PBAR NOTE #468

# TEV I SURVEY PLAN

Arlene Lennox

# CAVEAT

The following note was written in the Fall of 1984 in an attempt to clarify in my own mind the plan to be used for aligning TeV I Magnets. As it turned out the scheme described here was used as planned, so the document is accurate even though it is incomplete.

I submit it to the pbar "library" because I think it would be a good introduction for anyone involved with TeV I alignment. Of course, specific details and lists of coordinates of reference marks would have to be obtained from Fermilab's Alignment Group.

A. J. L.
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# TEV I SURVEY PLAN

by Arlene Lennox

## Introduction

The ultimate goal of the survey work is to position magnets and other devices in the Tev I rings and transport lines as accurately as possible within the physical constraints of the system and the limitations of the measuring instruments. Time spent devising a good reference system and simple methods for aligning the devices should pay off in time saved during the actual installation and alignment. It is anticipated that the floor may continue to move for some time after the initial magnet installation. Hence the method used should be such that it is easy to detect floor motion and make the appropriate position adjustments in a systematic manner. This paper first describes the reference systems and alignment techniques for the rings and then summarizes some of the measurements which have already been made.

## I. REFERENCE SYSTEM

The coordinate system used is the Fermilab site coordinate system, with the x-axis parallel to "lab East" and the y-axis parallel to "lab North". The coordinates of A0 are given by (100000., 100000.) ft. Positive z is in the upward direction, the origin of the z axis being at sea-level. Elevations (z) in the tunnel are established by means of tie rods mounted on walls in the tunnel.

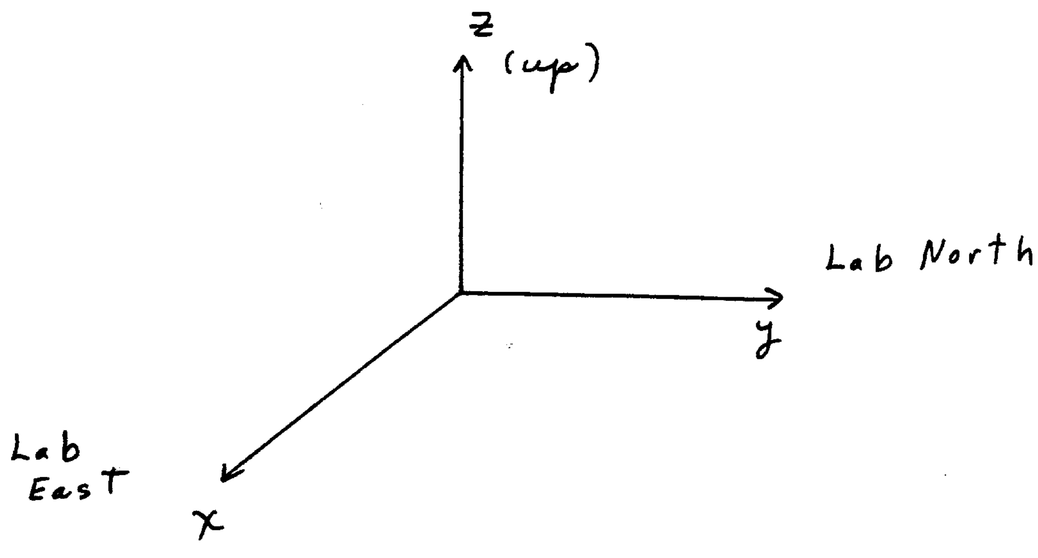


Fig. 1.

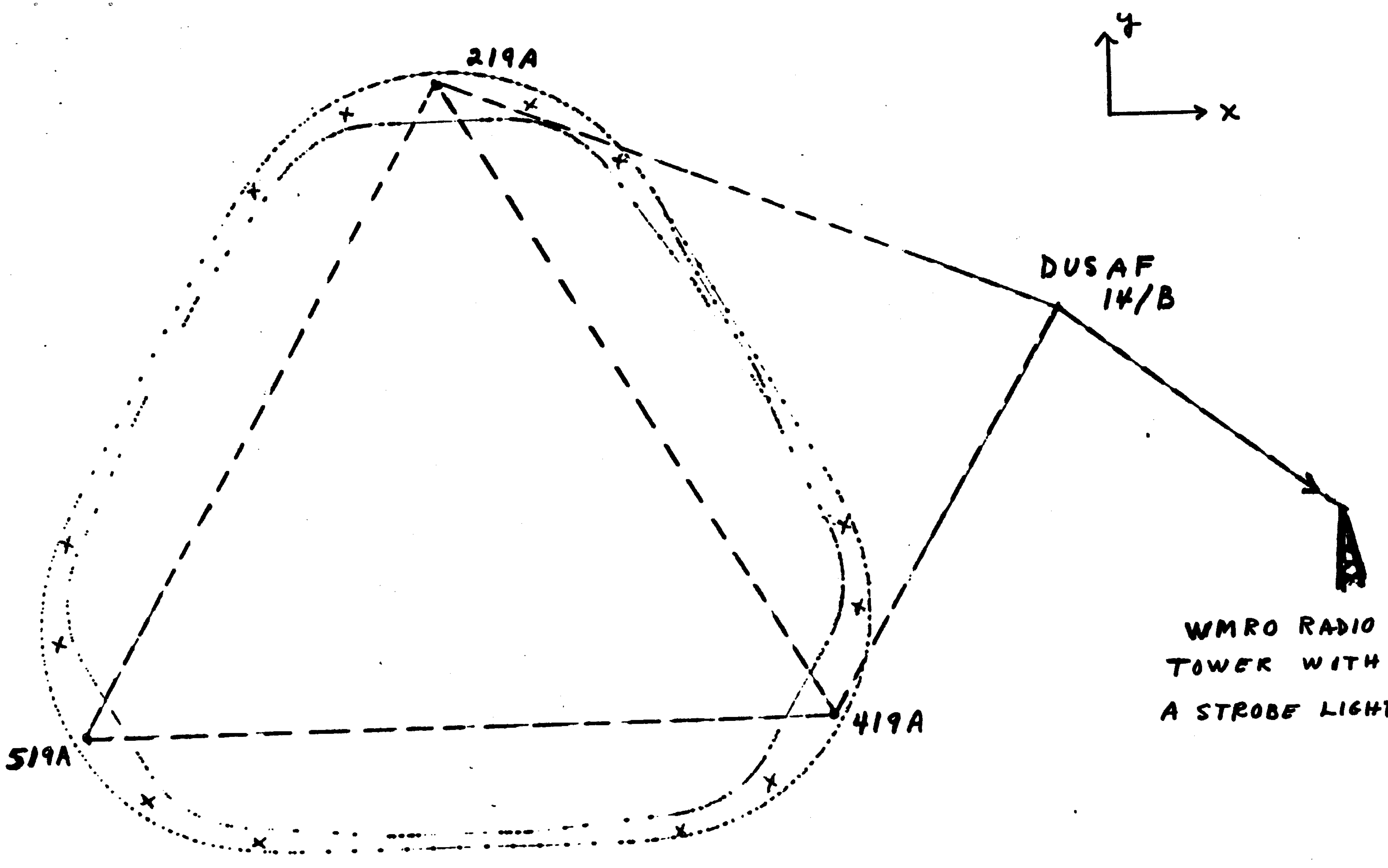


Fig. 2. Primary reference points are connected by dashed lines. Secondary points are shown by crosses.

(x,y) coordinates are located by means of punch marks in brass plugs installed in the tunnel floor. These plugs are categorized as belonging to the primary system, the secondary system or the magnet alignment system. This section describes the method of establishing each system.

## IA. Primary Reference System

As is seen in Fig. 2 the Tev I tunnel is roughly triangular. The primary system includes a point in each "corner" of the triangle and two outside the tunnel. The three points in the tunnel are visible from the outside through vertical pipes which extend up through the tunnel ceiling and the shielding berm. No two are on a direct line of sight from either outside or inside the tunnel. DUSAF 14/B extends ~ 40 feet into the ground and its position with respect to other DUSAF monuments on site is known to better than one part in 50,000. The radio tower is ~ 4.5 miles from 14/B and the direction of a line between it and 14/B is known to better than two seconds of arc with respect to lab North. Using 14/B as the point of beginning and the direction to the tower as a known bearing the two triangles in Fig. 2 are traversed and closure is forced using the compass rule adjustment. Measurements and calculations are made in accordance with a document entitled "Classification, Standards of Accuracy, and Specifications for Geodetic Control Surveys", which is taken from the Code of State Regulations of the State of Missouri. The procedures used for setting the control points 219A, 419A and 519A correspond to second order, first class measurements with a minimum relative accuracy between directly connected adjacent points good to 1 part in 50,000 and a maximum value of the error ellipse semi-major axis of 95% confidence region with respect to any two stations of the survey good to 50 ppm. The time required for three persons to complete a measurement of the primary reference system and perform the associated calculations is two eight-hour shifts. Best accuracy is obtained if these shifts occur at night or in the early morning hours.

## IB. Secondary Reference System

The secondary system consists of twelve additional brass plugs installed in the floor, with two plugs on either side of the three primary points. Their positions are sketched as crosses on Fig. 2. Using theodolites and calibrated Invar tapes the 15 points are traversed and closure is forced, with the requirement that the coordinates of 219A, 419A and 519A remain fixed at the values determined from the primary survey described in part IA. This operation requires four shifts of three people and produces a set of coordinates with each point known relative to any other to better than 1 part in 50,000.

## IC. Magnet Alignment system

Positioning a magnet involves locating it with respect to the x,y plane and setting it to the appropriate elevation. The corresponding reference systems are described separately.

### I.C.1. Alignment System in the (x,y) Plane

This consists of two sets of brass plugs, one for the Accumulator ring and one for the Debuncher ring. In each ring a brass plug is installed near each bend point such that reference lines connecting these plugs are parallel to the quadrupole axes. For the Debuncher the offset between a quadrupole axis and its associated reference line is 36 inches except near the stairwells where the walls obscure the line of sight. In these areas the offset is 30 inches. In the Accumulator the offset is 40 inches. The magnet alignment brass is installed relative to the primary/secondary reference plugs. The positions are checked carefully with respect to the local reference brass but an overall ring traversal and closure are not required for the magnet alignment brass. Distances between any two points in the magnet alignment system are known to better than 1 part in 20000. There are 66 Debuncher dipoles and 30 Accumulator dipoles, giving a total of 96 points in the magnet alignment system. Initial installation requires four persons working for one month because of the time required to drill the concrete and install the plugs, besides the normal survey work involved in locating the points. Should the punch positions need adjustments as a result of subsequent floor movement the work could be completed in two weeks by a crew of three persons.

### I.C.2. Elevation Reference System

Reference marks for setting the magnet elevations are tie rods mounted on walls near the stair wells. Their absolute elevations are determined by referencing to the outside via vertical riser pipes in the tunnel ceiling.

## I.D. Corrections for Horizontal Floor Movement

If a subsequent survey of the primary reference system indicates movement of any or all of the primary points 219A, 419A or 519A existing software can be used to calculate the corresponding shifts in magnet alignment brass. If the shift is significant the secondary system would be resurveyed and the new coordinates would be used as references for placing new punch marks in the magnet alignment brass. It would require two weeks for a three person crew to grind and re-punch all of this brass. However it is, of course, possible to adjust only a subset of the alignment brass if the floor movement is significant in only a portion of the tunnel.

## II. ALIGNMENT TECHNIQUES

In general, the alignment procedure involves positioning a magnet correctly in the x,y plane, adjusting the elevation and adjusting the rotation angle to minimize the effect of magnet twist. Though the process is iterative the techniques will be discussed separately.

### IIA. Quad Alignment With Respect to the (x,y) Plane

A scheme for positioning a quadrupole is shown in Fig. 3. Points 1 and 2 are punch marks in the marks in the magnet alignment system brass.

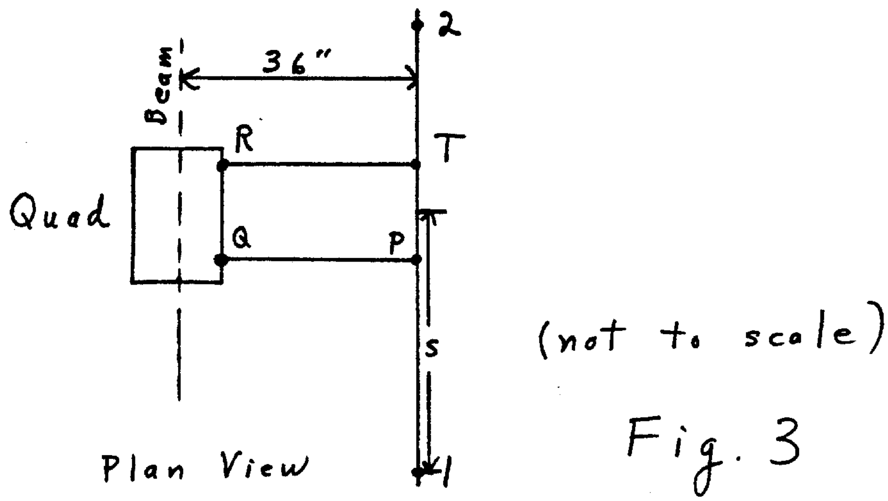


Fig. 3

The longitudinal distance, s, from point 1 to the center of the magnet steel is measured using a steel tape, with an accuracy of about ±30 mils. This is adequate with respect to the beam optics and further adjustment in this direction need only be made to accommodate welding the vacuum system, if necessary.

Positioning in the transverse direction is done as follows. A Brunson transit mounted on a hollow-axis instrument stand can be located over point 1 to within a few mils, the error being determined by the ability of the surveyor to see the point, rather than errors in the instrument itself. A line of sight between points 1 and 2 is established. A scale is held against a lamination at point Q and the distance from Q to P is read through the transit. A leveling bubble mounted on the scale is used to assure that the scale is level. The scale is pivoted back and forth about point Q and along the line of sight until a minimum reading is observed. The transverse position of the quad is adjusted until the distance PQ is correct. The same procedure is used to set the distance RT. At this point PQ is checked again and the procedure is repeated until both PQ and RT equal the calculated design value to within 2 mils. For every quadrupole in the rings the reference line is parallel to the magnet so the choice of the longitudinal position of points R and Q is not critical though the iterations will proceed more quickly if the points are chosen near the magnet stand positions.

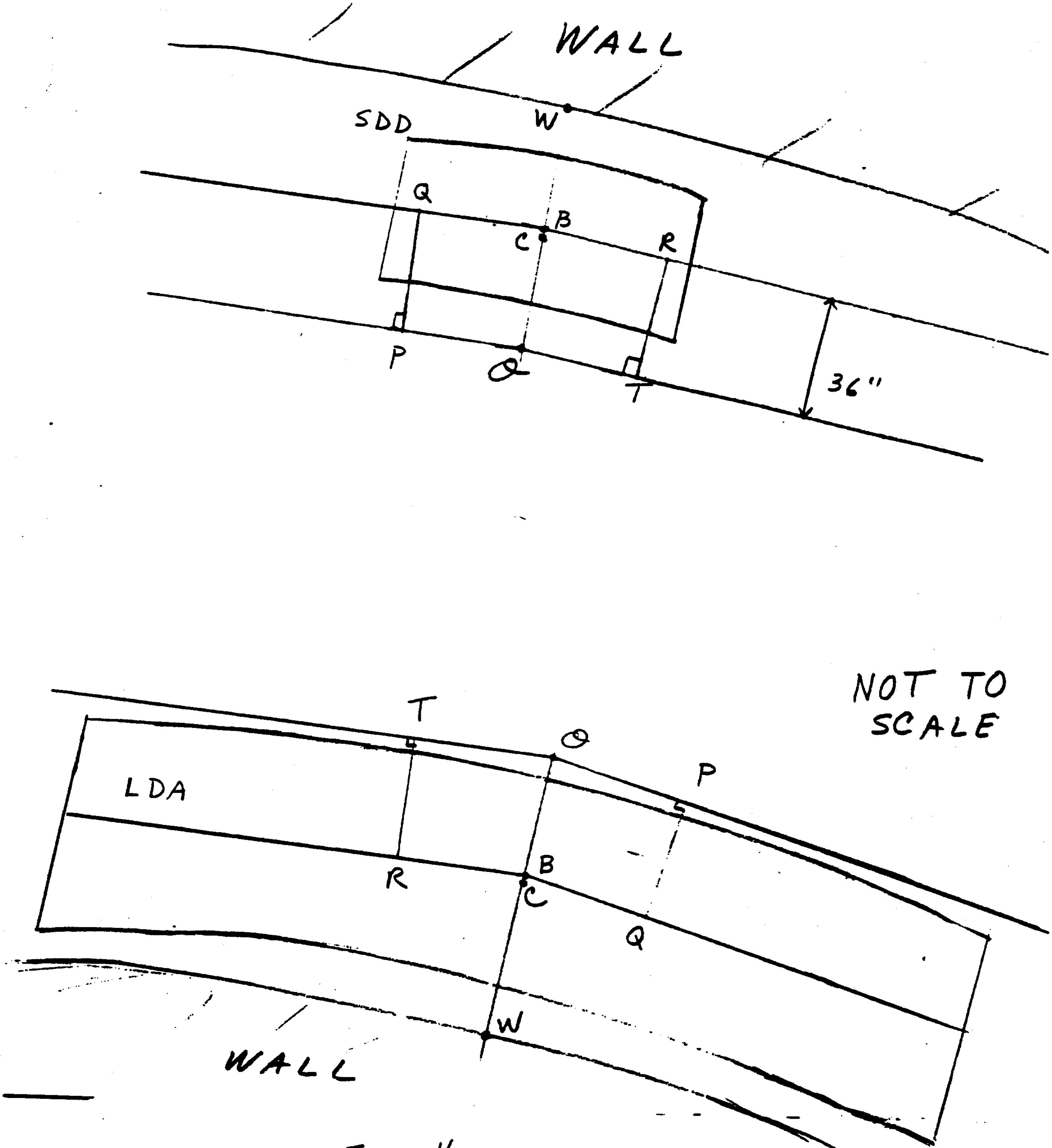


Fig. 4

## IIB. Dipole Alignment With Respect to the(x,y) Plane

Considering only beam optics the position of the dipole bend center along the beam is critical whereas distances corresponding to PQ and RT in Fig. 3 are relatively unimportant. However, as a practical matter the vacuum pipe through a dipole must be welded to one passing through a neighboring quadrupole. Hence, it is desirable to set the dipole position perpendicular to the beam as accurately as one sets the quadrupole position. Fig. 4 shows the geometry of Debuncher and Accumulator dipoles. The points labeled O are punch marks in the brass magnet alignment plugs. To establish the position of the bendpoint B along the beam directions a specially modified hollow-axis Kern DKM-2 theodolite is positioned over point O and is adjusted so that O is on the vertical axis of the theodolite within a circle of radius 2 mils. This is done by directly viewing O through the scope. (It should be noted that the ordinary Kern DKM-2 can be positioned only to within a radius of 5 mils while the Wild T-2 can be set within a radius of 20 mils. In the latter two cases point O would be viewed through a prism rather than directly. This accounts for the difference in positioning errors.) The lines OT and OP are defined by sighting to the upstream and downstream bendpoints immediately adjacent to O and the angle POT is turned and bisected. Then the point W is marked on the wall. This procedure will be done once for each of the 96 offset bendpoints. For the initial survey the points W will be established before dipoles are moved into the tunnel. The error in installing these points ± 3 mils. To position the dipole in the $\hat{s}$ direction a Brunson transit on a hollow-axis instrument stand will be mounted over O and a line of sight toward W will be established. A target will be mounted in a reamed hole (O.D. = .5" $^{-0}_{+0.0005}$)at C, the center of the top of the magnet. The magnet will be moved until C is on the line of sight. Before the Brunson is positioned at O two other Brunsons positioned over each of the adjacent bendpoints will have established lines of sight along PO to TO. With all three Brunsons in place the distances PQ and RT will be adjusted and the position of C checked in an iterative fashion. A fixture mounted on the top of the dipole and centered on a pin at C will determine the points Q and R to within a few mils. A sketch of this fixture is given in Fig. 5. The fixture is in the custody of the lab Alignment Group.

## IIC. Elevation and Twist

For both quadrupoles and dipoles, the elevation is set by mounting vertical scales at four positions on the top of the magnet and reading the values using a Wild N-3. Ideally the plane of the top of the magnet should be parallel to a plane defining the magnet elevation. In fact there are imperfections in the way the magnet laminations are stacked and there can be an overall twist in the magnet, particularly in the longer dipoles. Hence, the process of setting the elevation will be iterative and could disturb the setting in the (x,y) plane. It is anticipated that the instruments used for setting the (x,y) position will remain in place as the elevation is adjusted and the magnet will not be considered aligned until the overall position is good to within previously described tolerances.

(Note: A fixture for measuring twist was designed later. It is in the custody of the Lab Alignment Group)

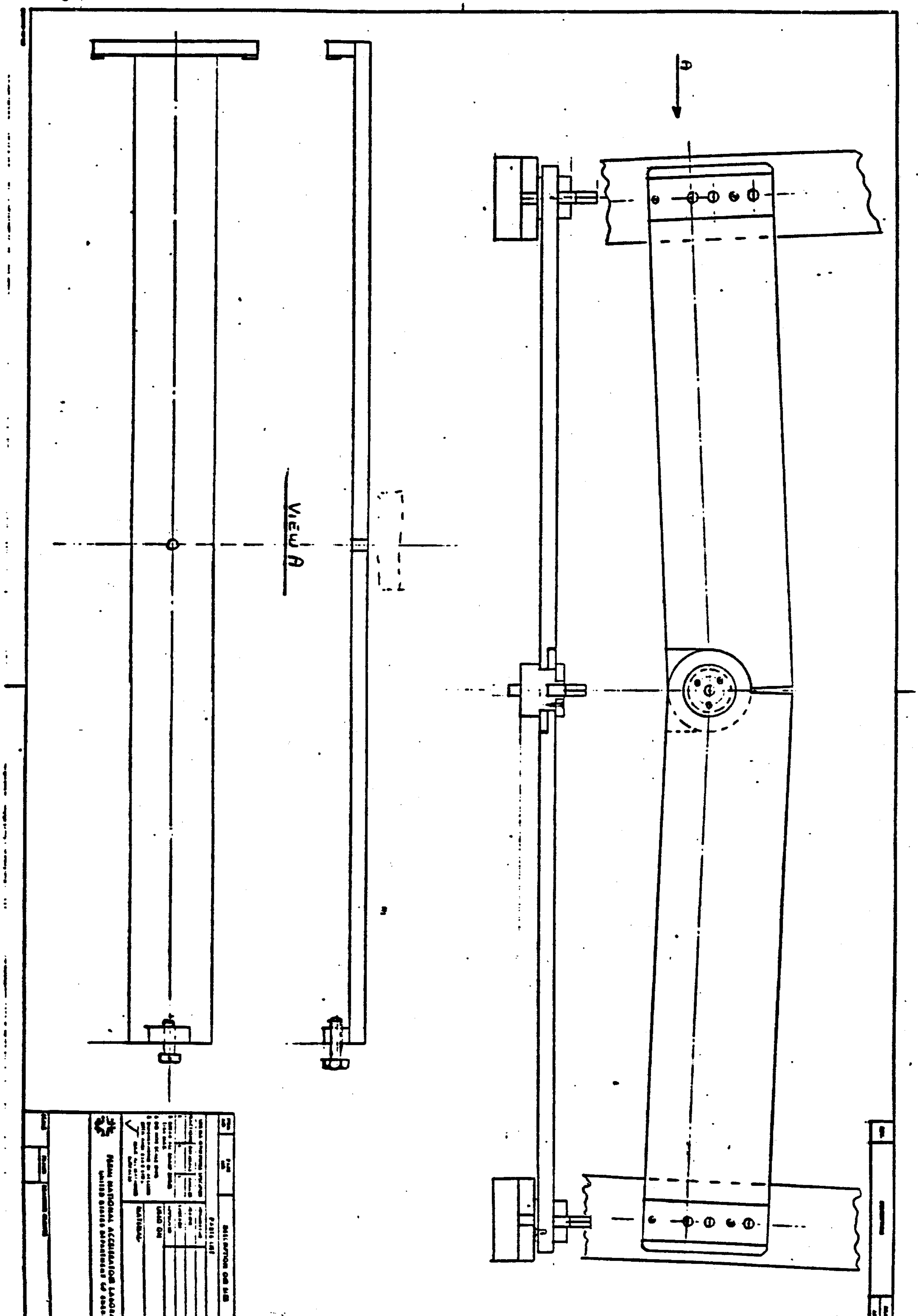


Fig 5

## III. SOME EARLY RESULTS

At the time of this writing no magnets have been installed in the tunnel and a serious effort to precisely align a magnet has not been made. It is not clear that the stands are adjustable in fine enough increments to actually position the magnets with an accuracy comparable to the tolerances described earlier. It is also possible that the four-point suspension design for the quadrupole stands may permit movement perpendicular to the quad axis as a result of adjustments being made to set an elevation or remove twist. The desired tolerances may have to be relaxed simply because it would take too long to satisfy them.

On the other hand we have had some positive experiences using and checking the primary and secondary reference systems, whose installation was completed in May, 1984. In July, 1984 during the survey work related to constructing the Booster to Tev I line (AP4) it was noticed that the location of the secondary point 110 A disagreed with the expected location by about a quarter of an inch. The primary points were resurveyed and it was found that the corners of the triangle had indeed moved. The coordinates of the temporary magnet center marks to be used for installing magnet stands were re-calculated relative to the new primary coordinates and the marks were found to have moved radially outward by as much as 0.6 inches. Consequently, for two-thirds of the tunnel the magnet stands were subsequently installed 3/8 inches radially inward from the positions that would have otherwise been used. Later, when the main ring floor was exposed near F17 points on Murphy's reference line were located relative to the primary system. A ~ 2 inch discrepancy was found between the measured and expected values. Using this information the design of the AP1 line has been modified, thus eliminating a targeting problem which would have become apparent only at the time of actually extracting the main ring protons. Finally some results of consistency checks can be presented. In August, 1984 a set of measurements was made corresponding to those described in sections IA and IB. As a check the lengths of the triangle sides were calculated independently based on the two separate sets of measurements. The per cent difference between the two results was 0.0014%. As an indication of the precision involved in installing the primary and secondary reference system it can be noted that before making any adjustments to the raw data a closure was obtained to 0.0011 meters over a traversed distance of 450.5486 meters.

## ACKNOWLEDGEMENTS

In devising this approach to the problem I had many useful discussions with Fred Mills and Jim Michelassi of Fermilab, Larry Ketcham of Anderson Survey Company and John Sendera of Sendera Survey Company.

## REFERENCES

1. The initial survey work at Fermilab was done by Daniel, Urbahn, Seelye and Fuller (DUSAF). It is described by Robert L. Wagner in "Survey Requirement for the 200 BeV Proton Accelerator" which was published in the December, 1969 issue of Consulting Engineer.