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The 1985 Horizontal Survey Part II Magnets

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1. INTRODUCTION

During 1985 a partial survey of the radial position of the AGS magnets was done. The radial survey can be broken into two parts. The first determines the locations of the primary survey monuments in the ring, and is reported in reference 1. The second determines the positions of the magnets relative to the monuments, and is reported here. This second part was interrupted to allow the crews to do a vertical realignment before the AGS turn-on in the fall of 1985. This report shows what has been accomplished so far.

The primary reference for the radial position is the set of 24 control stations, or monuments, placed evenly around the ring, about 110 inches outside the beam line at each 10 foot straight section. The magnets themselves have survey sockets on top, three inches from each end above the nominal magnetic centerline of the magnet. These sockets are measured with respect to the primary monuments to give the radial and azimuthal position of the magnet.

2. MAGNET MEASUREMENTS AND RECONSTRUCTION

The position of the magnets relative to the monuments is determined by four sets of measurements, shown in Figure 1a:

1. Angle at monument, from first magnet socket to next monument.

2. Distance from monument to first socket.

3. Distances between magnet sockets.

4. Perpendicular offsets from sockets to line between monuments.

There is a small amount of redundancy in these measurements, which is used for a consistency check of some of the data.

The offset measurements are incomplete, and although 21 of the 24 half-superperiods have been measured almost completely, the remaining ones are the most difficult since they are in areas obstructed by injection and extraction lines. In addition, within the measured areas there are a few measurements missing or obviously in error; these have been filled in or corrected using using educated guesses, to avoid breaking the chain of coordinate reconstruction and losing the entire half-superperiod of magnets. Thus the data here only show a sample of the radial positions and the quality of the data, but do not show the entire ring.

The positions of the magnets are reconstructed in the local coordinate system where the monument line is the x-axis, and then, using the monument coordinates, transformed to the coordinate system with the origin at ring center. Although such calculations are straightforward, they are shown here for the record:

$$y_1 = O_1 \quad (1)$$
$$x_1 = d \cos\phi \quad (2)$$
$$y_n = O_n \quad (3)$$
$$x_n = x_{n-1} + \sqrt{l_{n-1}^2 - (O_n - O_{n-1})^2} \qquad (n = 2, 3, \cdots 20) \quad (4)$$
$$X_n = X_{mon} + x_n \cos\theta - y_n \sin\theta \quad (5)$$
$$Y_n = Y_{mon} + y_n \cos\theta + x_n \sin\theta \quad (6)$$

where the various measurements and coordinates are shown in Figure 1a. (The measured data and the results of the reconstruction are available in tabular form from the author, and will be published when the measurements are completed). The coordinate system for X, Y, R, and θ has the origin at the center of the ring (actually, the center of the monument circle, as determined in Reference 1).

The original magnetic measurements of the magnets determined an offset, from the survey sockets to a defined magnetic centerline, such that the integrated B·dl for each magnet along this magnetic centerline is the same for all members of a given class (A, B, or C) of magnets (Ref 2). This procedure compensated for differences in the gap, iron characteristics, or exact length of the individual magnets, and for errors in the positions of the socket holes relative to the magnet gap. Since it is the position of this magnetic centerline, not the survey sockets, that is of interest for machine performance, these offsets have to be accounted for in the survey. These offsets range to about 40 mils maximum, with an rms spread of 16 mils, and are taken into acount in the determination of R in table 1.

Figure 2 shows the magnet ring resulting from the data, with the radial errors magnified a factor of 10,000 (so magnets in the design position appear on the circle). Also shown are the monument positions, with their radial errors magnified by the same factor. The magnets clearly have a large amount of scatter from their design positions, and the general trend is that the magnet ring follows the monument figure. This would be expected if any magnets were realigned using the design offsets from the monument line, and not taking into account the distortion of the monument figure. But most magnets have not been realigned since the 1962 realignment, so apparently whatever forces have moved the primary monuments have also moved the nearby magnet piers about the same amount. The relative positions of the magnets and the monuments show up more clearly in Figure 3, where the magnet positions are reconstructed as if the monuments were in their ideal, or design, locations.

Figure 4 shows these radial position errors (and Figure 5 the azimuthal errors) for all measured magnets, showing both ends separately. Also on Figure 4 is a moving 11-magnet average, formed by averaging the error for each magnet and its five neighbors on each side.

The magnet position errors consist of a low frequency part, approximately following the distorted monument figure, with a high frequency magnet-to-magnet scatter, or noise. To better see the noise, the radius for each magnet is compared to the moving average. Figure 6 shows the distribution of radius differences from the moving average. This distribution has a good 'eyeball' fit to a 32-mil gaussian as shown in Figure 6b (the actual rms of the distribution is somewhat higher because of the high tails). This scatter is several times larger than the expected measuring errors and is thus real.

An interesting fact has shown up in the radial error numbers - the magnets, in spite of the large scatter, or noise, in their present positions, seem to remember the offsets for Bdl correction, mentioned above. Figure 7 is a scatter plot of the offset vs. radial error (relative to the 11-magnet moving average), where the radial error has been calculated neglecting the Bdl offset correction. There is clearly a correlation between the two quantities. Figure 8 shows the same thing, but this time the measured positions are corrected for this offset, and the correlation is essentially gone. The amount of the offset correction to add in to make the correlation (the "covariance") vanish exactly can by calculated:

$$r_{corrected} = r_{uncorrected} + k \cdot \text{offset}$$

$$\text{covariance} = \sum (r_{corr.} \times \text{offset})$$

$$= \sum (r_{uncorr.} + k \cdot \text{offset})(\text{offset})$$

$$= 0$$

$$\Rightarrow \; k = -\sum (r_{uncorr.} \cdot \text{offset}) / \sum (\text{offset})^2$$

Doing the sums over the data (and omitting several points with the largest errors) gives k = 1.01, where k = 1 would be expected. (The actual sums to be done are somewhat more complicated, since the effect of the correction on the moving average must be accounted for.) This is also the linear combination with the smallest rms variation. The value k=1 is used for calculating the radial position of the magnetic centerline for this report.

3. DISTRIBUTIONS AND DATA CHECKS

The AGS lattice is made up of two lengths of magnets and three lengths of straight sections. The distributions of measured lengths for the five categories are shown in Figures 9 and 10. These are from measurements to the sockets, not the ends of the steel, and thus are not exactly the distributions of actual magnet and straight section lengths.

There are a few checks that can be done to detect possible mistakes in the data and to get some idea of the size of the measurement errors. Figure 1b indicates how the offset measurements were actually done (with errors greatly exagerrated). The telescope was set up on one monument and the line of sight established to the next monument. The offsets were measured for the half of the section closest to the telescope. Then the telescope was put at the other monument and the second half of the magnets done. The two offsets in the middle were measured both times, giving some data which can check both the offset measurements themselves and the accuracy of establishing the line of sight between monuments. From Figure 1b, the distance (at the center of the section) between the two lines of sight is L = 0.5*[(a-b)+(c-d)]; the distribution of these quantities for the 21 measured sections is shown in figure 11. The worst point is from data using a different telescope, which appeared to have something wrong; this data should be redone. The other data appear to have an spread of around 10 mils.

The repeatability of the offset measurements themselves can be checked from these duplicated measurements if the line of sight error is accounted for;

thus the measure is

$$D = a-b-L = -(c-d-L)$$

The distribution of this quantity is shown in Figure 12; the rms spread is about 8 - 10 mils.

The reconstruction of the magnet positions from the string of lengths and offsets has two redundancies which can be used as data checks. First, the measured offset at each end of the half-superperiod can be checked against the offset calculated from the length and angle from the monument. Figure 13 shows the distribution of these differences; the rms spread is about 12-15 mils. The two points at about -90 mils are at the same monument and may be due to an interchange of the length measurements; they should be remeasured.

The distance between monuments, as measured in the monument survey, can be compared to the sum of the projected lengths of the measurements along the magnet string. The distribution of differences is shown in Figure 14. The expected rms for this distribution is, for a string of 21 magnet length measurements with individual errors of perhaps 10 mils, and an intermonument length error of 14 mils, is

$$\sigma = \sqrt{21 \cdot .010^2 + .014^2} = .048''$$

which is consistent with the data.

4. CONCLUSIONS

The missing half superperiods should be finished (and the suspicious points rechecked) so we will have a complete picture of the present shape of the AGS ring and can study what it means. Also, the general shape of the ring is determined by the monuments. Thus the intermonument lengths should be remeasured to give more confidence that the ring shape is as indicated here.

The high frequency magnet scatter, or noise, has an rms spread three or four times greater than the expected measuring errors. Thus the data is meaningful in that studies of the beam effects from these position errors would not be dominated by measuring errors. For example, from eqn 4.2.2 of reference 3, the rms orbit distortion expected from a .032 mil scatter is

$$\langle y \rangle = \frac{\pi}{\sqrt{2}\,|\sin \pi Q|} \quad \frac{R}{Q} \quad \frac{|n|}{\rho} \quad \frac{\langle \delta \rangle}{\sqrt{m}}$$

$$= \frac{\pi}{\sqrt{2}\,|\sin \pi (8.75)|} \cdot \frac{128.5\,m}{8.75} \cdot \frac{|357|}{85.3\,m} \cdot \frac{.032''}{\sqrt{240}}$$

$$= 0.40''$$

REFERENCES

1. R. E. Thern, "The 1985 Horizontal Survey. Part I. Monuments", AGS Accelerator Division Technical Note No. 250, April 28, 1986.

2. J. P. Palmer and R. H. Phillips, "Summary of Magnetic Measurements of Classes A, B, and C Magnets Reduced to Equivalent Radial Offset Corrections on the AGS Ring", Accelerator Development Department Internal Report JPP/RHP-2, July 17, 1959. This report covers the magnets that were originally placed in the ring. Over the years the magnets have been shuffled and the spares brought in; the offsets for the spares were found in the data books with the help of J. Weisenbloom, and the present order of the magnets in the ring was determined by looking at each magnet in the ring.

3. C. Bovet et al, "A Selection of Formulae and Data Useful for the Design of A.G. Synchrotrons", CERN/MPS-SI/Int. DL/70/4.

FIGURE CAPTIONS

1. Geometry of magnets relative to the monuments, showing lengths, angles, and offsets which are measured. Figure 1b shows how the offsets are measured with the telescope at the closest monument, with the center two sockets measured twice

2. Displacements of magnet centers (i.e., average of upstream and downstream ends) and monuments from their ideal, or design, values. The radial errors are multiplied by 10000. magnets at the design location will appear on the circle

3. Same as Figure 2, but with all calculations made assuming the monuments are in their ideal positions.

4. Displacements of magnetic centerline, at the upstream and downstream ends, from the design positions. The upstream end of magnet K15 is off scale. The line is an 11-magnet moving average, formed by averaging with 5 neighbors on each side. Mock data was interpolated in the gaps in A, F, and H to avoid a break in this average.

5. Azimuthal (tangential) displacements of the magnet sockets from their ideal positions.

6. Distribution of the differences between the measured radial position and the 11-magnet moving average. The gaussian with a sigma of 32 mils is an eyeball fit. Note that in all figures in this report that use a bar chart to plot a histogram, the abscissa numbers are to be interpreted as the left edge of the bin.

7. Scatter plot of the offsets from the Bdl measurements (Ref. 2) versus the radial error (relative to the 11-magnet moving average. The offset has not been applied, so these are the radii of the sockets.

8. Same as Figure 7, except the offset corrections have been applied, so these are the radii of the magnetic centerlines.

9. Distribution of the lengths of magnets, as measured between sockets.

10. Distribution of the lengths of straight sections. Lengths are measured (or, for the 10' straight sections, calculated) between magnet sockets, so they are nominally 6" longer than the length between magnet ends.

11. Distribution of errors in setting up the line-of-sight between monuments, as calculated from the duplicated offset measurements on the center magnets of each half-superperiod.

12. Distribution of errors in the duplicated offset measurements, corrected for the line-of-sight error (see text).

13. Differences in the offset of the first (and last) magnet socket in each half-superperiod, as measured directly and as calculated from the length and angle from the monument. The two points in the tails are at the same monument, and may be a mistake in the survey notetaking.

14. Differences in the length between monuments, as measured directly (in the monument survey) and as calculated from the lengths along the magnets.

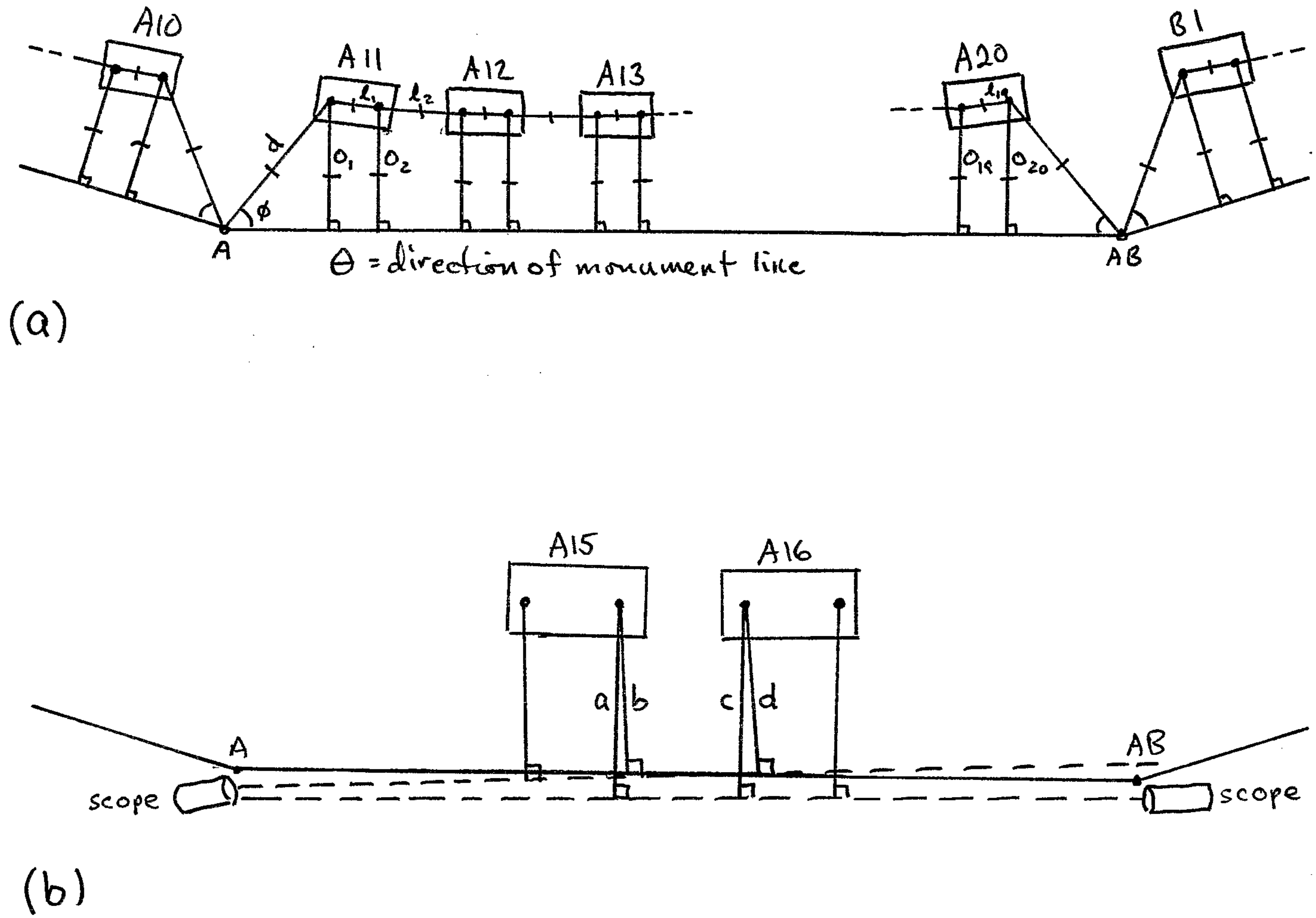

A10
A11
A12
A13
A20
B1
d
ℓ_1
ℓ_2
ℓ_{19}
O_1
O_2
O_{19}
O_{20}
ϕ
A
AB
θ = direction of monument line
(a)
A15
A16
a
b
c
d
A
AB
scope
scope
(b)

Figure 1.

FIGURE 2. MONUMENTS AS MEASURED

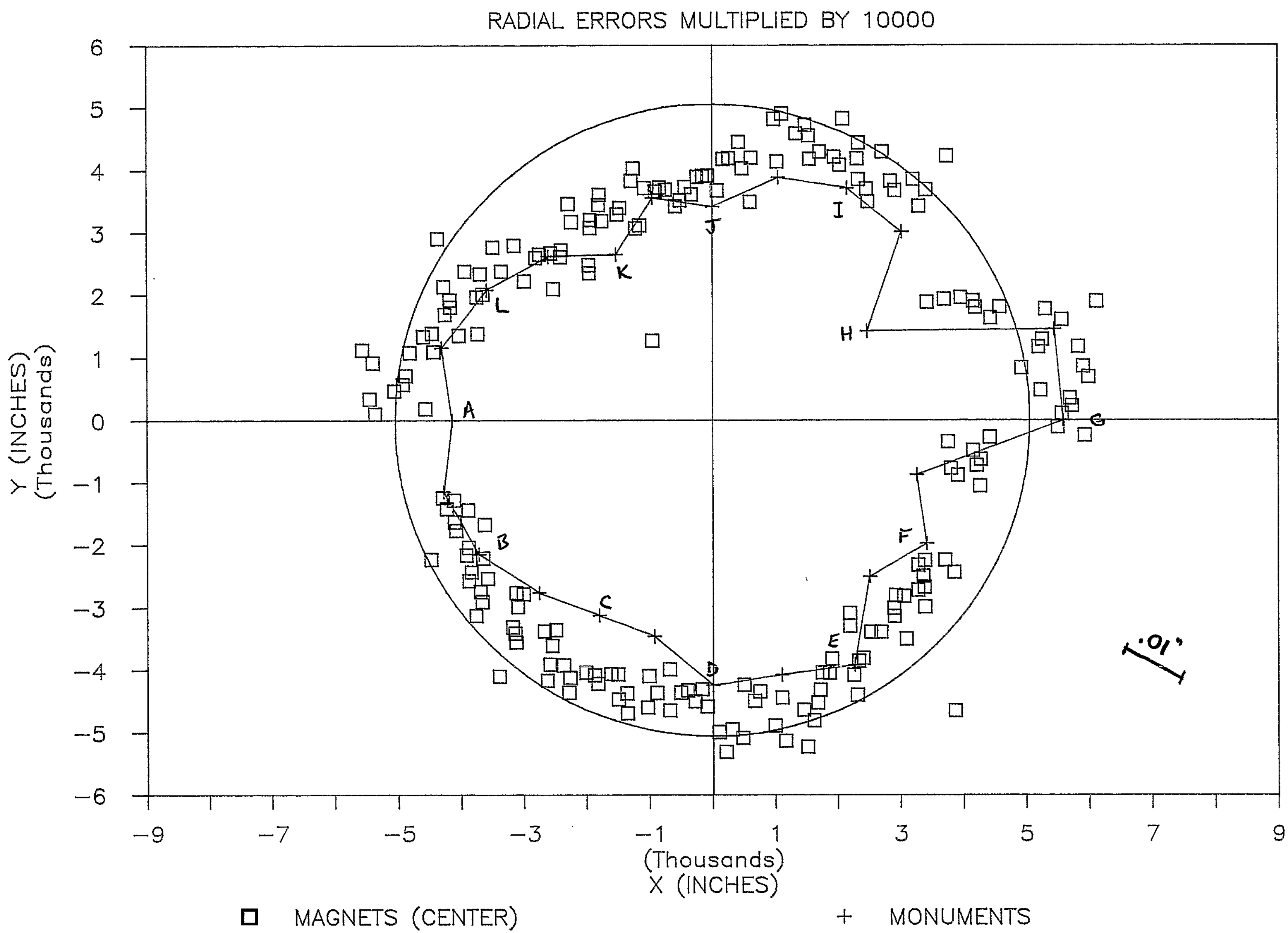


FIGURE 3. MONUMENTS AS DESIGNED

RADIAL ERRORS MULTIPLIED BY 10000

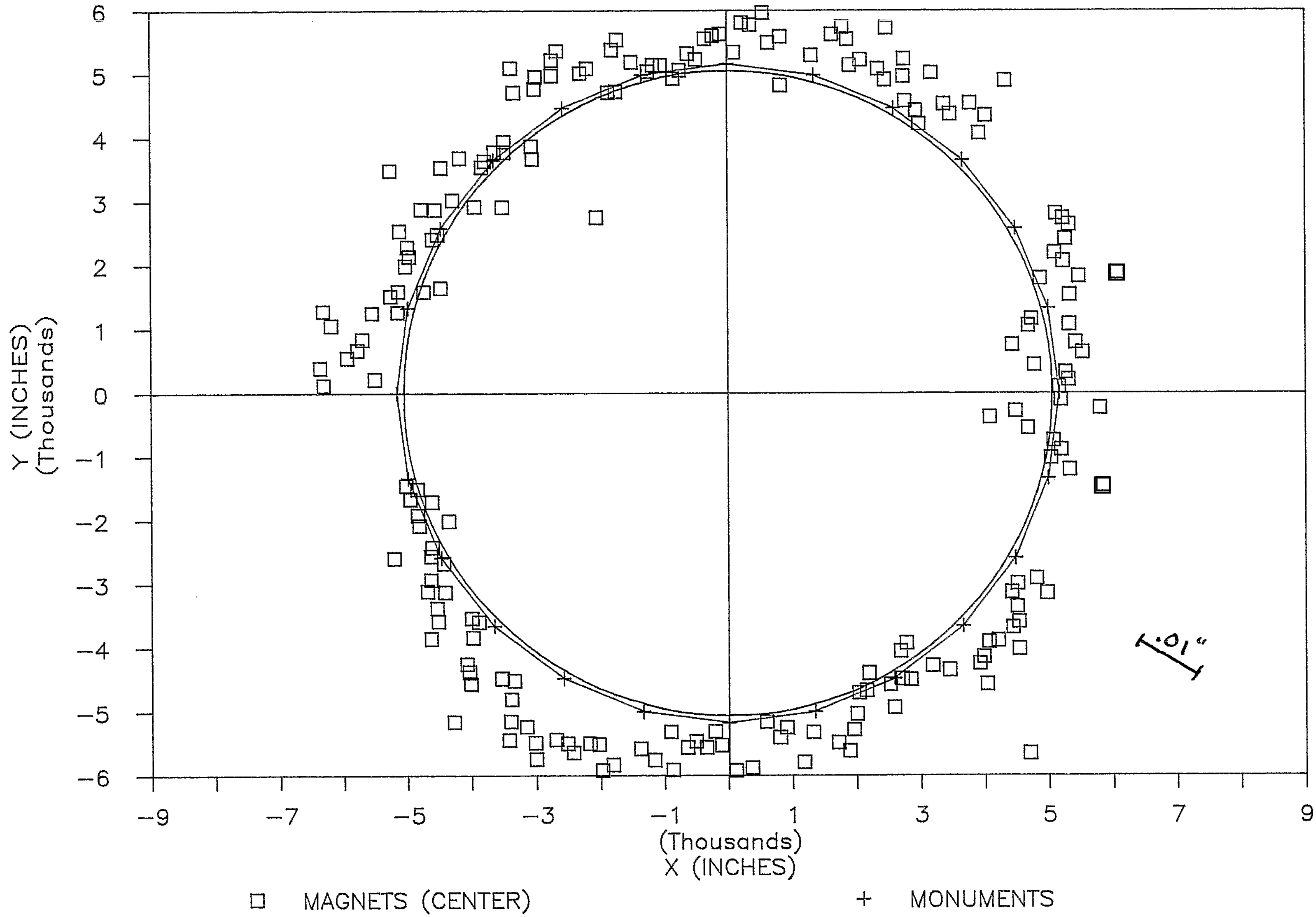
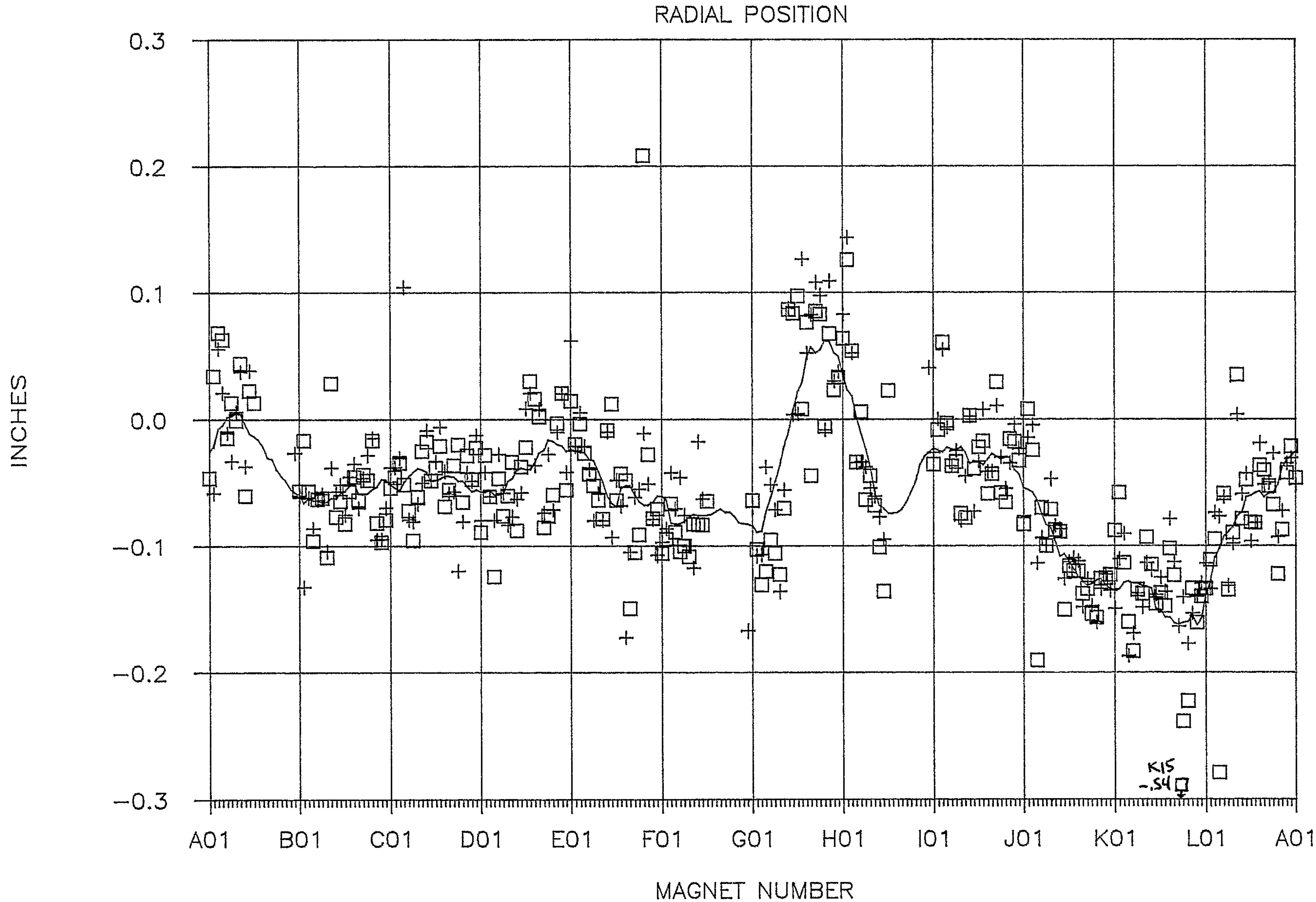


FIGURE 4. DIFFERENCES FROM IDEAL



□ UPSTREAM END + DOWNSTREAM END

FIGURE 5. DIFFERENCES FROM IDEAL

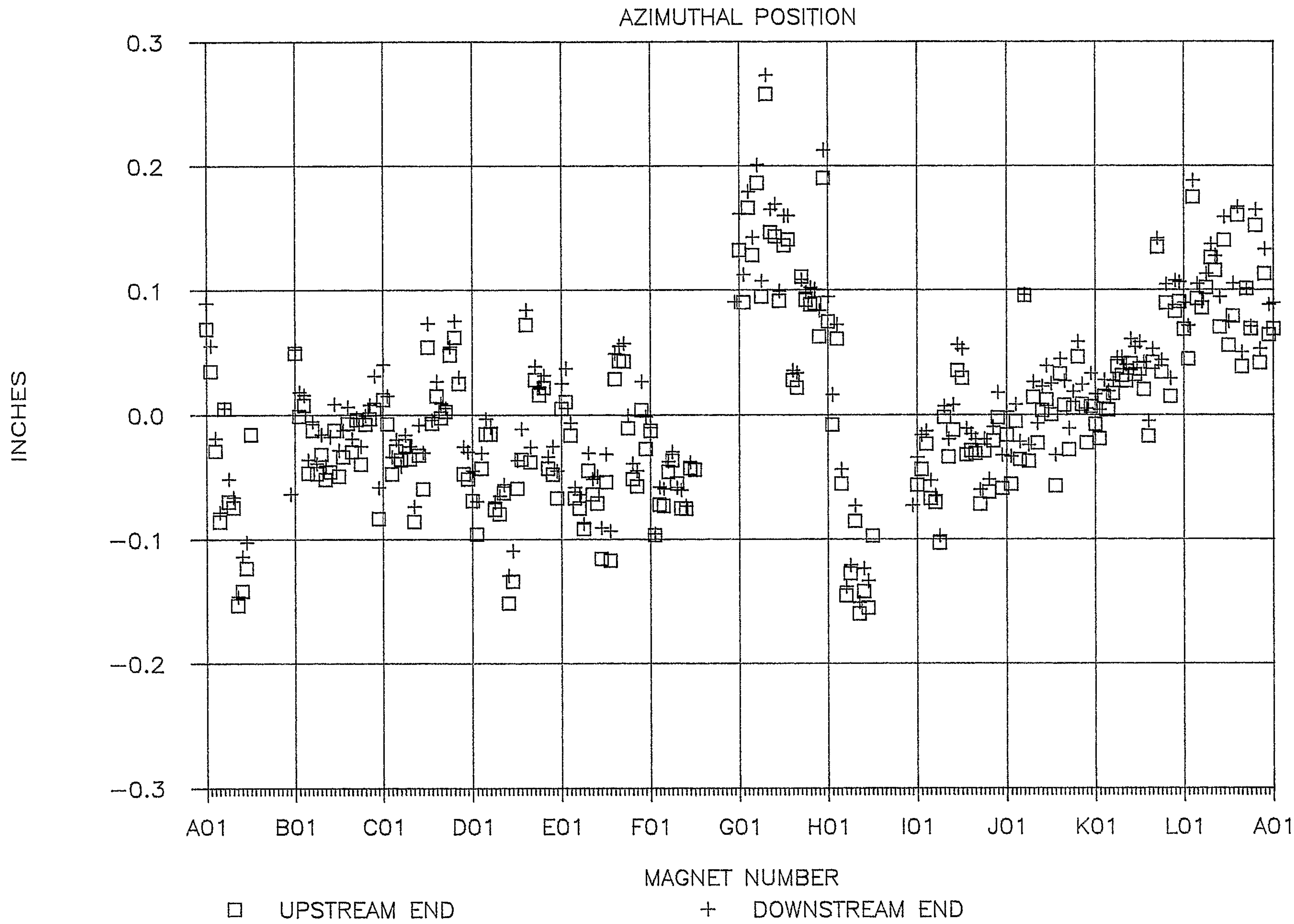


FIGURE 6A. RADIAL ERROR DISTRIBUTION

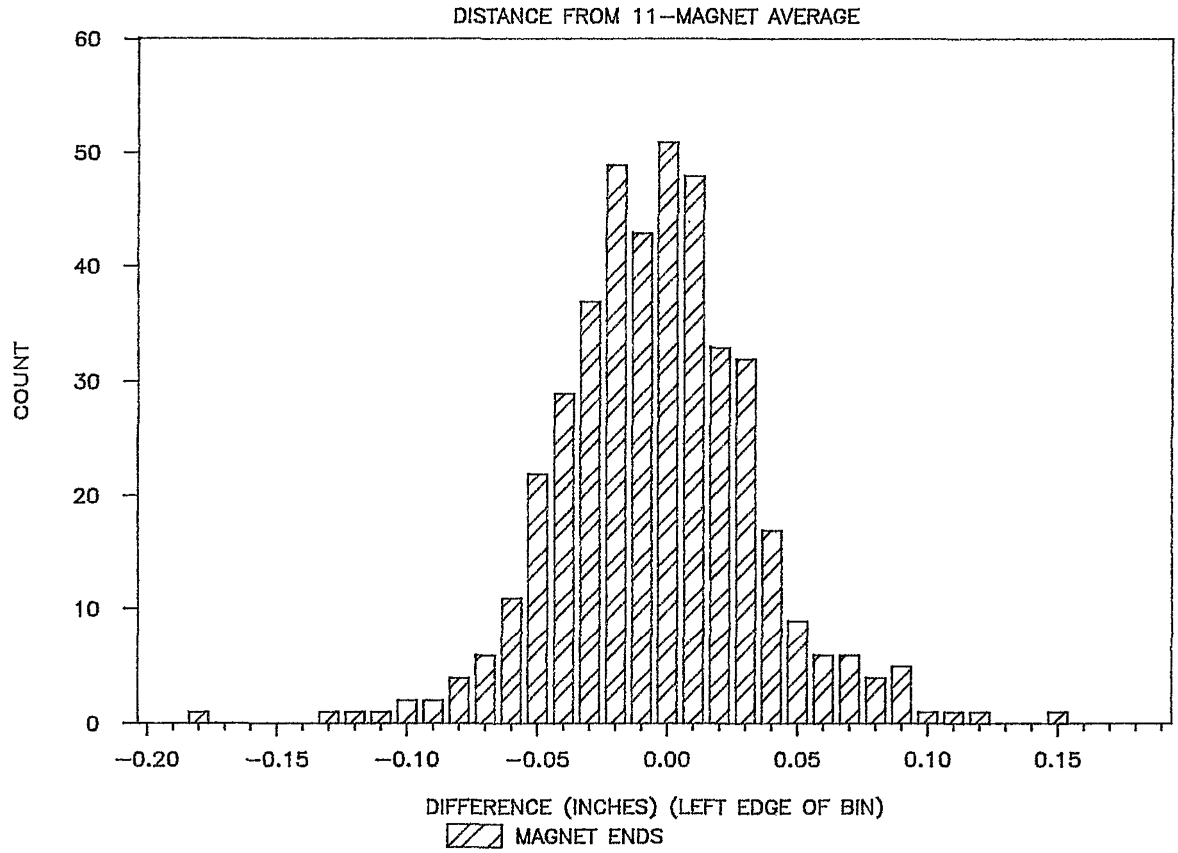


FIGURE 6B. RADIAL ERROR DISTRIBUTION

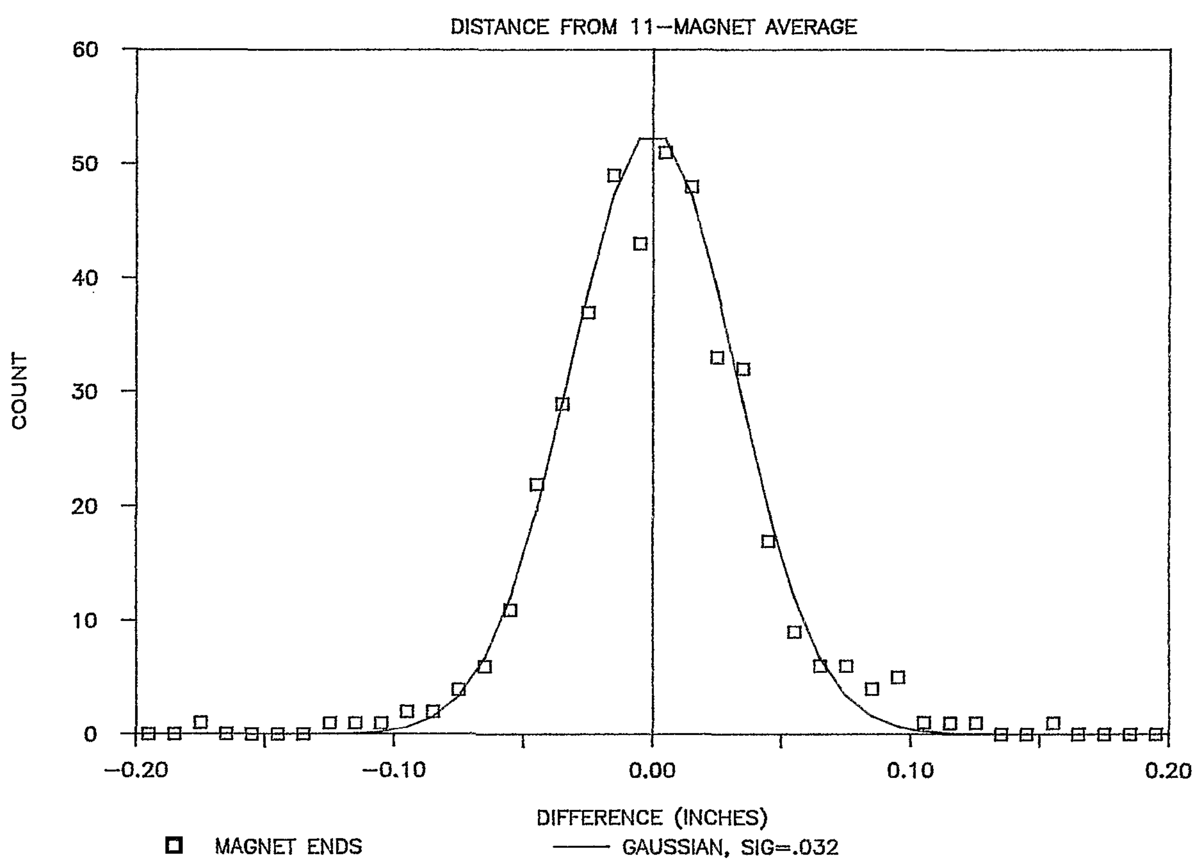


FIGURE 7. WITHOUT OFFSET CORRECTION

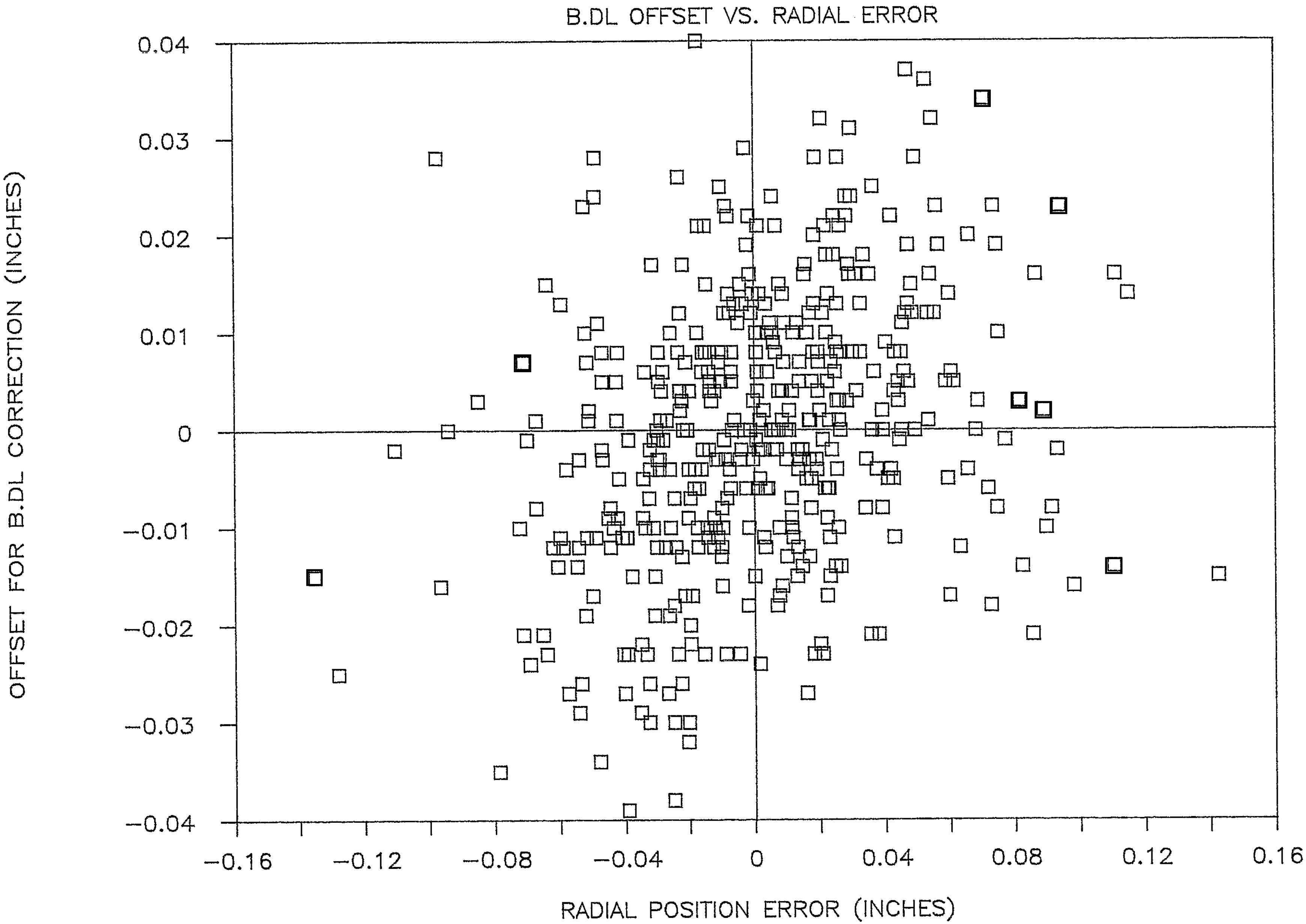


FIGURE 8. WITH OFFSET CORRECTION

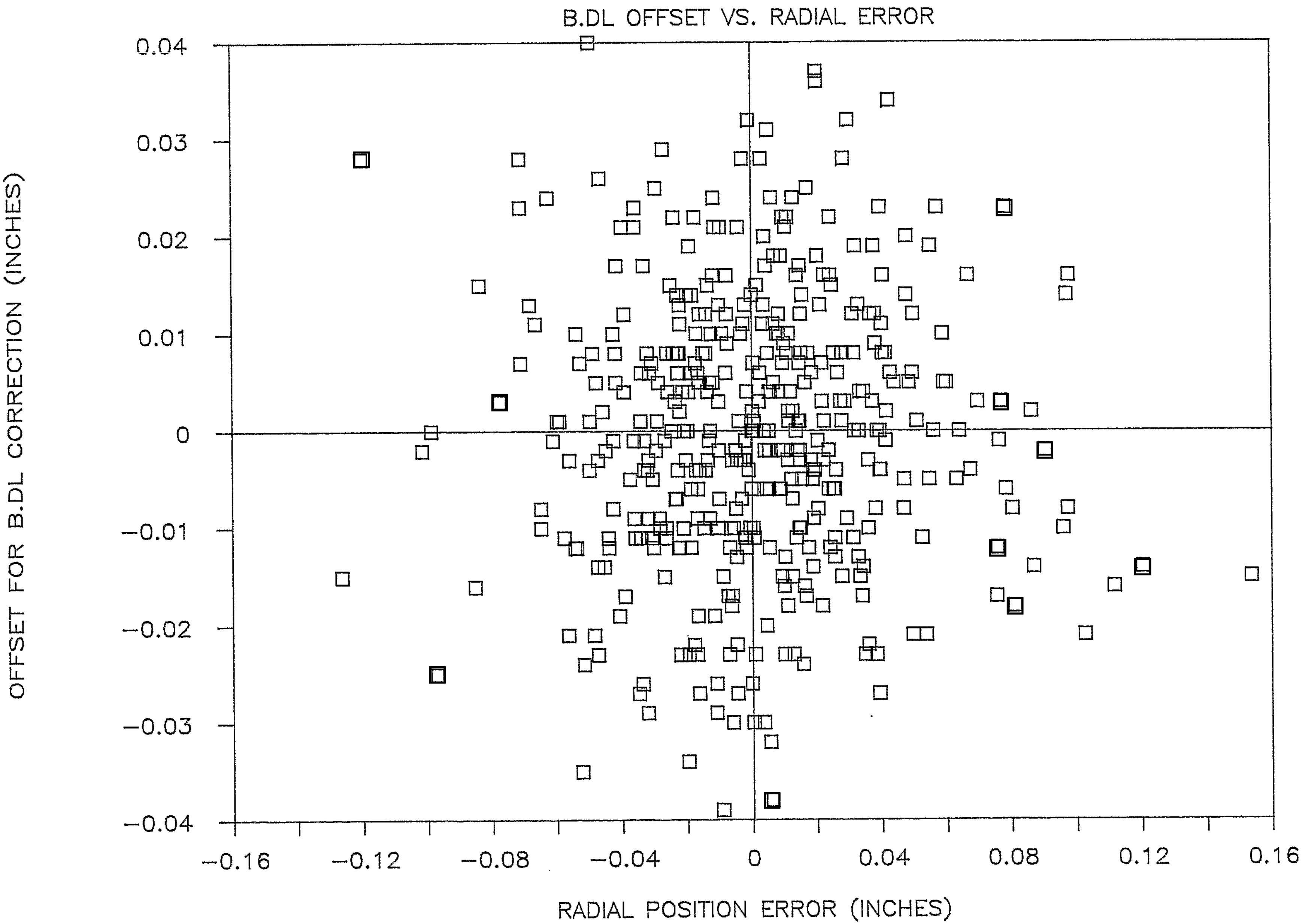


FIGURE 9A. MAGNET LENGTHS (LONG)

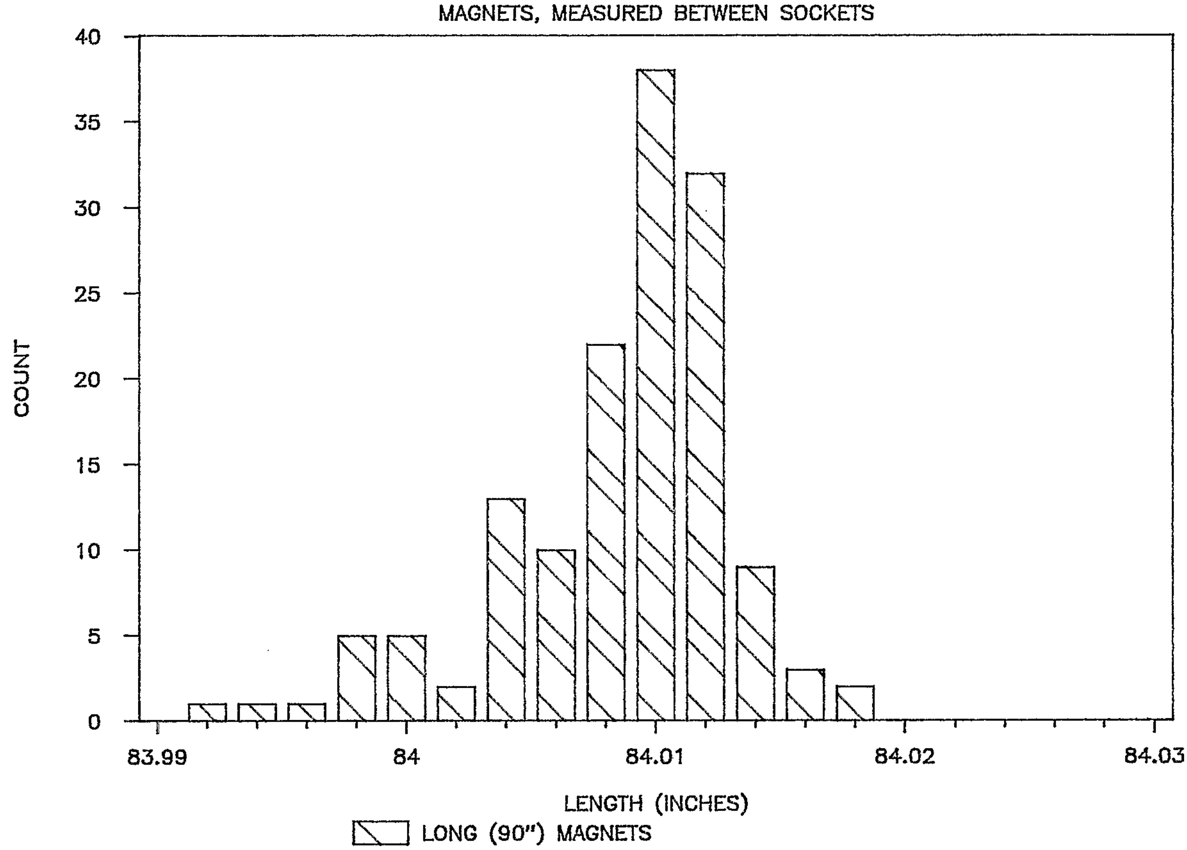


FIGURE 9B. MAGNET LENGTHS (SHORT)

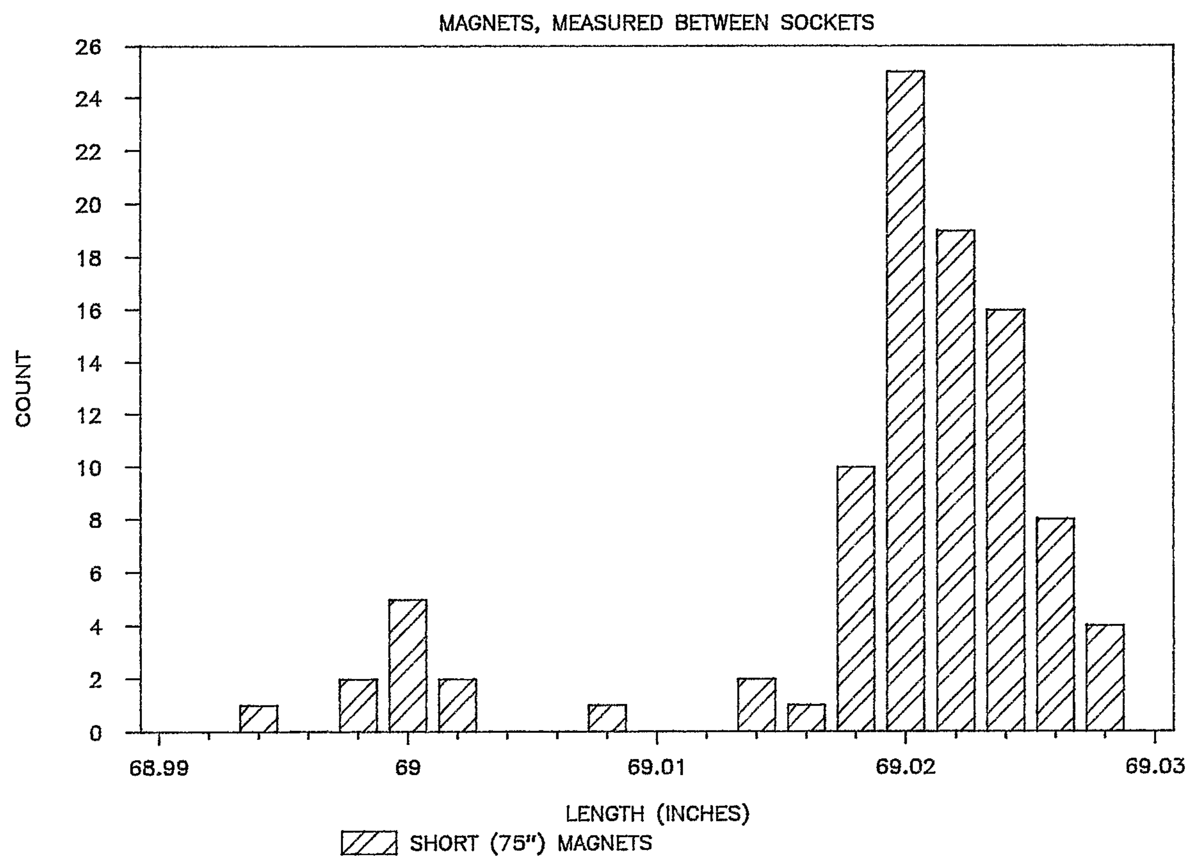


FIGURE 10A. STRAIGHT SECTION LENGTHS

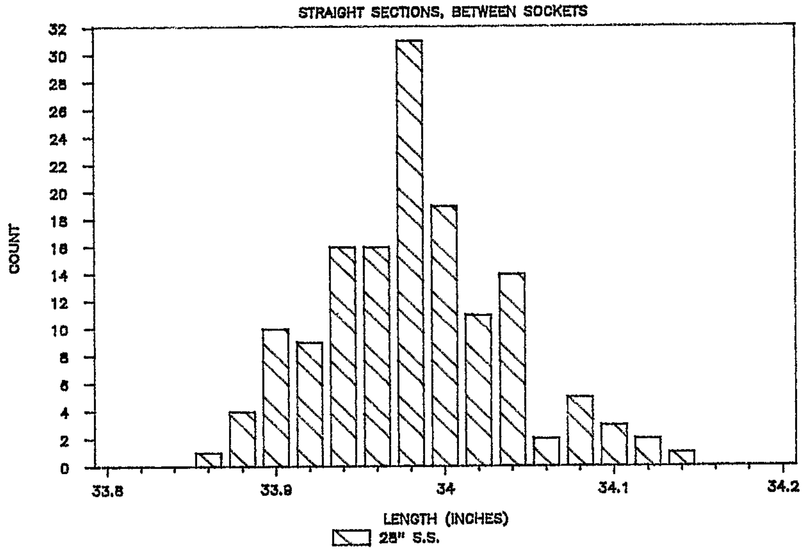


FIGURE 10B. STRAIGHT SECTION LENGTHS

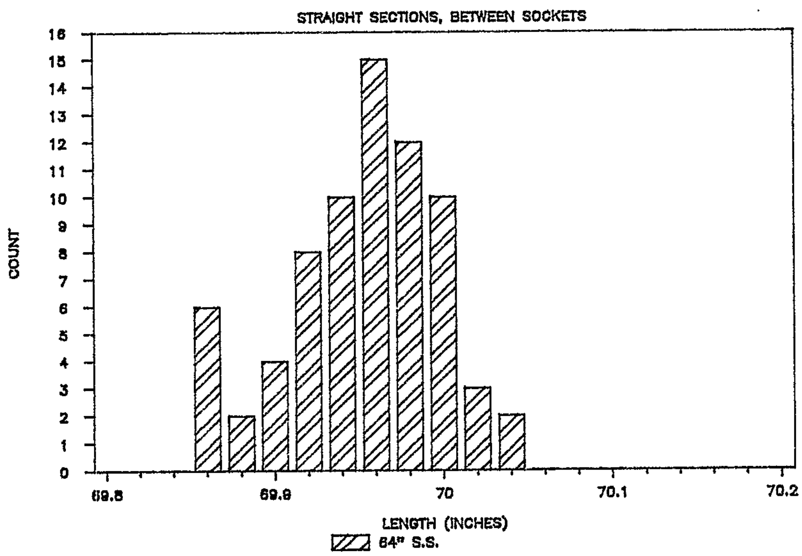


FIGURE 10C. STRAIGHT SECTION LENGTHS

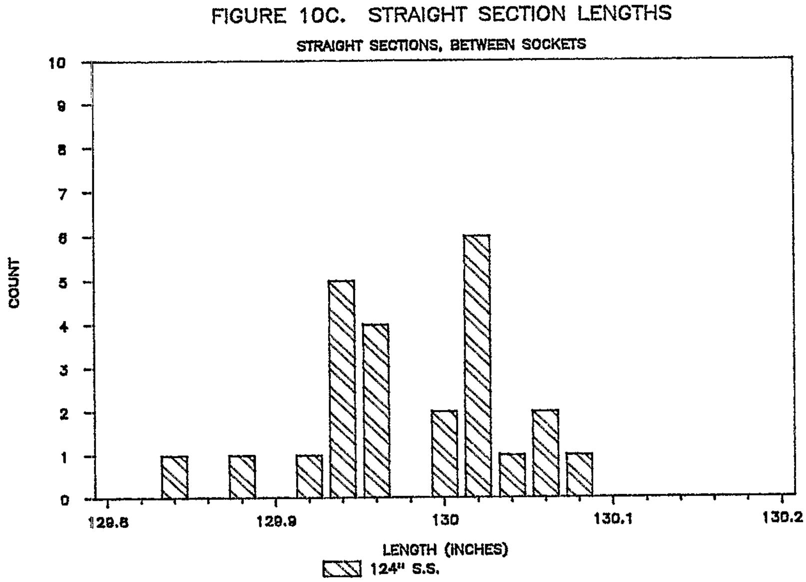


FIGURE 11. LINE-OF-SIGHT DIFFERENCES

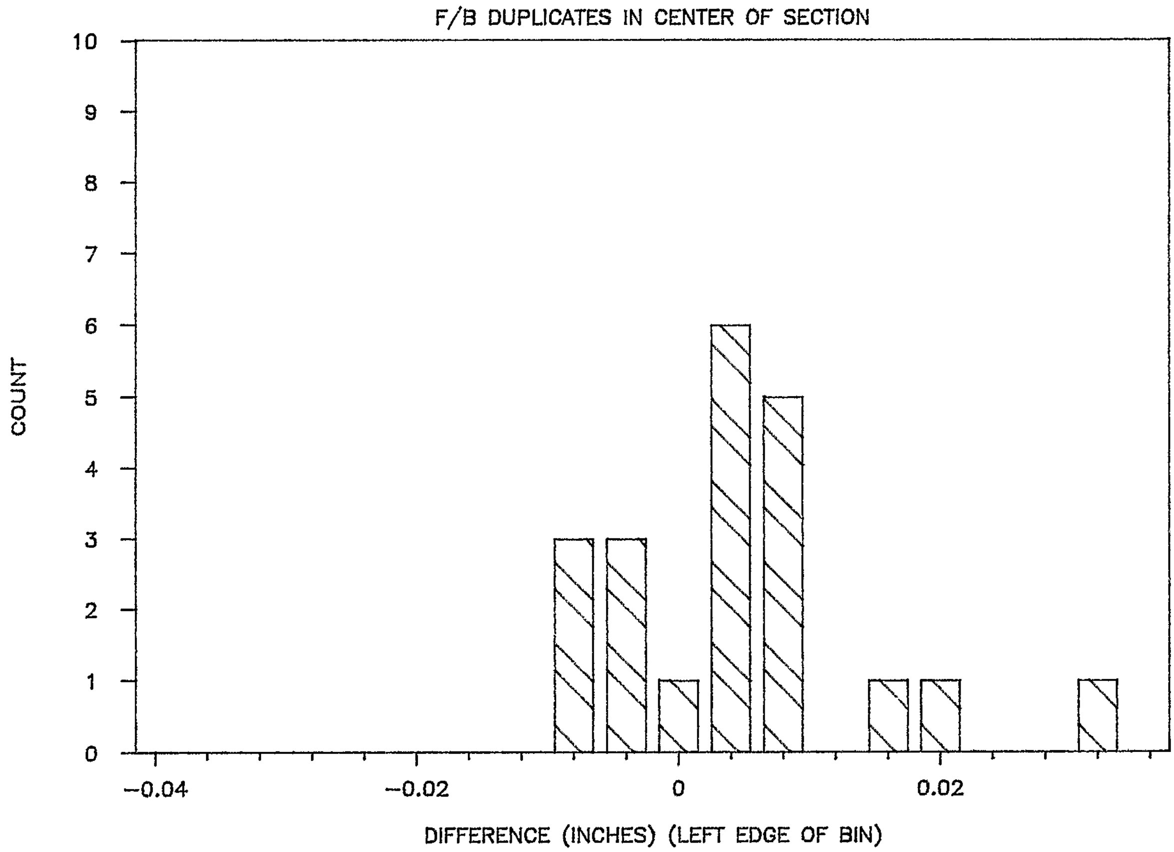


FIGURE 12. OFFSET DIFFERENCES

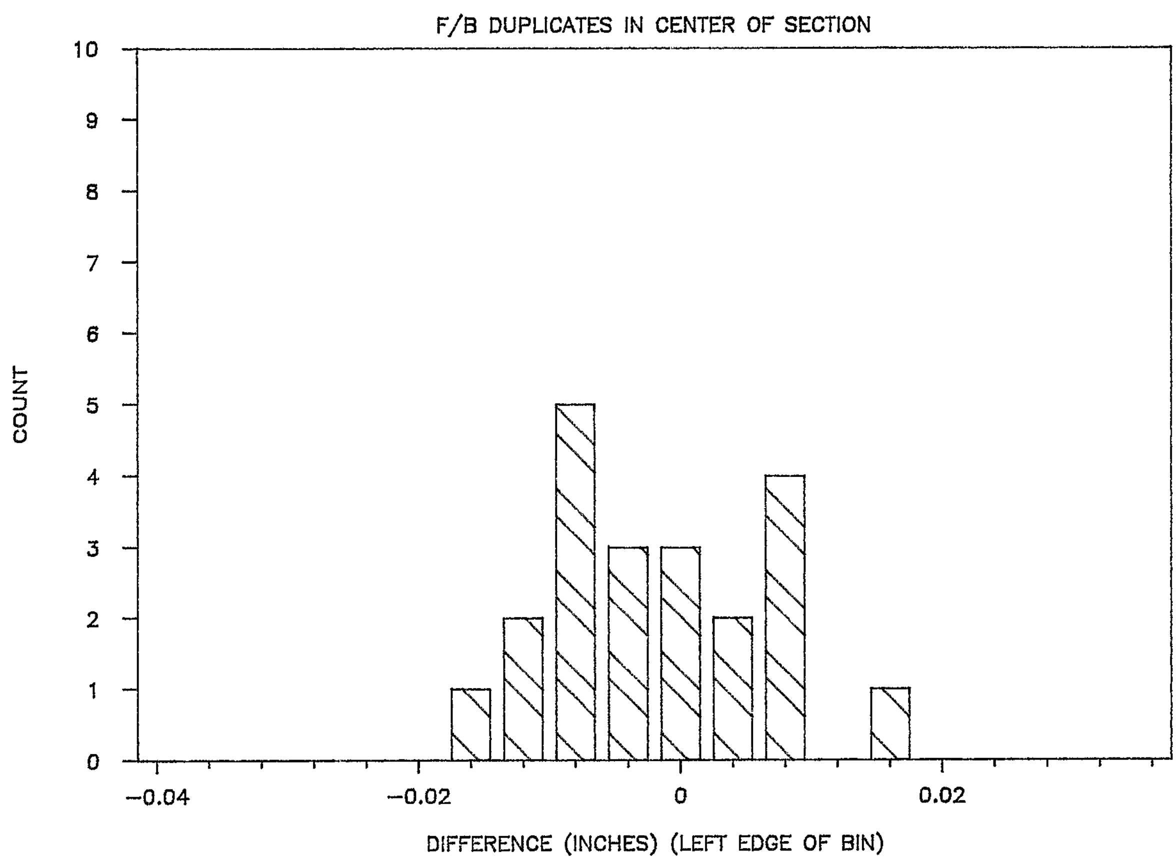


FIGURE 13. OFFSET DIFFERENCES

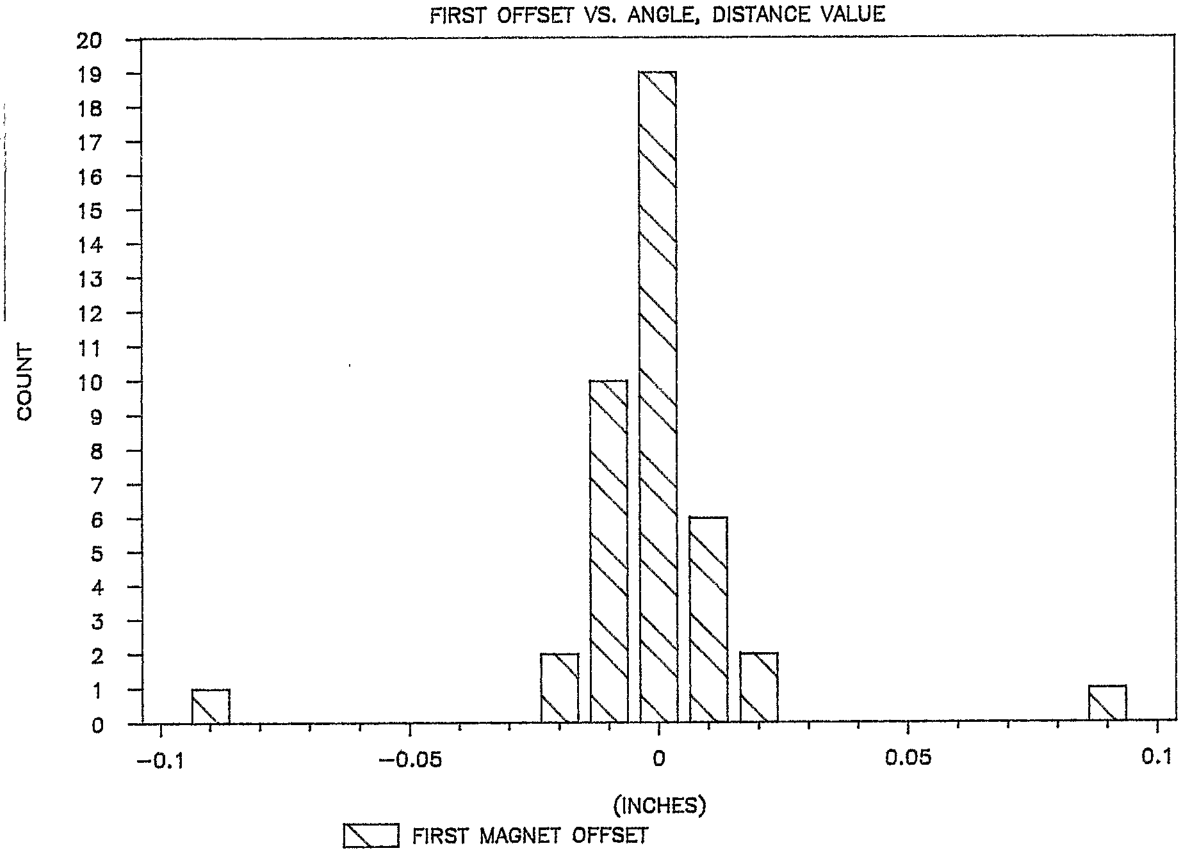


FIGURE 14. LENGTH DIFFERENCES