main Ring.

There was a problem associated with using the radial monuments: the overpass was mainly located in a separate tunnel, and due to the inward sweep of the overpass (to keep the circumference the same) some of the overpass elements were physically located over the radial plugs. Hence, a new set of radial plugs were installed 30" to the radial inside of the old system (Fig. 2), and provision was made in the construction to have vertical sight tubes located over the new plugs

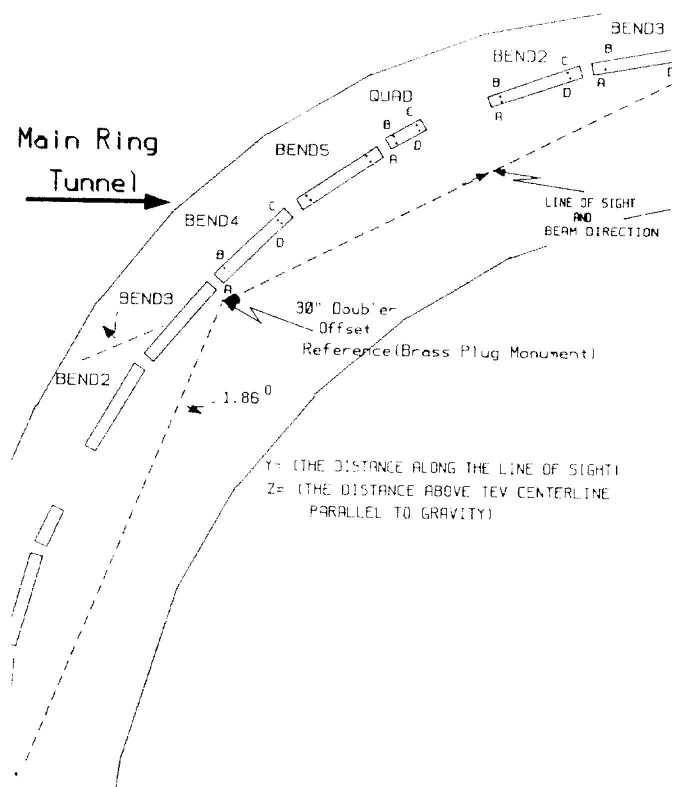

Fig. 2 Schematic of the Radial Monument System

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The elements are aligned using chord offset measurements, with separate measurements for longitudinal distances, radial offsets, and vertical offsets. Hence, one can easily generate coordinates of any point on a magnet (e.g., the tip of the ball foot) in the coordinate system depicted in Fig. 3, where the y-axis is along the line joining two adjacent radial monuments, the z-axis is parallel to gravity, and the x-axis forms a right handed coordinate system. However, as Fig. 3 indicates, a point defined in these cartesian coordinates, when expressed in polar coordinates , is defined using the natural angles that a theodolite would use. This observation led to the consideration of a polar coordinate measuring system.

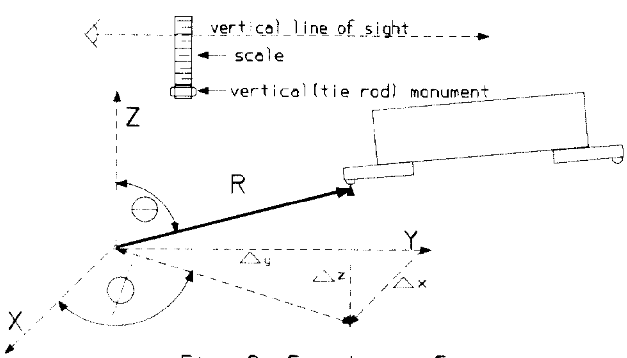

Fig. 3 Coordinate System

Justification

The main problem with polar coordinate measuring schemes is the inaccuracy of distance measuring. However, the accuracy (+/-0.060") is sufficient for stand placement, especially in view of the tolerance of the positioning of the ball foot supports with respect to the steel of the magnet(the magnets had their ball feet reworked to remove gross misplacement, >0.120"). Furthermore, each half-cell was set from an independent setup using the sight tubes, so there was no accumulation of longitudinal error.

There were four cups to be placed on a stand, all at slightly differing longitudinal distances. The main systematic error with the infrared distance measuring system is associated with distances much larger than the cup spacings on a stand[1] . When we take into account the difficulty of accurately taping and marking four places along the sloping floor, making a direct measurement of spatial distances is a great advantage for a quick measurement.

The decision was made to use a polar coordinate system for aligning the stands, because it is intrinsically faster, with one setup versus three setups for normal alignment, uses fewer people, and has the desired accuracy for stand placement.

Equipment

The equipment used to do the polar coordinate measuring included a Kern E-2 theodolite, a Kern DM-503 distance meter with pentaprism reflector, magnet stand prism fixtures, and a Hewlett Packard HPCV programmable calculator. The Kern E-2 theodolite is a 32x telescopic instrument that electronically reads and displays horizontal and vertical angles to one-second of arc, and transmits and receives data via a built-in I/O port. The DM-503 transmits and receives infrared signal for measuring distances, and electronically outputs data to the E-2 for display and data transfer. The magnet stand fixtures (Fig. 4) are simple devices that allow targets or prisms to rotate about the centerline of a point six inches above the point of reference. The HPCV calculator was programmed to hold a half-cell of magnet support points (20 points, with three values per point and an alpha-numeric identifier). The points were stored in the cartesian coordinate system described above and converted into polar coordinates after the height of the instrument was recorded.

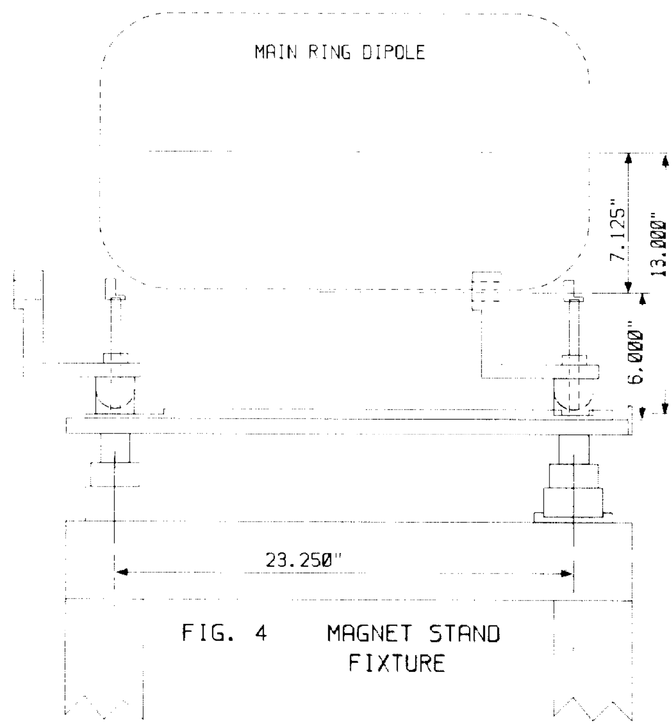

FIG. 4 MAGNET STAND FIXTURE

Calibration

Before using these instruments and fixtures for polar coordinate measuring, the accuracy of measuring was established. The electronic E-2 theodolite measured vertical and horizontal angles repeatedly to +/- 2 seconds of arc, which is well within the accuracy needed for preliminalry alignment.

An in situ procedure was developed to check the Kern DM 503 distance meter, i.e. we made the measurements in the tunnel at the distances that would be involved in stand placement. The calibration procedure began with stretching a steel tape between two radial monuments until it agreed with the known distance between the plugs. Using an optical plummeting Wild tribach with a DM 503 prism, prism locations were established by reading the steel tape with the plummet. Then the DM 503 was mounted on the theodolite and infrared distance measurements to the prism were made ten or more times per positon. The readings were averaged and compared to the respective plummet readings to the steel tape. The difference between the infrared distance and the tape reading was used to calibrate the DM-503 distances. As noted above, the distances measured were representative of the distances required for support stand locations for the BO overpass magnets. The differences between the tape readings and the infrared readings ranged from approximately 0.21" to 0.38". An accumulation of errors approximating 0.2" was attributed to mismatches between the DM-503 transmitter center, the prism centerline, the centerline of the prism mount, the centerline of the tribach, and the centerline of the optical plummet. These errors were easily rectified by turning dials on the DM-503 to electronically calibrate the DM-503 to match the test setup and base line. To guarantee the mismatches are accounted for, system checks against known base lines were added to the operating procedure. Another source of error appeared to be related to the Kern power supply system. Without using the battery and running on just the Kern converter and regulator, and after making the dial adjustments, the accuracy of measurements was approximately +/-0.06".

Operating Procedure

The operating procedure includes a setup procedure and a measuring procedure. The setup procedure is mainly concerned with defining the coordinate system in which the measurements will take place. The E-2 is optically plummetted over a radial monument, thereby defining x=0 and y=0. After the height of the instrument (HI) is found by rotating the scope to read ninty degrees and reading a scale mounted to the nearest vertical monument, the HI is entered into the HPCV stands program. The origin of our coordinate system has now been completely specified. Next, the Kern reflector prism coupled to the magnet stand fixture is positioned over the next radial monument using an optical plummet. After pointing at the prism target and setting the horisontal angle, we have oriented our coordinate system (utilising gravity also). At this stage, the distance between the two monuments is measured as a field check of the DM 503.

The measuring procedure starts with reading magnetic cards with the magnet ball feet coordinates into the data base of the HPCV stands program. After a point has been chosen, the theodolite was rotated to the horisontal and vertical angles given by the program. With the support stand fixture and prism in place, the stand's longidudinal position was adjusted to agree with the program calculated distance. The prism was then replaced with a target and the horisontal and vertical positions were adjusted. Periodically pure radial or vertical offsets were measured to double-check the integrity of the HPCV stands program.

Results

Using this three-dimensional system for this intrinsically three-dimensional operation, the support stands were positioned to an accuracy of +/-0.060". It took approximately 15 man/days to set and anchor the 82 stands (with four points per stand) from A42 to B18. On the magnets, the ball feet placement with respect to the magnet steel was not precisely controlled; however, the longitudinal spacing between ball feet was well controlled. Hence, a definite proof of the accuracy of the alignment procedure was the fact that the Main Ring magnets were placed on the stands without having to make adjustments due to placement errors, thereby expediting the installation of the overpass.

References

1. L. Ketcham, "Private Communication"