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1985-1987 HORIZONTAL SURVEY AND REALIGNMENT

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Introduction

The present horizontal (radial) survey and realignment of the AGS ring has been underway since the summer of 1985. The data to determine the positions of the magnets is now complete, and the first part of the realignment was done in June, 1987. This note will describe the survey data, the realignment procedure, the limits on the present understanding of the shape of the AGS ring, and future plans. As the work is not yet complete, this is not the last Technical Note on this subject. Note that this is apparently the first complete horizontal survey and realignment since 1962, when the AGS was only about 10% of its present age.

The design positions for the magnets and monuments are taken from the AGS Standards Book.[1] A recent note by E. Bleser[2] discusses the prescription for that layout, duplicates the data, and concludes that the origional layout is indeed what we want.

Update on Monument Positions

The 24 primary monuments (actually 25, including the "temporary" monument near monument FG, needed because the original is partially hidden by the SEB magnets) were measured in 1985. The surveyors measure the distances and angles between adjacent monuments, and this is analyzed by making a least-squares fit for the monument coordinates, as described in Reference 3.

The monuments were resurveyed in the summer of 1986, with the results in Tables 1 - 3. In the 1986 survey, most distances between

monuments were measured with a laser interferometer, while in 1985 the distances were measured with an invar tape which was calibrated by an interferometric measurement at one location.

Figure 1 shows the monument circle with the distortions magnified, with the results from both the 1985 and 1986 surveys. The 1985 survey shows the average radius about 0.1" less than the design value of 5165.4"; the 1986 survey--with presumably better distance measurements--shows the radius close to the design value. When the 1985 distances are scaled to give the same average radius as 1986, the reconstructed monument figure agrees well with the 1986 figure, as shown in the figure. This gives confidence that the distortions of the monument circle, in particular the large bump at FG-G-GH-H, are real and not due to survey errors. The 1986 results are used in the rest of this note, to get the magnet positions.

The coordinate system for Table 2 has the center of the ring at (0,0), and the monument system has been translated and rotated to make the sum of the x (east), y (north), and azimuth deviations (from the design values) vanish. This was felt to be the best choice in the absence of any absolute reference.

Beam line layouts and site plans generally use two other coordinate systems, the AGS coordinate system and the BNL coordinate system. The AGS system is in inches, with the center of the ring at 12000N, 6942.6E (the center of the G10 straight section is at 12000N, 12000E). The BNL system is in feet, with its origin somewhere in the Great South Bay. (See Appendix B for a complication in the definition of a foot or inch.) Table 3 gives the AGS monuments in these systems also, for use in layout work. For reference, Table 4 gives, in the same format, the design coordinates for the AGS monuments.

It should be noted that the present distortions of the monument figure are considerably larger than found in the previous survey in 1962.

Magnet Positions

The 1985 survey of the magnet positions[4] was incomplete, omitting the magnets obstructed by injection and extraction lines, and a few

others. In 1986 these remaining magnets were measured, completing the first radial survey since 1962. One section, F11-F20, is congested with large SEB extraction line magnets and has been particularly troublesome to measure accurately--the magnets in this region were measured again in June 1987 prior to the realignment.

Unfortunately, reconstructing the positions of the magnets has become something of a patchwork because the surveyors needed several different approaches to measure the magnets in difficult areas. The geometry and formulas for the different cases are given in Appendix A.

The surveyors measured the positions of the survey sockets at the top of the magnets, but what is really of interest is the position of the magnetic centerline. There are two effects to account for in making that translation--the offset (determined by the original magnetic measurements) relating the magnetic centerline to the sockets, and a correction due to roll.

The offset was determined by the original magnetic measurements,[5] such that all magnets of the same class (open or closed, long or short) will have the same bending strength (i.e., integrated Bdl) at a particular current of about 5,000 A. This is needed because of magnetic and mechanical variations in the magnets and inaccuracies in placing the survey sockets on the magnets. These offsets are tabulated in Reference 6 to correspond to the present order of the magnets in the ring.

Figure 2 shows how the roll of the magnet, which is determined by the "vertical" survey, affects the horizontal position. The mechanism which controls the horizontal position--a locating pin through a hole in a bracket welded to the magnet--is at the bottom of the magnet. If the roll of the magnet is changed, the magnet pivots around this point, changing the horizontal position of the magnetic axis and of the sockets. The dimensions of the magnet are such that the sockets move by about twice the amount of roll change. That is, if the magnet is rolled to change the difference between the inner and outer pads by 1 mil, the sockets will move horizontally by about 2 mils. Ideally, the magnets should be placed so as to be correct horizontally when any roll is removed. Unfortunately, we found inconsistencies in the survey of vertical positions which were taken at the same time as the horizontal measurements, so we did not apply this correction except in superperiods B, C, and D.

Table 5 shows the positions of the magnets as found by the 1985-87 surveys, before any realignment. These data are plotted in Figure 3, with the radial deviations magnified to give a view of the shape of the distorted ring and in Figure 4. The accuracy of this data will be discussed later in this note. For reference, the data for the design positions are given in Table 6.

Realignment (June 1987)

There was some apprehension about doing the realignment, since in moving all the magnets there was a perceived risk of turning a working machine into a non-working machine. Thus, the procedure was planned with care, to be sure that each of the 240 magnets would be moved with no mistakes. The realignment was done on June 9 and 10, 1987, during the "studies week" following the SEB run. By doing it at that time instead of during the summer shutdown, we could bring the AGS back on during and after the job to check that no blunders had been made and that the machine still worked.

Figure 5 shows a sample of the worksheet prepared for the realignment. The worksheets were set up so no calculations or figuring of signs had to be done by the crew. The alignments were done using three dial gauges, one at each end (3 inches from the end, below the survey socket) and one in the center which served as a check. A three-man crew--each person setting up his own gauge and recording the final reading--could move a magnet in only two or three minutes.

The magnets were realigned to a position 0.050" outside the design position. This number was chosen since it was close to the average position of the magnets over a large portion of the ring. The absolute accuracy of the survey is not, of course, good enough to determine the actual radius of the AGS to this accuracy--that will be done by frequency measurements on the beam.

Several times during the realignment, we accelerated the beam and compared the actual change in orbit with that expected for the readjustments just done. This ws done to help isolate any major blunders (there were none). The final measured (with PUE's) and calculated (with MAD[7]) difference orbits, Figure 6, show good agreement.

We had moved several magnets between the time they were surveyed and the June 1987 realignment.[8,9] Thus, the worksheets do not correspond for some magnets with the values in Table 5. These earlier motions are summarized below.

Magnet	U/S Motion	D/S Motion	Units	Date
E17	-0.268	-0.028	inches	12/11/86
K15	0.368	0.031		"
E13	0.045	0.045		5/4/87
E14	0.056	0.056		"
F7	-0.068	-0.068		"
F8	-0.060	-0.060		"

Present Status and Plans

All but 13 magnets were realigned in June and the work tested by accelerating beam in the AGS. The remaining magnets in the E and F superperiods were too radioactive to move at that time. At the time of this writing, these magnets have now been realigned also. We expect that moving these last magnets will not cause any serious orbit distortions that could cause trouble when turning the AGS back on in the fall.

A vertical survey and realignment has also been done during the summer.[10] Following the moves of the main ring magnets, all devices in the straight sections--which are positioned relative to their neighboring ring magnets--are now being realigned also.

At present, we expect that the ring is much closer to its design shape than before the realignment, and that both the bumps and the large magnet-to-magnet variations shown in Figure 3 are greatly reduced. However, the accuracy of the survey (i.e., our knowledge about where the magnets were before the realignment) is not sufficient to ensure a smooth orbit. In fact, the remaining ninth harmonic is expected to be comparable to what it was before. This is because in the past, some magnets were moved specifically to reduce the ninth harmonic, giving less ninth than might be expected in a machine so misaligned, while our present alignment has not yet had the benefits of such selective doctoring.

We can get an idea of the accuracy of the survey by comparing the measured orbit (with the pick-up electrodes) with that predicted from our measured magnet positions. Figure 7 shows the difference between the measured and predicted orbits before the realignment, plotted at the positions of the PUE's. The PUE's are assumed to be centered at the downstream ends of their magnets, and thus the PUE signals have been corrected for the magnet misalignment. The discrepancy in the orbits is quite large, comparable in magnitude to the orbit change induced by the realignment (Figure 6), showing that there are substantial errors in our knowledge of the magnet positions from the survey. Interestingly, the discrepancies appear to be greatest in the F-G-H superperiods, where the survey was most difficult. Figure 7 also shows the "ringing" induced by a single kick in the G superperiod. Outside the F-G-H area, the orbit discrepancy approximately follows this ringing, indicating that there are only small survey errors there.

When the AGS is turned on again, we plan to measure orbits and then move a small number of magnets (perhaps 10 or 20) to reduce the most troublesome harmonics--certainly the 9th, and perhaps 8th and 10th as well--in both horizontal and vertical planes. We may also roll some magnets slightly to eliminate the coupling due to skew quadrupoles.

APPENDIX A

Determining Magnet Positions

Most magnets were located by measuring the lengths of the magnets and straight sections between magnet sockets, and the perpendicular offsets from the sockets to the line between monuments, as shown in Figure Ala. The magnet positions (x, y) are then reconstructed in the local coordinate system where the monument line is the x axis, and then transformed to the main coordinate system (X, Y) with the origin at the center of the ring (see Figure Ala):

$$
\begin{aligned}
x_1 &= d \cos \phi \\
y_1 &= 0_1 \\
x_n &= x_{n-1} + \left[\ell^2_{n-1} - (0_n - 0_{n-1})^2\right]^{1/2} \\
X_n &= X_{mon} + x_n \cos \theta - y_n \sin \theta \\
Y_n &= Y_{mon} + y_n \cos \theta + x_n \sin \theta
\end{aligned}
$$

where θ is the angle of the intermonument line in the central coordinate system.

In the areas near the external beam lines, the surveyors were unable to measure the perpendicular offsets. Instead, they measured angles from one monument to the magnet sockets, as shown in Figure Alb. If (x0, y0) are known, then (x, y) satisfies:

$$
\begin{aligned}
(x_o - x)^2 + (y_1 - y)^2 &= \ell^2 \\
y &= x \tan \phi
\end{aligned}
$$

which can be solved to give

$$
x = \frac{x_o + y_o \tan \phi \pm \left[(x_o + y_o \tan \phi)^2 - (x_o^2 + y_o^2 + \ell^2)(1 + \tan^2 \phi)\right]^{1/2}}{1 + \tan^2 \phi}
$$

$$
y = x \tan \phi
$$

where the sign in the expression for x is chosen to select the correct solution (positive as shown).

All calculations for the monument and magnet coordinates were performed on an IBM-PC using the Lotus Symphony spreadsheet.

APPENDIX B

What is a Foot?

There is a potential complication in units because the definition of the foot in terms of the meter was changed in the 1960's. In the old definition, 1 meter = 39.37 inches (exact), so 1 inch = 2.54000508 cm (approximately). In the new definition, 1 inch = 2.54 cm (exact). The difference between the two definitions is exactly 2 parts per million:

$$2.54 \times 0.3937 = 999998/1000000.$$

This change by itself would cause no problems, since the difference is too small to show up in most measurements. However, the old definition is still shown in recent tables of conversion factors as the "U.S. Survey" foot.[B1] A problem arises when the two definitions are inadvertently mixed. On a machine the size of ISABELLE/RHIC, for example, converting the radius of a crossing point from meters to feet (for example, to calculate the BNL grid coordinates) will show a discrepancy of over 1 mm if the wrong conversion factor is used.

So, which definition should we use? The AGS was built before the change of definition, so one would expect the AGS coordinate system, and also presumably the BNL grid system, to use old U.S. Survey feet. However, the Ammann & Whitney dawings of accelerator geometry for ISABELLE (drawing C-2 in the portfolio of January 15, 1979) show coordinates (in BNL grid) and lengths (in feet and meters) which are consistent only if all "feet" are interpreted as the new definition (1 foot = 12 x 0.0254 = 0.3048 meter). (Two Technical Notes on ISABELLE coordinates[B2,B3] each used different conversion factors, which certainly did not help.)

Thus, I suggest that we use the new definition, and assume that our coordinate systems use units given by 1 inch = 0.0254 meters exactly, regardless of which unit was originally used.

For those who might think that ths type of problem does not occur in the metric system, note that the definition of the liter was also changed sometime in the 1960's from 1.000027 to 1 (exact) cubic decimeters.

Tables

1. Monuments: survey data (measured and fitted).
2. Monuments: coordinates and deviations from design positions.
3. Monuments: coordinates in AGS-centered system, and AGS and BNL grid systems.
4. Design values for monument coordinates.
5. Magnet positions before realignment.
6. Design values for magnet survey data.

Figures

1. Monument circle. The x and y deviations from the design values have been multiplied by 10000 to make the errors visible.
2. AGS magnet, showing survey reference points. Because of the large vertical displacement between the survey pads and the horizontal positioner, changes in the magnets' roll give a significant change in horizontal position.
3. AGS ring, showing radial misalignments of the monuments and of the centers of the magnets (i.e., average of upstream and downstream ends) before realignment. A magnet or monument which is at the correct radius would be plotted on the circle. Note that, unlike Figure 1, only the radial errors are shown.
4. Radial misalignments of both ends of magnets, before realignment.
5. Sample realignment worksheet.
6. Predicted and measured change in orbit caused by realignment in June. The line is the predicted orbit change, evaluated only at the PUE locations. The boxes are the measured difference orbit, before and after the realignment. Some PUE's were not operational and are not plotted. The PUE's are mounted in the magnets; thus, the PUE signals have been corrected to compensate for the magnet motion.
7. Difference between measured orbit and that predicted by the survey data. Before taking the difference, the PUE signals have been corrected to compensate for the magnet misalignment.

A1. Reconstruction of magnet coordinates from survey measurements.

References

1. O.S. Reading and M. Buchanen, "Standard Survey Data", August 20, 1957, in the AGS Standards Book.
2. E.J. Bleser, "Where are the AGS Magnets?", Accelerator Division Technical Note No. 215, May 20, 1985.

3. R.E. Thern, "The 1985 Horizontal Survey, Part I. Monuments", Accelerator Division Technical Note No. 250.
4. R.E. Thern, "The 1985 Horizontal Survey Part II. Magnets", Accelerator Division Technical Note No. 253.
5. 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", ADD Internal Report JPP/RHP-2.
6. R.E. Thern, "Present Order of Magnets in the AGS Ring, with B.dl Offsets", Accelerator Division Technical Note No. 254.
7. F.C. Iselin and J. Niederer, "The MAD Program", CERN/LEP-TH/87-33, April, 1987.
8. R. Thern, "Orbit Changes from Moving Magnets E17 and K15", AGS Studies Report No. 217. There is an error in the table on page 2--the reference to K17 should be E17.
9. M. Tanaka, "An Inward Orbit Bump at the E20 Catcher", AGS/AD Operations Note 11.
10. E. Bleser, E. Auerbach, M. Tanaka, R. Thern, "The 1987 Vertical Survey of the AGS: I", AGS/AD/Tech. Note 283, August 12, 1987.

B1. CRC Handbook of Chemistry and Physics, "Conversion Factors", p. F-304 in the 65th Edition, 1984-85.
B2. M. Cornacchia and G.F. Dell, "Position Coordinates of ISA Components", ISABELLE Project Technical Note No. 254, December 1, 1980.
B3. G.F. Dell, "Note on ISA Lattice Coordinates (1-in-1)", ISABELLE Project Technical Note No. 388, July, 1982.

TABLE 1. Monument survey data with least-squares fit for coordinates.
The data and coordinates in this table use 'temporary' monument FG'.
Lengths and coordinates are in inches.

Data: Angles - 1986 Lengths - 1986

The angle is the 'turning angle' at that monument, and the length is the distance to the next monument.

The 'adjusted' quantities are the result of the least squares fit, and the residuals are the differences between the measured and adjusted values.

	Measured				Adjusted		Residuals	
Monument	deg	min	sec	angle length	angle	length	angle(sec)	length
LA	15	0	15.5	15.004306 1348.418	15.004085	1348.424	-0.7954	0.0062
A	14	59	43.3	14.995361 1348.398	14.995131	1348.405	-0.8290	0.0067
AB	15	0	9.4	15.002611 1348.428	15.002377	1348.435	-0.8420	0.0068
B	15	0	3.2	15.000889 1348.453	15.000657	1348.459	-0.8338	0.0064
BC	14	59	59.7	14.999917 1348.448	14.999693	1348.454	-0.8047	0.0055
C	14	59	58.2	14.999500 1348.399	14.999290	1348.404	-0.7569	0.0043
CD	14	59	48.0	14.996667 1348.450	14.996474	1348.453	-0.6935	0.0028
D	15	0	12.5	15.003472 1348.441	15.003300	1348.442	-0.6188	0.0011
DE	14	59	54.9	14.998583 1348.393	14.998434	1348.392	-0.5381	-0.0007
E	15	0	20.6	15.005722 1348.502	15.005595	1348.500	-0.4567	-0.0024
EF	14	59	39.3	14.994250 1348.484	14.994144	1348.480	-0.3802	-0.0040
F	12	11	16.2	12.187833 1036.941	12.187746	1036.936	-0.3138	-0.0051
FG tmp	16	42	59.2	16.716444 1664.094	16.716369	1664.088	-0.2717	-0.0062
G	16	5	54.1	16.098361 1348.498	16.098298	1348.491	-0.2286	-0.0067
GH	15	0	45.8	15.012722 1348.328	15.012662	1348.321	-0.2155	-0.0068
H	14	58	49.2	14.980333 1348.460	14.980271	1348.454	-0.2238	-0.0064
HI	15	0	20.4	15.005667 1348.421	15.005596	1348.415	-0.2528	-0.0055
I	15	0	6.9	15.001917 1348.418	15.001833	1348.413	-0.3007	-0.0043
IJ	15	0	4.9	15.001361 1348.467	15.001260	1348.465	-0.3641	-0.0028
J	14	59	46.1	14.996139 1348.414	14.996017	1348.413	-0.4387	-0.0011
JK	15	0	16.5	15.004583 1348.470	15.004439	1348.471	-0.5195	0.0007
K	14	59	42.3	14.995083 1348.465	14.994916	1348.467	-0.6009	0.0024
KL	15	0	5.8	15.001611 1348.419	15.001423	1348.423	-0.6773	0.0040
L	15	0	0.7	15.000194 1348.437	14.999988	1348.443	-0.7437	0.0053

		Raw	Fitted		Sum of squares:
Closure errors:	Angle:	12.7	-0.00	seconds	7.894120 0.000554
	X:	-0.0500	-0.0000	inches	Weighted:
	Y:	0.1678	-0.0000	inches	21.92811 2.408475
					Total Chisquare:
					24.33658

Data to locate permanent monument FG:
Distance from FG to G: 1348.392
Angle FG-G-GH: 15.008611
(turning angle)

Comments:
1. Least squares fit uses sigmas of .6 sec and .015 inch for the measured angles and lengths.
2. The angle closure error is large but is probably due mostly to a systematic error in the instrument used, which does not affect the final result. If the closure error is removed, the angle contribution to chisquare is 3.26 (instead of 21.93) and the total is 5.67. These are are still somewhat high for the fit (3 degrees of freedom, or 2 if the angle closure is accounted for separately), so the sigmas above are probably too optimistic.

TABLE 2. Monument coordinates (X-Y and polar) and deviations from design coordinates.
This table uses permanent monument FG.
Lengths and coordinates are in inches.

Data: Angles - 1986 Lengths - 1986

Monument	Coordinates X	Y	Polar Coord. radius	azimuth	Deviations (x-y) dx	dy	Dev. (polar) dr	da
LA	-4989.454	1336.891	5165.456	165.000307	-0.061	-0.012	0.056	0.028
A	-5165.391	-0.006	5165.391	-179.999936	0.009	-0.006	-0.009	0.006
AB	-4989.435	-1336.881	5165.434	-165.000364	-0.042	0.023	0.034	-0.033
B	-4473.403	-2582.669	5165.414	-150.000490	-0.035	0.031	0.014	-0.044
BC	-3652.493	-3652.459	5165.380	-135.000267	-0.003	0.031	-0.020	-0.024
C	-2582.682	-4473.331	5165.359	-120.000025	0.019	0.037	-0.041	-0.002
CD	-1336.919	-4989.342	5165.354	-105.000305	-0.015	0.052	-0.046	-0.028
D	-0.013	-5165.431	5165.431	-90.000140	-0.013	-0.031	0.031	-0.013
DE	1336.893	-4989.429	5165.431	-75.000210	-0.010	-0.035	0.031	-0.019
E	2582.661	-4473.459	5165.459	-60.000880	-0.039	-0.091	0.059	-0.079
EF	3652.442	-3652.473	5165.355	-45.000233	-0.047	0.017	-0.045	-0.021
F	4473.382	-2582.681	5165.403	-29.999722	0.015	0.020	0.003	0.025
FG	4989.346	-1336.760	5165.317	-14.998581	-0.047	0.145	-0.083	0.128
G	5165.538	0.071	5165.538	0.000801	0.138	0.072	0.138	0.072
GH	4989.515	1337.025	5165.549	15.000954	0.122	0.122	0.149	0.086
H	4473.251	2582.593	5165.246	29.999630	-0.117	-0.106	-0.154	-0.033
HI	3652.489	3652.489	5165.400	45.000007	-0.001	0.000	-0.000	0.001
I	2582.734	4473.372	5165.421	59.999701	0.034	0.005	0.021	-0.027
IJ	1336.956	4989.371	5165.392	74.999382	0.052	-0.022	-0.008	-0.056
J	0.021	5165.333	5165.334	89.999766	0.021	-0.066	-0.066	-0.021
JK	-1336.862	4989.376	5165.372	104.999599	0.042	-0.017	-0.028	-0.036
K	-2582.664	4473.284	5165.310	120.000113	0.036	-0.083	-0.090	0.010
KL	-3652.512	3652.438	5165.380	135.000581	-0.023	-0.051	-0.020	0.052
L	-4473.402	2582.679	5165.419	150.000388	-0.034	-0.021	0.019	0.035
(LA)	-4989.454	1336.891	5165.456	165.000307				
averages	-0.000	0.000	5165.398		0.000	0.001	-0.002	0.000

Coordinates of temporary monument:

FG tmp	4916.758	-1645.315	5184.744	-18.501991	-72.635	-308.4	19.344	-316.9

TABLE 3. Monument coordinates in AGS-centered system, and in AGS and BNL grid systems.

Coordinates for the BNL grid are in feet, the others are inches.

Data: Angles - 1986 Lengths - 1986

Monument	AGS-centered X	AGS-centered Y	AGS grid North	AGS grid East	BNL grid North	BNL grid East
LA	-4989.454	1336.891	13336.891	1953.146	102261.4076	98584.2122
A	-5165.391	-0.006	11999.994	1777.209	102149.9995	98569.5507
AB	-4989.435	-1336.881	10663.119	1953.165	102038.5932	98584.2137
B	-4473.403	-2582.669	9417.331	2469.197	101934.7776	98627.2165
BC	-3652.493	-3652.459	8347.541	3290.107	101845.6284	98695.6256
C	-2582.682	-4473.331	7526.669	4359.918	101777.2224	98784.7765
CD	-1336.919	-4989.342	7010.658	5605.681	101734.2215	98888.5901
D	-0.013	-5165.431	6834.569	6942.587	101719.5474	98999.9989
DE	1336.893	-4989.429	7010.571	8279.493	101734.2143	99111.4078
E	2582.661	-4473.459	7526.541	9525.261	101777.2117	99215.2217
EF	3652.442	-3652.473	8347.527	10595.042	101845.6272	99304.3702
F	4473.382	-2582.681	9417.319	11415.982	101934.7766	99372.7819
FG	4989.346	-1336.760	10663.240	11931.946	102038.6034	99415.7788
G	5165.538	0.071	12000.071	12108.138	102150.0060	99430.4615
GH	4989.515	1337.025	13337.025	11932.115	102261.4187	99415.7929
H	4473.251	2582.593	14582.593	11415.851	102365.2161	99372.7709
HI	3652.489	3652.489	15652.489	10595.089	102454.3741	99304.3741
I	2582.734	4473.372	16473.372	9525.334	102522.7810	99215.2278
IJ	1336.956	4989.371	16989.371	8279.556	102565.7809	99111.4130
J	0.021	5165.333	17165.333	6942.621	102580.4444	99000.0018
JK	-1336.862	4989.376	16989.376	5605.738	102565.7813	98888.5949
K	-2582.664	4473.284	16473.284	4359.936	102522.7737	98784.7780
KL	-3652.512	3652.438	15652.438	3290.088	102454.3698	98695.6240
L	-4473.402	2582.679	14582.679	2469.198	102365.2233	98627.2165
(LA)	-4989.454	1336.891	13336.891	1953.146	102261.4076	98584.2122

Coordinates of the temporary monument near FG:

FG tmp	4916.758	-1645.315	10354.685	11859.358	102012.8904	99409.7299

Coordinates of the center of the AGS ring:

center	0.000	0.000	12000.000	6942.600	102150.0000	99000.0000

TABLE 4. Monument coordinates in AGS-centered system, and in AGS and BNL grid systems.
THESE ARE THE DESIGN VALUES, NOT MEASURED COORDINATES!
Coordinates for the BNL grid are in feet, the others are inches.

Data: Angles - ideal Lengths - ideal

	AGS-centered		AGS grid		BNL grid	
Monument	X	Y	North	East	North	East
LA	-4989.393	1336.904	13336.904	1953.207	102261.4087	98584.2172
A	-5165.400	0.000	12000.000	1777.200	102150.0000	98569.5500
AB	-4989.393	-1336.904	10663.096	1953.207	102038.5913	98584.2172
B	-4473.368	-2582.700	9417.300	2469.232	101934.7750	98627.2194
BC	-3652.489	-3652.489	8347.511	3290.111	101845.6259	98695.6259
C	-2582.700	-4473.368	7526.632	4359.900	101777.2194	98784.7750
CD	-1336.904	-4989.393	7010.607	5605.696	101734.2172	98888.5913
D	-0.000	-5165.400	6834.600	6942.600	101719.5500	99000.0000
DE	1336.904	-4989.393	7010.607	8279.504	101734.2172	99111.4087
E	2582.700	-4473.368	7526.632	9525.300	101777.2194	99215.2250
EF	3652.489	-3652.489	8347.511	10595.089	101845.6259	99304.3741
F	4473.368	-2582.700	9417.300	11415.968	101934.7750	99372.7806
FG	4989.393	-1336.904	10663.096	11931.993	102038.5913	99415.7828
G	5165.400	0.000	12000.000	12108.000	102150.0000	99430.4500
GH	4989.393	1336.904	13336.904	11931.993	102261.4087	99415.7828
H	4473.368	2582.700	14582.700	11415.968	102365.2250	99372.7806
HI	3652.489	3652.489	15652.489	10595.089	102454.3741	99304.3741
I	2582.700	4473.368	16473.368	9525.300	102522.7806	99215.2250
IJ	1336.904	4989.393	16989.393	8279.504	102565.7828	99111.4087
J	-0.000	5165.400	17165.400	6942.600	102580.4500	99000.0000
JK	-1336.904	4989.393	16989.393	5605.696	102565.7828	98888.5913
K	-2582.700	4473.368	16473.368	4359.900	102522.7806	98784.7750
KL	-3652.489	3652.489	15652.489	3290.111	102454.3741	98695.6259
L	-4473.368	2582.700	14582.700	2469.232	102365.2250	98627.2194
(LA)	-4989.393	1336.904	13336.904	1953.207	102261.4087	98584.2172

TABLE 5.1 Magnet coordinates and deviations from ideal, before realignment.
All quantities are in inches.

Magnet	Upstream End of Magnet						Downstream End of Magnet					
Name	Coordinates		Radius	Radius	Errors		Coordinates		Radius	Radius	Errors	
	X	Y	(Socket)	(Magnetic)	Radial	Azim'al	X	Y	(Socket)	(Magnetic)	Radial	Azim'al
"A01"	-4900.353	1245.671	5056.200	5056.200	0.076	0.083	-4917.430	1178.788	5056.744	5056.740	0.069	0.110
"A02"	-4925.541	1145.821	5057.060	5057.041	0.154	0.059	-4940.928	1078.530	5057.272	5057.277	0.059	0.086
"A03"	-4948.321	1045.425	5057.548	5057.565	0.184	0.005	-4965.079	963.092	5057.623	5057.628	0.171	0.024
"A04"	-4978.076	894.368	5057.779	5057.783	0.175	-0.035	-4992.482	811.594	5058.019	5058.025	0.132	-0.020
"A05"	-4997.817	777.927	5057.998	5058.025	0.096	0.068	-5009.987	694.803	5057.936	5057.926	0.101	0.076
"A06"	-5019.105	625.466	5057.926	5057.949	0.124	0.009	-5028.903	542.011	5058.028	5058.005	0.075	0.036
"A07"	-5032.394	508.210	5057.991	5058.001	0.108	0.017	-5039.844	424.522	5057.692	5057.722	0.114	0.034
"A08"	-5045.150	354.802	5057.611	5057.611	0.154	-0.046	-5050.269	270.940	5057.532	5057.528	0.147	-0.030
"A09"	-5051.710	236.962	5057.264	5057.267	0.049	-0.022	-5054.167	167.970	5056.957	5056.961	0.074	0.013
"A10"	-5055.014	133.986	5056.789	5056.804	0.133	0.007	-5055.863	64.962	5056.280	5056.274	0.150	0.035
"A11"	-5055.819	-64.972	5056.237	5056.231	0.107	-0.025	-5054.971	-133.988	5056.746	5056.740	0.069	-0.004
"A12"	-5054.221	-167.964	5057.011	5057.009	0.122	-0.021	-5051.788	-236.933	5057.341	5057.337	0.119	-0.011
"A13"	-5050.228	-270.929	5057.490	5057.470	0.090	0.021	-5045.102	-354.778	5057.561	5057.543	0.085	0.025
"A14"	-5039.804	-424.521	5057.652	5057.638	0.030	-0.032	-5032.349	-508.198	5057.945	5057.939	0.046	-0.024
"A15"	-5028.878	-541.985	5057.999	5057.995	0.066	-0.059	-5019.088	-625.407	5057.902	5057.890	0.065	-0.066
"A16"	-5009.955	-694.787	5057.903	5057.892	0.067	-0.088	-4997.834	-777.905	5058.012	5057.995	0.066	-0.092
"A17"	-4992.431	-811.609	5057.972	5057.950	0.057	0.042	-4977.967	-894.359	5057.671	5057.665	0.057	0.046
"A18"	-4964.990	-963.109	5057.539	5057.528	0.071	0.010	-4948.170	-1045.416	5057.398	5057.395	0.015	0.017
"A19"	-4940.920	-1078.621	5057.284	5057.277	0.059	0.004	-4925.506	-1145.894	5057.043	5057.037	0.150	0.019
"A20"	-4917.443	-1178.839	5056.768	5056.774	0.103	-0.064	-4900.362	-1245.709	5056.217	5056.205	0.081	-0.048
"B01"	-4866.649	-1371.359	5056.174	5056.174	0.050	0.054	-4848.003	-1437.794	5056.717	5056.717	0.046	0.055
"B02"	-4838.475	-1470.366	5056.957	5056.978	0.091	-0.008	-4818.190	-1536.341	5057.203	5057.192	-0.026	0.015
"B03"	-4807.935	-1568.749	5057.392	5057.430	0.049	0.007	-4781.317	-1648.433	5057.501	5057.501	0.044	0.019
"B04"	-4758.168	-1714.432	5057.612	5057.616	0.009	-0.040	-4729.303	-1793.332	5057.899	5057.911	0.018	-0.025
"B05"	-4717.176	-1825.124	5057.947	5057.970	0.041	0.001	-4686.144	-1903.194	5057.875	5057.868	0.042	0.012
"B06"	-4659.338	-1967.817	5057.839	5057.869	0.044	-0.026	-4626.139	-2044.992	5057.979	5057.974	0.045	-0.014
"B07"	-4612.191	-2076.009	5057.877	5057.888	-0.005	-0.004	-4576.810	-2152.216	5057.591	5057.608	0.000	0.016
"B08"	-4546.597	-2215.325	5057.589	5057.591	0.134	-0.016	-4509.038	-2290.479	5057.442	5057.448	0.067	-0.001
"B09"	-4493.362	-2320.647	5057.243	5057.247	0.029	-0.004	-4461.001	-2381.623	5056.941	5056.937	0.050	0.028
"B10"	-4444.667	-2411.451	5056.695	5056.713	0.042	0.035	-4410.903	-2471.654	5056.198	5056.180	0.056	0.059
"B11"	-4345.902	-2584.107	5056.132	5056.143	0.019	-0.044	-4310.723	-2643.491	5056.716	5056.697	0.026	-0.022
"B12"	-4293.028	-2672.518	5056.920	5056.933	0.046	-0.027	-4256.460	-2731.059	5057.286	5057.275	0.057	-0.005
"B13"	-4238.134	-2759.705	5057.445	5057.437	0.056	0.001	-4191.783	-2829.777	5057.537	5057.525	0.068	0.016
"B14"	-4152.324	-2887.554	5057.644	5057.646	0.038	-0.019	-4104.037	-2956.304	5057.949	5057.925	0.033	-0.007
"B15"	-4084.105	-2983.869	5058.002	5057.988	0.059	0.009	-4033.912	-3051.228	5057.908	5057.884	0.059	0.012
"B16"	-3991.290	-3106.711	5057.870	5057.883	0.058	-0.024	-3939.266	-3172.683	5058.037	5058.005	0.076	-0.009
"B17"	-3917.802	-3199.076	5057.990	5057.981	0.088	0.010	-3863.922	-3263.532	5057.721	5057.698	0.090	0.018
"B18"	-3818.208	-3316.543	5057.487	5057.482	0.025	0.017	-3762.523	-3379.450	5057.397	5057.392	0.011	0.029
"B19"	-3739.592	-3404.550	5057.224	5057.228	0.010	0.027	-3692.542	-3455.058	5056.905	5056.900	0.013	0.054
"B20"	-3669.162	-3479.586	5056.705	5056.699	0.028	-0.060	-3620.935	-3528.970	5056.164	5056.162	0.038	-0.034

TABLE 5.2 Magnet coordinates and deviations from ideal, before realignment.
All quantities are in inches.

Magnet Name	Upstream End of Magnet						Downstream End of Magnet					
	Coordinates		Radius	Radius	Errors		Coordinates		Radius	Radius	Errors	
	X	Y	(Socket)	(Magnetic)	Radial	Azim'al	X	Y	(Socket)	(Magnetic)	Radial	Azim'al
"C01"	-3528.977	-3620.930	5056.165	5056.176	0.053	0.025	-3479.624	-3669.196	5056.756	5056.740	0.069	0.055
"C02"	-3455.037	-3692.613	5056.943	5056.949	0.062	0.010	-3404.550	-3739.685	5057.292	5057.287	0.069	0.034
"C03"	-3379.474	-3762.554	5057.436	5057.454	0.073	-0.026	-3316.565	-3818.245	5057.529	5057.535	0.078	-0.010
"C04"	-3263.483	-3863.889	5057.664	5057.665	0.057	-0.002	-3199.124	-3917.894	5058.092	5058.107	0.214	0.010
"C05"	-3172.639	-3939.192	5057.951	5057.966	0.037	-0.004	-3106.728	-3991.263	5057.859	5057.858	0.033	-0.006
"C06"	-3051.160	-4033.865	5057.831	5057.843	0.017	0.013	-2983.823	-4084.102	5057.973	5057.961	0.031	0.025
"C07"	-2956.294	-4104.024	5057.933	5057.945	0.052	0.007	-2887.553	-4152.326	5057.645	5057.655	0.047	0.020
"C08"	-2829.795	-4191.772	5057.539	5057.549	0.091	-0.037	-2759.718	-4238.117	5057.438	5057.448	0.067	-0.022
"C09"	-2731.056	-4256.486	5057.306	5057.318	0.100	0.021	-2672.549	-4293.116	5057.011	5056.998	0.111	0.047
"C10"	-2643.521	-4310.724	5056.733	5056.743	0.072	-0.002	-2584.154	-4345.951	5056.198	5056.197	0.073	0.029
"C11"	-2471.552	-4410.961	5056.198	5056.200	0.077	0.057	-2411.382	-4444.778	5056.759	5056.752	0.081	0.079
"C12"	-2381.612	-4461.037	5056.968	5056.981	0.094	-0.001	-2320.692	-4493.450	5057.342	5057.326	0.108	0.004
"C13"	-2290.450	-4509.035	5057.426	5057.426	0.045	0.024	-2215.291	-4546.580	5057.559	5057.531	0.074	0.038
"C14"	-2152.225	-4576.892	5057.669	5057.666	0.058	0.011	-2076.025	-4612.278	5057.963	5057.948	0.055	0.025
"C15"	-2044.995	-4626.161	5058.000	5058.006	0.077	0.019	-1967.842	-4659.394	5057.900	5057.884	0.059	0.024
"C16"	-1903.137	-4686.221	5057.924	5057.921	0.096	0.069	-1825.051	-4717.209	5057.952	5057.924	-0.006	0.078
"C17"	-1793.291	-4729.371	5057.948	5057.942	0.050	0.087	-1714.386	-4758.225	5057.650	5057.642	0.034	0.102
"C18"	-1648.383	-4781.397	5057.561	5057.545	0.088	0.054	-1568.710	-4808.037	5057.477	5057.455	0.074	0.061
"C19"	-1536.362	-4818.255	5057.271	5057.287	0.069	-0.015	-1470.366	-4838.478	5056.960	5056.956	0.069	0.008
"C20"	-1437.767	-4848.049	5056.753	5056.766	0.095	-0.016	-1371.317	-4866.725	5056.236	5056.230	0.106	0.007
"D01"	-1245.742	-4900.263	5056.130	5056.139	0.015	-0.009	-1178.870	-4917.370	5056.705	5056.697	0.026	0.017
"D02"	-1145.888	-4925.419	5056.957	5056.966	0.079	-0.033	-1078.623	-4940.928	5057.292	5057.284	0.066	-0.005
"D03"	-1045.382	-4948.199	5057.420	5057.428	0.047	0.022	-963.057	-4964.965	5057.505	5057.507	0.050	0.036
"D04"	-894.246	-4977.902	5057.587	5057.595	-0.013	0.054	-811.495	-4992.418	5057.941	5057.927	0.034	0.068
"D05"	-777.934	-4997.791	5057.973	5057.996	0.067	0.056	-694.815	-5009.984	5057.935	5057.916	0.090	0.064
"D06"	-625.466	-5019.024	5057.846	5057.868	0.043	-0.001	-542.035	-5028.863	5057.990	5057.990	0.061	0.007
"D07"	-508.222	-5032.336	5057.934	5057.953	0.061	-0.001	-424.535	-5039.771	5057.620	5057.647	0.039	0.015
"D08"	-354.733	-5045.078	5057.534	5057.549	0.092	0.018	-270.878	-5050.178	5057.438	5057.431	0.050	0.027
"D09"	-237.006	-5051.687	5057.244	5057.258	0.040	-0.068	-168.027	-5054.158	5056.951	5056.955	0.067	-0.044
"D10"	-134.040	-5054.976	5056.753	5056.764	0.093	-0.048	-65.018	-5055.781	5056.199	5056.199	0.075	-0.022
"D11"	64.946	-5055.796	5056.213	5056.225	0.101	-0.050	133.969	-5055.047	5056.822	5056.802	0.131	-0.025
"D12"	167.963	-5054.254	5057.044	5057.041	0.154	-0.023	236.948	-5051.813	5057.366	5057.361	0.143	0.004
"D13"	270.999	-5050.266	5057.532	5057.520	0.139	0.089	354.857	-5045.108	5057.573	5057.545	0.088	0.103
"D14"	424.545	-5039.911	5057.761	5057.733	0.125	-0.016	508.228	-5032.430	5058.028	5058.024	0.132	-0.002
"D15"	542.094	-5028.832	5057.966	5057.967	0.038	0.054	625.541	-5019.086	5057.917	5057.877	0.052	0.067
"D16"	694.917	-5009.911	5057.876	5057.875	0.050	0.047	778.057	-4997.847	5058.048	5058.027	0.097	0.056
"D17"	811.622	-4992.424	5057.967	5057.959	0.066	0.057	894.382	-4977.965	5057.672	5057.662	0.055	0.069
"D18"	963.106	-4965.039	5057.587	5057.582	0.125	-0.003	1045.430	-4948.276	5057.506	5057.499	0.118	0.009
"D19"	1078.631	-4941.006	5057.369	5057.367	0.149	-0.004	1145.896	-4925.508	5057.046	5057.038	0.151	0.021
"D20"	1178.874	-4917.399	5056.734	5056.746	0.074	-0.019	1245.760	-4900.350	5056.219	5056.214	0.090	0.004

TABLE 5.3 Magnet coordinates and deviations from ideal, before realignment.
All quantities are in inches.

Magnet	Upstream End of Magnet						Downstream End of Magnet					
Name	Coordinates		Radius	Radius	Errors		Coordinates		Radius	Radius	Errors	
	X	Y	(Socket)	(Magnetic)	Radial	Azim'al	X	Y	(Socket)	(Magnetic)	Radial	Azim'al
"E01"	1371.344	-4866.747	5056.264	5056.264	0.140	0.013	1437.816	-4848.146	5056.860	5056.858	0.187	0.035
"E02"	1470.404	-4838.495	5056.987	5056.993	0.106	0.022	1536.416	-4818.304	5057.334	5057.321	0.103	0.052
"E03"	1568.776	-4808.043	5057.503	5057.502	0.121	-0.001	1648.451	-4781.390	5057.577	5057.588	0.131	0.012
"E04"	1714.449	-4758.233	5057.679	5057.705	0.097	-0.046	1793.357	-4729.395	5057.994	5057.996	0.103	-0.035
"E05"	1825.090	-4717.229	5057.984	5058.010	0.081	-0.050	1903.167	-4686.205	5057.921	5057.912	0.087	-0.036
"E06"	1967.799	-4659.386	5057.876	5057.899	0.074	-0.061	2044.952	-4626.148	5057.971	5057.974	0.045	-0.054
"E07"	2076.038	-4612.269	5057.960	5057.954	0.061	-0.010	2152.242	-4576.886	5057.671	5057.675	0.067	0.007
"E08"	2215.282	-4546.526	5057.507	5057.506	0.048	-0.023	2290.464	-4509.024	5057.423	5057.428	0.047	-0.008
"E09"	2320.664	-4493.446	5057.325	5057.336	0.118	-0.026	2381.627	-4461.073	5057.006	5057.005	0.118	-0.003
"E10"	2411.414	-4444.813	5056.805	5056.811	0.140	-0.067	2471.548	-4410.918	5056.159	5056.160	0.036	-0.041
"E11"	2584.135	-4345.951	5056.188	5056.184	0.061	-0.045	2643.513	-4310.762	5056.760	5056.747	0.076	-0.024
"E12"	2672.474	-4293.114	5056.970	5056.969	0.082	-0.111	2730.986	-4256.502	5057.281	5057.273	0.055	-0.088
"E13"	2759.748	-4238.142	5057.476	5057.456	0.075	0.033	2829.751	-4191.679	5057.437	5057.409	-0.049	0.052
"E14"	2887.556	-4152.215	5057.555	5057.580	-0.027	0.045	2956.335	-4103.974	5057.917	5057.910	0.017	0.055
"E15"	2983.863	-4084.041	5057.947	5057.945	0.016	0.043	3051.257	-4033.879	5057.899	5057.886	0.061	0.055
"E16"	3106.704	-3991.265	5057.846	5057.856	0.031	-0.014	3172.672	-3939.247	5058.015	5057.993	0.064	-0.006
"E17"	3199.168	-3918.021	5058.217	5058.220	0.328	-0.057	3263.494	-3863.977	5057.738	5057.715	0.107	-0.047
"E18"	3316.528	-3818.317	5057.559	5057.548	0.091	-0.066	3379.437	-3762.635	5057.472	5057.447	0.066	-0.055
"E19"	3404.550	-3739.643	5057.261	5057.256	0.038	-0.007	3455.045	-3692.586	5056.928	5056.924	0.037	0.015
"E20"	3479.602	-3669.151	5056.709	5056.716	0.045	-0.040	3528.978	-3620.917	5056.157	5056.131	0.007	-0.015
"F01"	3620.898	-3528.964	5056.133	5056.135	0.011	0.012	3669.119	-3479.598	5056.682	5056.691	0.020	0.020
"F02"	3692.532	-3455.059	5056.899	5056.910	0.023	-0.062	3739.602	-3404.597	5057.263	5057.249	0.031	-0.055
"F03"	3762.548	-3379.470	5057.429	5057.431	0.050	-0.028	3818.248	-3316.563	5057.530	5057.534	0.077	-0.006
"F04"	3863.838	-3263.455	5057.607	5057.637	0.029	-0.014	3917.779	-3199.034	5057.946	5057.942	0.049	0.007
"F05"	3939.186	-3172.598	5057.921	5057.944	0.015	0.024	3991.336	-3106.725	5057.915	5057.903	0.078	0.041
"F06"	4033.845	-3051.162	5057.815	5057.849	0.024	-0.000	4084.094	-2983.830	5057.971	5057.977	0.047	0.014
"F07"	4104.088	-2956.358	5058.022	5058.025	0.132	-0.008	4152.301	-2887.566	5057.632	5057.639	0.031	-0.005
"F08"	4191.760	-2829.759	5057.508	5057.502	0.045	-0.015	4238.088	-2759.663	5057.384	5057.392	0.011	0.008
"F09"	4256.428	-2731.048	5057.252	5057.264	0.046	-0.004	4293.094	-2672.586	5057.012	5057.002	0.115	0.004
"F10"	4310.721	-2643.471	5056.703	5056.720	0.049	0.038	4345.961	-2584.136	5056.198	5056.196	0.072	0.049
"F11"	4410.894	-2471.605	5056.166	5056.184	0.060	-0.022	4444.705	-2411.443	5056.724	5056.720	0.049	-0.010
"F12"	4461.014	-2381.579	5056.932	5056.934	0.047	0.017	4493.387	-2320.628	5057.257	5057.245	0.027	0.031
"F13"	4509.015	-2290.543	5057.450	5057.435	0.054	-0.067	4546.487	-2215.338	5057.496	5057.477	0.020	-0.044
"F14"	4576.832	-2152.211	5057.609	5057.603	-0.005	-0.002	4612.198	-2075.988	5057.875	5057.867	-0.026	0.026
"F15"	4626.092	-2044.982	5057.932	5057.941	0.012	0.003	4659.348	-1967.824	5057.851	5057.827	0.002	0.023
"F16"	4686.082	-1903.103	5057.783	5057.794	-0.031	0.049	4717.204	-1825.055	5057.949	5057.921	-0.009	0.073
"F17"	4729.244	-1793.356	5057.853	5057.832	-0.061	-0.018	4758.108	-1714.441	5057.559	5057.538	-0.070	0.011
"F18"	4781.244	-1648.362	5057.409	5057.410	-0.047	0.024	4807.956	-1568.690	5057.393	5057.366	-0.014	0.055
"F19"	4818.149	-1536.276	5057.143	5057.145	-0.073	0.034	4838.323	-1470.283	5056.787	5056.769	-0.118	0.043
"F20"	4847.906	-1437.652	5056.583	5056.583	-0.088	0.052	4866.579	-1371.213	5056.068	5056.053	-0.071	0.067

TABLE 5.4 Magnet coordinates and deviations from ideal, before realignment.
All quantities are in inches.

Magnet	Upstream End of Magnet						Downstream End of Magnet					
Name	Coordinates X	Coordinates Y	Radius (Socket)	Radius (Magnetic)	Errors Radial	Errors Azim'al	Coordinates X	Coordinates Y	Radius (Socket)	Radius (Magnetic)	Errors Radial	Errors Azim'al
"G01"	4900.313	-1245.622	5056.149	5056.157	0.033	0.120	4917.392	-1178.739	5056.695	5056.698	0.027	0.149
"G02"	4925.368	-1145.761	5056.879	5056.882	-0.005	0.079	4940.874	-1078.502	5057.213	5057.207	-0.011	0.102
"G03"	4948.165	-1045.238	5057.357	5057.347	-0.034	0.156	4964.923	-962.913	5057.436	5057.448	-0.009	0.170
"G04"	4977.889	-894.177	5057.562	5057.585	-0.023	0.120	4992.418	-811.427	5057.930	5057.953	0.060	0.134
"G05"	4997.742	-777.802	5057.905	5057.931	0.002	0.179	5009.950	-694.679	5057.882	5057.873	0.048	0.194
"G06"	5018.988	-625.371	5057.798	5057.819	-0.006	0.089	5028.850	-541.938	5057.967	5057.956	0.027	0.102
"G07"	5032.278	-507.987	5057.852	5057.868	-0.024	0.226	5039.739	-424.304	5057.569	5057.569	-0.038	0.242
"G08"	5045.016	-354.630	5057.465	5057.486	0.028	0.117	5050.158	-270.768	5057.412	5057.423	0.042	0.136
"G09"	5051.844	-236.831	5057.392	5057.402	0.184	0.115	5054.301	-167.846	5057.087	5057.073	0.186	0.141
"G10"	5055.051	-133.930	5056.825	5056.822	0.151	0.064	5055.802	-64.924	5056.219	5056.226	0.102	0.072
"G11"	5055.886	65.094	5056.306	5056.318	0.194	0.096	5055.000	134.113	5056.778	5056.771	0.100	0.119
"G12"	5054.201	168.084	5056.996	5056.992	0.104	0.100	5051.897	237.068	5057.456	5057.440	0.222	0.119
"G13"	5050.295	270.898	5057.556	5057.553	0.172	-0.014	5045.160	354.751	5057.617	5057.606	0.148	-0.007
"G14"	5039.807	424.532	5057.656	5057.658	0.050	-0.021	5032.481	508.226	5058.078	5058.070	0.177	-0.010
"G15"	5028.973	542.123	5058.109	5058.109	0.180	0.068	5019.198	625.552	5058.030	5058.030	0.205	0.065
"G16"	5010.038	694.936	5058.005	5058.004	0.179	0.048	4997.953	778.071	5058.154	5058.120	0.191	0.053
"G17"	4992.453	811.614	5057.994	5057.981	0.088	0.044	4978.009	894.378	5057.715	5057.692	0.085	0.057
"G18"	4965.085	963.163	5057.643	5057.619	0.161	0.044	4948.356	1045.494	5057.596	5057.582	0.202	0.055
"G19"	4940.964	1078.643	5057.331	5057.333	0.115	0.017	4925.478	1145.905	5057.018	5057.010	0.123	0.037
"G20"	4917.418	1179.047	5056.792	5056.796	0.125	0.144	4900.348	1245.926	5056.258	5056.253	0.129	0.166
"H01"	4866.729	1371.441	5056.274	5056.289	0.165	0.111	4848.105	1437.904	5056.845	5056.853	0.182	0.132
"H02"	4838.592	1470.441	5057.091	5057.112	0.225	0.030	4818.409	1536.452	5057.445	5057.459	0.241	0.054
"H03"	4808.018	1568.874	5057.510	5057.532	0.151	0.100	4781.321	1648.534	5057.538	5057.552	0.095	0.113
"H04"	4758.201	1714.472	5057.657	5057.668	0.060	-0.013	4729.342	1793.373	5057.950	5057.951	0.058	-0.001
"H05"	4717.272	1825.051	5058.010	5058.027	0.098	-0.102	4686.200	1903.103	5057.892	5057.884	0.059	-0.093
"H06"	4659.355	1967.764	5057.834	5057.853	0.028	-0.081	4626.171	2044.940	5057.987	5057.979	0.050	-0.073
"H07"	4612.238	2075.994	5057.913	5057.936	0.044	-0.037	4576.850	2152.191	5057.617	5057.640	0.032	-0.024
"H08"	4546.510	2215.179	5057.447	5057.476	0.019	-0.109	4509.068	2290.384	5057.425	5057.404	0.024	-0.099
"H09"	4493.363	2320.551	5057.200	5057.201	-0.017	-0.089	4461.013	2381.519	5056.904	5056.894	0.006	-0.070
"H10"	4444.656	2411.290	5056.608	5056.618	-0.053	-0.101	4410.901	2471.495	5056.119	5056.111	-0.013	-0.078
"H11"	4345.981	2584.135	5056.215	5056.223	0.099	-0.060	4310.726	2643.486	5056.716	5056.716	0.045	-0.029
"H12"	4292.983	2672.471	5056.857	5056.867	-0.020	-0.043	4256.395	2731.006	5057.203	5057.200	-0.018	-0.014
"H13"	4238.127	2759.613	5057.390	5057.377	-0.004	-0.071	4191.800	2829.706	5057.512	5057.483	0.025	-0.052
"H14"	4152.341	2887.489	5057.621	5057.618	0.010	-0.082	4104.096	2956.277	5057.982	5057.957	0.064	-0.063
"H15"	4084.128	2983.792	5057.975	5057.983	0.054	-0.066	4033.973	3051.187	5057.932	5057.899	0.074	-0.057
"H16"	3991.323	3106.716	5057.899	5057.891	0.066	-0.041	3939.264	3172.660	5058.021	5058.009	0.080	-0.025
"H17"	3917.803	3198.986	5057.934	5057.925	0.032	-0.060	3863.913	3263.451	5057.661	5057.642	0.035	-0.038
"H18"	3818.423	3316.587	5057.677	5057.650	0.193	-0.091	3762.683	3379.456	5057.520	5057.507	0.126	-0.073
"H19"	3739.684	3404.568	5057.303	5057.309	0.091	-0.021	3692.621	3455.071	5056.972	5056.968	0.080	0.010
"H20"	3669.201	3479.613	5056.752	5056.758	0.087	-0.067	3621.015	3529.040	5056.270	5056.254	0.130	-0.039

TABLE 5.5 Magnet coordinates and deviations from ideal, before realignment.
All quantities are in inches.

Magnet	Upstream End of Magnet						Downstream End of Magnet					
Name	Coordinates		Radius	Radius	Errors		Coordinates		Radius	Radius	Errors	
	X	Y	(Socket)	(Magnetic)	Radial	Azim'al	X	Y	(Socket)	(Magnetic)	Radial	Azim'al
"I01"	3529.028	3620.898	5056.179	5056.179	0.055	-0.034	3479.659	3669.132	5056.734	5056.737	0.066	-0.014
"I02"	3455.071	3692.600	5056.956	5056.972	0.085	-0.025	3404.599	3739.688	5057.327	5057.312	0.094	0.001
"I03"	3379.517	3762.631	5057.522	5057.536	0.156	-0.007	3316.599	3818.299	5057.592	5057.610	0.152	-0.000
"I04"	3263.540	3863.873	5057.688	5057.702	0.094	-0.056	3199.085	3917.758	5057.962	5057.986	0.093	-0.045
"I05"	3172.705	3939.179	5057.982	5057.991	0.062	-0.064	3106.791	3991.254	5057.891	5057.891	0.066	-0.061
"I06"	3051.267	4033.817	5057.856	5057.895	0.070	-0.101	2983.937	4084.048	5057.997	5058.007	0.078	-0.099
"I07"	2956.276	4103.980	5057.887	5057.922	0.029	-0.004	2887.555	4152.295	5057.621	5057.632	0.024	0.001
"I08"	2829.756	4191.706	5057.461	5057.485	0.028	-0.042	2759.723	4238.111	5057.436	5057.442	0.061	-0.031
"I09"	2731.101	4256.473	5057.319	5057.327	0.109	-0.024	2672.588	4293.078	5057.000	5056.997	0.109	-0.007
"I10"	2643.496	4310.727	5056.722	5056.739	0.068	0.020	2584.136	4345.940	5056.179	5056.158	0.034	0.038
"I11"	2471.602	4410.958	5056.220	5056.210	0.086	0.013	2411.415	4444.747	5056.748	5056.746	0.075	0.034
"I12"	2381.659	4461.019	5056.975	5056.979	0.092	-0.051	2320.722	4493.431	5057.339	5057.334	0.116	-0.032
"I13"	2290.532	4509.030	5057.459	5057.430	0.049	-0.050	2215.355	4546.534	5057.546	5057.525	0.068	-0.039
"I14"	2152.292	4576.878	5057.685	5057.673	0.065	-0.056	2076.094	4612.257	5057.972	5057.960	0.067	-0.046
"I15"	2045.131	4626.178	5058.071	5058.066	0.137	-0.099	1967.967	4659.399	5057.954	5057.946	0.120	-0.089
"I16"	1903.241	4686.136	5057.885	5057.877	0.051	-0.059	1825.194	4717.216	5058.009	5058.006	0.077	-0.052
"I17"	1793.453	4729.283	5057.923	5057.934	0.042	-0.095	1714.572	4758.184	5057.675	5057.660	0.052	-0.087
"I18"	1648.490	4781.365	5057.566	5057.549	0.092	-0.057	1568.806	4807.981	5057.453	5057.452	0.071	-0.048
"I19"	1536.396	4818.278	5057.303	5057.306	0.088	-0.041	1470.401	4838.487	5056.979	5056.989	0.102	-0.023
"I20"	1437.843	4848.013	5056.741	5056.744	0.073	-0.100	1371.387	4866.672	5056.205	5056.206	0.082	-0.075
"J01"	1245.781	4900.261	5056.138	5056.147	0.023	-0.046	1178.915	4917.368	5056.713	5056.700	0.029	-0.027
"J02"	1145.948	4925.451	5057.002	5057.002	0.114	-0.085	1078.683	4940.932	5057.308	5057.309	0.091	-0.062
"J03"	1045.441	4948.212	5057.445	5057.462	0.081	-0.033	963.118	4964.987	5057.538	5057.559	0.102	-0.019
"J04"	894.346	4977.803	5057.507	5057.522	-0.085	-0.062	811.600	4992.345	5057.886	5057.885	-0.008	-0.047
"J05"	777.913	4997.753	5057.932	5057.964	0.035	0.071	694.795	5009.904	5057.853	5057.839	0.013	0.073
"J06"	625.522	5018.994	5057.823	5057.832	0.007	-0.060	542.082	5028.796	5057.928	5057.934	0.005	-0.047
"J07"	508.226	5032.319	5057.917	5057.927	0.034	-0.007	424.547	5039.812	5057.662	5057.666	0.058	0.006
"J08"	354.788	5045.001	5057.461	5057.476	0.019	-0.042	270.929	5050.133	5057.395	5057.402	0.022	-0.026
"J09"	236.953	5051.677	5057.231	5057.235	0.017	-0.015	167.976	5054.120	5056.910	5056.907	0.020	0.005
"J10"	133.994	5054.839	5056.615	5056.627	-0.044	-0.005	64.972	5055.691	5056.109	5056.105	-0.019	0.023
"J11"	-64.986	5055.709	5056.127	5056.117	-0.007	-0.009	-134.005	5054.885	5056.661	5056.667	-0.004	0.015
"J12"	-167.913	5054.077	5056.865	5056.877	-0.010	-0.067	-236.895	5051.665	5057.216	5057.218	0.000	-0.043
"J13"	-270.926	5050.126	5057.388	5057.371	-0.010	0.023	-354.780	5044.992	5057.452	5057.457	-0.001	0.035
"J14"	-424.545	5039.744	5057.594	5057.581	-0.027	-0.003	-508.229	5032.255	5057.854	5057.857	-0.036	0.016
"J15"	-541.995	5028.781	5057.904	5057.907	-0.022	-0.038	-625.443	5019.025	5057.844	5057.813	-0.012	-0.022
"J16"	-694.856	5009.851	5057.809	5057.787	-0.039	-0.005	-777.988	4997.726	5057.917	5057.895	-0.034	0.007
"J17"	-811.587	4992.337	5057.876	5057.851	-0.042	0.035	-894.344	4977.876	5057.579	5057.562	-0.046	0.047
"J18"	-963.082	4964.916	5057.461	5057.447	-0.010	-0.003	-1045.407	4948.148	5057.375	5057.363	-0.018	0.012
"J19"	-1078.564	4940.843	5057.196	5057.208	-0.010	-0.035	-1145.834	4925.367	5056.894	5056.882	-0.005	-0.008
"J20"	-1178.872	4917.331	5056.667	5056.665	-0.006	-0.006	-1245.747	4900.233	5056.102	5056.106	-0.018	0.020

TABLE 5.6 Magnet coordinates and deviations from ideal, before realignment.
All quantities are in inches.

Magnet	Upstream End of Magnet						Downstream End of Magnet					
Name	Coordinates		Radius	Radius	Errors		Coordinates		Radius	Radius	Errors	
	X	Y	(Socket)	(Magnetic)	Radial	Azim'al	X	Y	(Socket)	(Magnetic)	Radial	Azim'al
"K01"	-1371.295	4866.643	5056.151	5056.156	0.032	-0.006	-1437.734	4847.931	5056.631	5056.641	-0.030	0.018
"K02"	-1470.354	4838.469	5056.948	5056.949	0.062	-0.017	-1536.339	4818.214	5057.225	5057.227	0.009	0.006
"K03"	-1568.756	4807.922	5057.382	5057.387	0.006	0.018	-1648.432	4781.277	5057.464	5057.487	0.030	0.031
"K04"	-1714.452	4758.082	5057.538	5057.567	-0.041	0.008	-1793.352	4729.217	5057.826	5057.825	-0.067	0.023
"K05"	-1825.110	4717.081	5057.853	5057.865	-0.064	0.022	-1903.178	4686.051	5057.782	5057.778	-0.047	0.033
"K06"	-1967.863	4659.266	5057.790	5057.812	-0.013	0.045	-2045.031	4626.065	5057.927	5057.911	-0.018	0.052
"K07"	-2076.046	4612.169	5057.872	5057.875	-0.018	0.039	-2152.237	4576.766	5057.560	5057.579	-0.029	0.054
"K08"	-2215.314	4546.457	5057.458	5057.485	0.028	0.036	-2290.497	4508.963	5057.383	5057.388	0.007	0.049
"K09"	-2320.682	4493.313	5057.215	5057.224	0.006	0.050	-2381.636	4460.936	5056.890	5056.889	0.002	0.070
"K10"	-2411.434	4444.619	5056.645	5056.647	-0.025	0.042	-2471.618	4410.828	5056.115	5056.107	-0.017	0.065
"K11"	-2584.158	4345.843	5056.107	5056.107	-0.017	0.030	-2643.522	4310.634	5056.656	5056.667	-0.004	0.050
"K12"	-2672.529	4292.973	5056.879	5056.861	-0.026	0.012	-2731.055	4256.387	5057.221	5057.203	-0.015	0.031
"K13"	-2759.652	4238.109	5057.395	5057.400	0.020	-0.028	-2829.742	4191.792	5057.525	5057.502	0.045	-0.018
"K14"	-2887.582	4152.283	5057.626	5057.607	-0.001	0.027	-2956.314	4103.979	5057.908	5057.903	0.011	0.036
"K15"	-2983.664	4083.643	5057.508	5057.521	-0.408	0.117	-3051.262	4033.774	5057.819	5057.787	-0.038	0.122
"K16"	-3106.645	3991.145	5057.715	5057.712	-0.113	0.013	-3172.651	3939.180	5057.949	5057.912	-0.017	0.020
"K17"	-3199.011	3917.634	5057.818	5057.794	-0.098	0.066	-3263.477	3863.764	5057.564	5057.554	-0.053	0.078
"K18"	-3316.504	3818.209	5057.462	5057.449	-0.009	-0.013	-3379.407	3762.521	5057.366	5057.351	-0.029	-0.001
"K19"	-3404.544	3739.549	5057.188	5057.182	-0.036	0.052	-3455.061	3692.515	5056.888	5056.872	-0.016	0.075
"K20"	-3479.642	3669.051	5056.663	5056.655	-0.016	0.058	-3529.019	3620.834	5056.126	5056.118	-0.006	0.072
"L01"	-3620.896	3528.912	5056.096	5056.116	-0.008	0.048	-3669.167	3479.580	5056.705	5056.683	0.012	0.067
"L02"	-3692.589	3454.998	5056.899	5056.902	0.015	0.021	-3739.628	3404.484	5057.206	5057.209	-0.009	0.046
"L03"	-3762.653	3379.327	5057.412	5057.411	0.030	0.149	-3818.338	3316.422	5057.506	5057.509	0.052	0.159
"L04"	-3863.765	3263.293	5057.446	5057.452	-0.156	0.062	-3917.812	3198.978	5057.935	5057.939	0.046	0.072
"L05"	-3939.248	3172.613	5057.979	5057.993	0.064	0.052	-3991.323	3106.698	5057.888	5057.888	0.062	0.054
"L06"	-4033.871	3051.102	5057.800	5057.814	-0.011	0.064	-4084.085	2983.752	5057.917	5057.918	-0.012	0.073
"L07"	-4104.040	2956.209	5057.896	5057.923	0.030	0.085	-4152.353	2887.483	5057.627	5057.628	0.021	0.093
"L08"	-4191.879	2829.738	5057.595	5057.611	0.154	0.070	-4238.219	2759.663	5057.494	5057.502	0.121	0.079
"L09"	-4256.436	2731.023	5057.246	5057.256	0.038	0.022	-4293.056	2672.516	5056.943	5056.945	0.057	0.044
"L10"	-4310.767	2643.441	5056.728	5056.739	0.067	0.089	-4345.993	2584.089	5056.201	5056.195	0.071	0.105
"L11"	-4410.917	2471.536	5056.152	5056.162	0.038	0.050	-4444.735	2411.369	5056.716	5056.695	0.023	0.069
"L12"	-4461.029	2381.522	5056.919	5056.926	0.039	0.074	-4493.422	2320.568	5057.259	5057.256	0.038	0.101
"L13"	-4509.161	2290.367	5057.500	5057.464	0.084	0.156	-4546.646	2215.184	5057.572	5057.560	0.102	0.164
"L14"	-4576.926	2152.213	5057.695	5057.688	0.080	0.036	-4612.306	2076.013	5057.983	5057.962	0.069	0.048
"L15"	-4626.190	2044.920	5057.997	5057.997	0.068	0.100	-4659.431	1967.775	5057.908	5057.898	0.073	0.100
"L16"	-4686.167	1903.116	5057.866	5057.881	0.056	0.068	-4717.281	1825.087	5058.032	5058.024	0.095	0.071
"L17"	-4729.348	1793.213	5057.900	5057.893	-0.000	0.153	-4758.250	1714.327	5057.654	5057.637	0.029	0.166
"L18"	-4781.338	1648.374	5057.502	5057.494	0.037	0.043	-4807.998	1568.704	5057.438	5057.432	0.051	0.055
"L19"	-4818.320	1536.244	5057.297	5057.299	0.081	0.116	-4838.542	1470.252	5056.988	5056.977	0.090	0.136
"L20"	-4848.102	1437.695	5056.784	5056.774	0.103	0.068	-4866.735	1371.231	5056.222	5056.218	0.094	0.092

TABLE 6. Design values for magnet and straight section lengths, offsets, and coordinates.
All measurements are to the survey sockets.
All quantities are in inches.

No.	Length		Offset from mon. line		Dist. along mon. line		Radius	
	Magnet	St. Sect.	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
01	69.0000	33.9996	100.2718	92.0698	78.7571	147.2679	5056.1239	5056.6711
02	69.0000	33.9995	88.4255	81.8359	181.0716	249.7562	5056.8872	5057.2180
03	84.0000	69.9995	78.9340	73.0660	283.6316	367.4264	5057.3807	5057.4572
04	84.0000	33.9994	69.1530	65.6304	437.3165	521.2426	5057.6077	5057.8928
05	84.0000	69.9994	64.6799	63.5052	555.2287	639.2205	5057.9293	5057.8252
06	84.0000	33.9994	63.5052	64.6799	709.2199	793.2117	5057.8252	5057.9293
07	84.0000	69.9995	65.6304	69.1530	827.1978	911.1239	5057.8929	5057.6078
08	84.0000	33.9995	73.0660	78.9340	981.0139	1064.8087	5057.4572	5057.3807
09	69.0000	33.9996	81.8359	88.4255	1098.6841	1167.3688	5057.2180	5056.8872
10	69.0000	129.9900	92.0698	100.2718	1201.1725	1269.6833	5056.6711	5056.1240

(This table repeats for each superperiod)

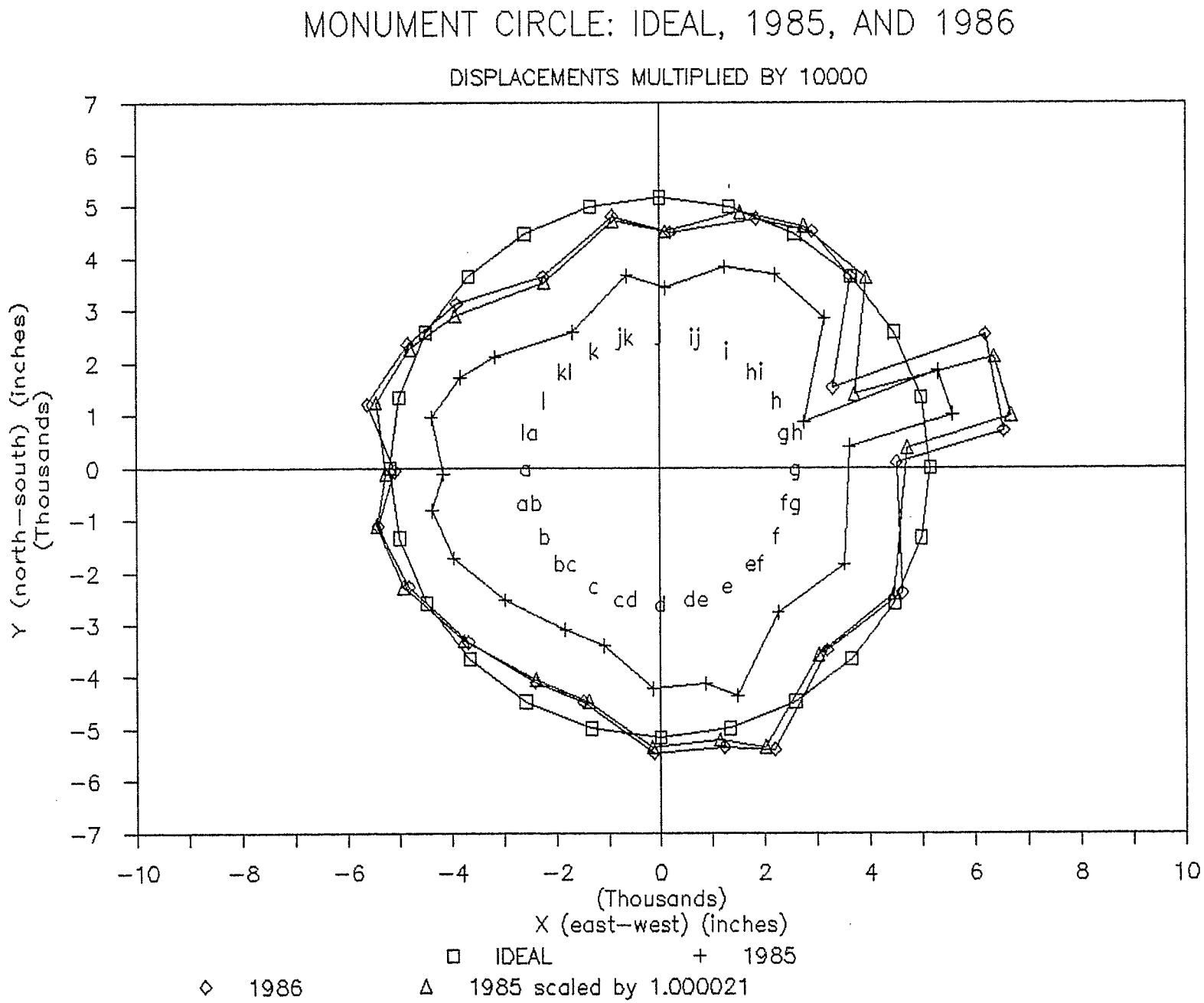

MONUMENT CIRCLE: IDEAL, 1985, AND 1986
DISPLACEMENTS MULTIPLIED BY 10000
Y (north–south) (inches)
(Thousands)
X (east–west) (inches)
(Thousands)
7
6
5
4
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
−10
−8
−6
−4
−2
0
2
4
6
8
10
jk
k
ij
i
kl
hi
l
h
la
gh
a
g
ab
fg
b
f
bc
ef
c
cd
d
de
e
□ IDEAL
+ 1985
◇ 1986
Δ 1985 scaled by 1.000021

Figure 1

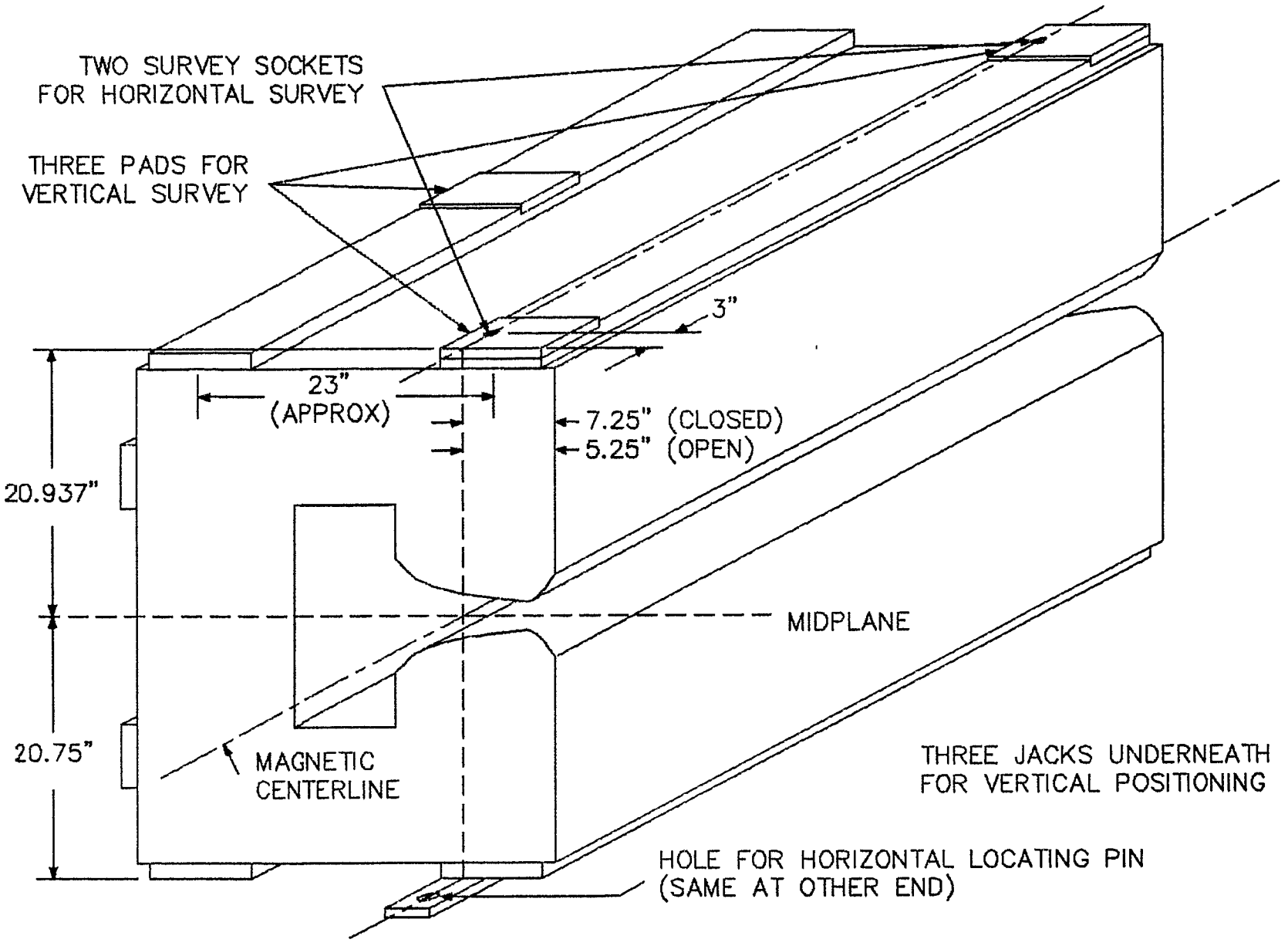

TWO SURVEY SOCKETS
FOR HORIZONTAL SURVEY
THREE PADS FOR
VERTICAL SURVEY
3"
23"
(APPROX)
7.25" (CLOSED)
5.25" (OPEN)
20.937"
MIDPLANE
20.75"
MAGNETIC
CENTERLINE
THREE JACKS UNDERNEATH
FOR VERTICAL POSITIONING
HOLE FOR HORIZONTAL LOCATING PIN
(SAME AT OTHER END)

Figure 2

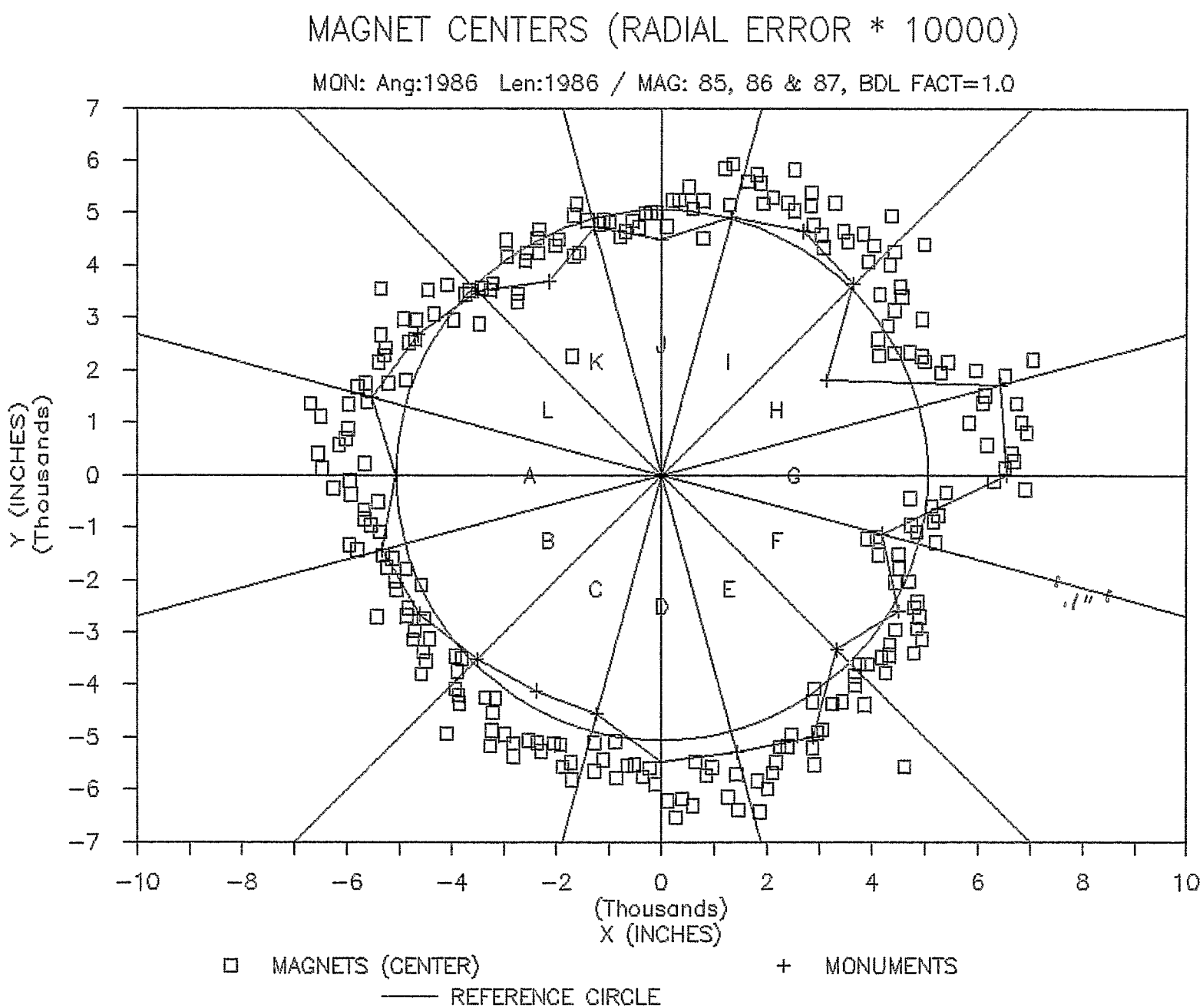

MAGNET CENTERS (RADIAL ERROR * 10000)
MON: Ang:1986 Len:1986 / MAG: 85, 86 & 87, BDL FACT=1.0
Y (INCHES)
(Thousands)
X (INCHES)
(Thousands)
A
B
C
D
E
F
G
H
I
J
K
L
MAGNETS (CENTER)
MONUMENTS
REFERENCE CIRCLE

Figure 3

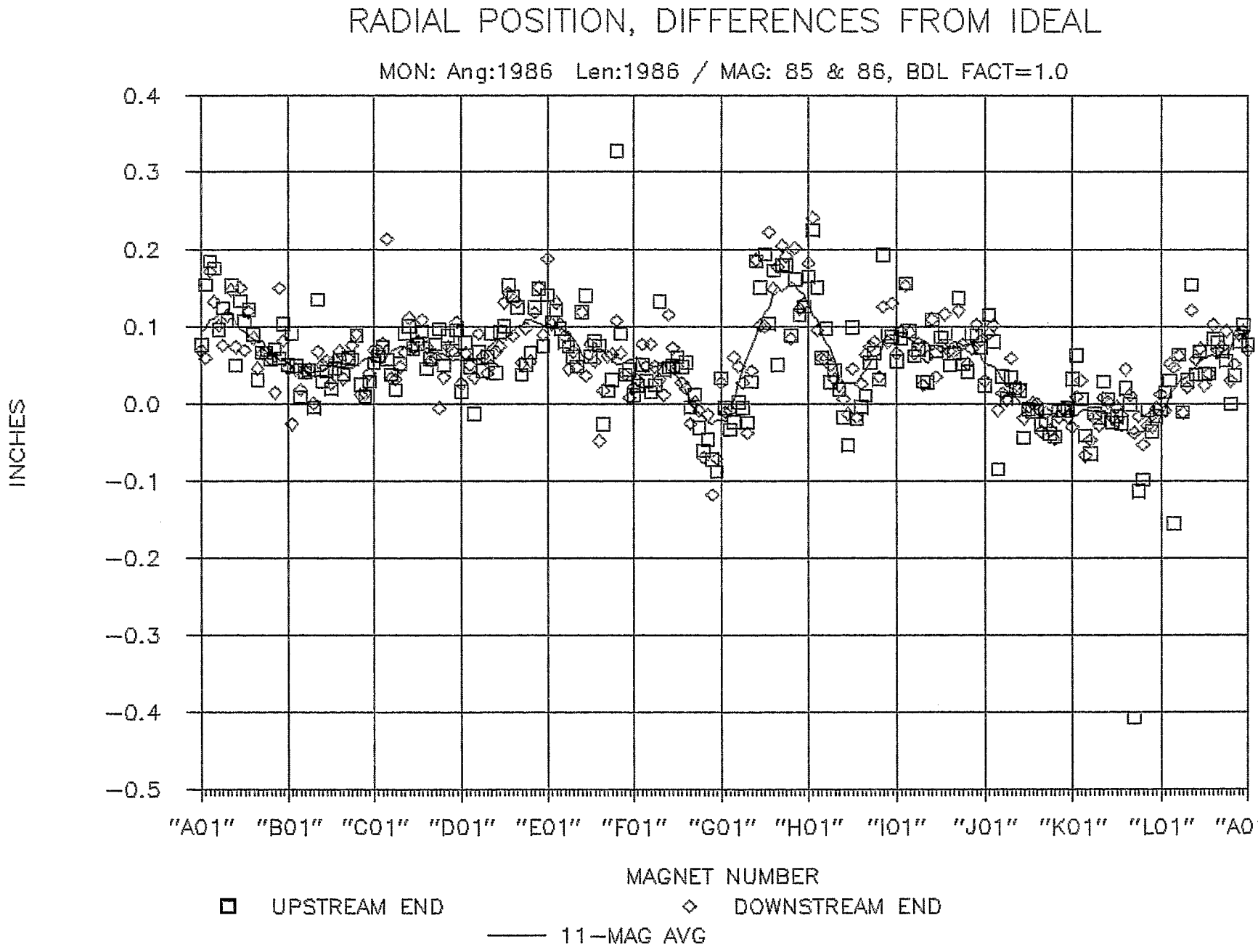

RADIAL POSITION, DIFFERENCES FROM IDEAL
MON: Ang:1986 Len:1986 / MAG: 85 & 86, BDL FACT=1.0
INCHES
0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.4
−0.5
"A01" "B01" "C01" "D01" "E01" "F01" "G01" "H01" "I01" "J01" "K01" "L01" "A01"
MAGNET NUMBER
UPSTREAM END
DOWNSTREAM END
11−MAG AVG

Figure 4

[Data MGRA8604, NO roll, add E131417F0708K15]
[Desired DR =0.050]

TEAM HARRISON - KARL - LEHN DATE 6-10-87

PRESET DIAL GAUGES TO 0.500 INCHES

MAGNET	U/S		MID		D/S		
G01	0.517		0.520	.520	0.523		G01
G02	0.556		0.558	.559	0.561		G02
G03	0.584		0.571	.571	0.559		G03
G04	0.573		0.532	.531	0.490		G04
G05	0.548		0.525	525	0.502		G05
G06	0.556		0.540	.541	0.523		G06
G07	0.575		0.581	.581	0.588		G07
G08	0.522		0.515	.517	0.508		G08
G09	0.366		0.365	.366	0.364		G09
G10	0.399		0.424	.424	0.448		G10

Figure 5

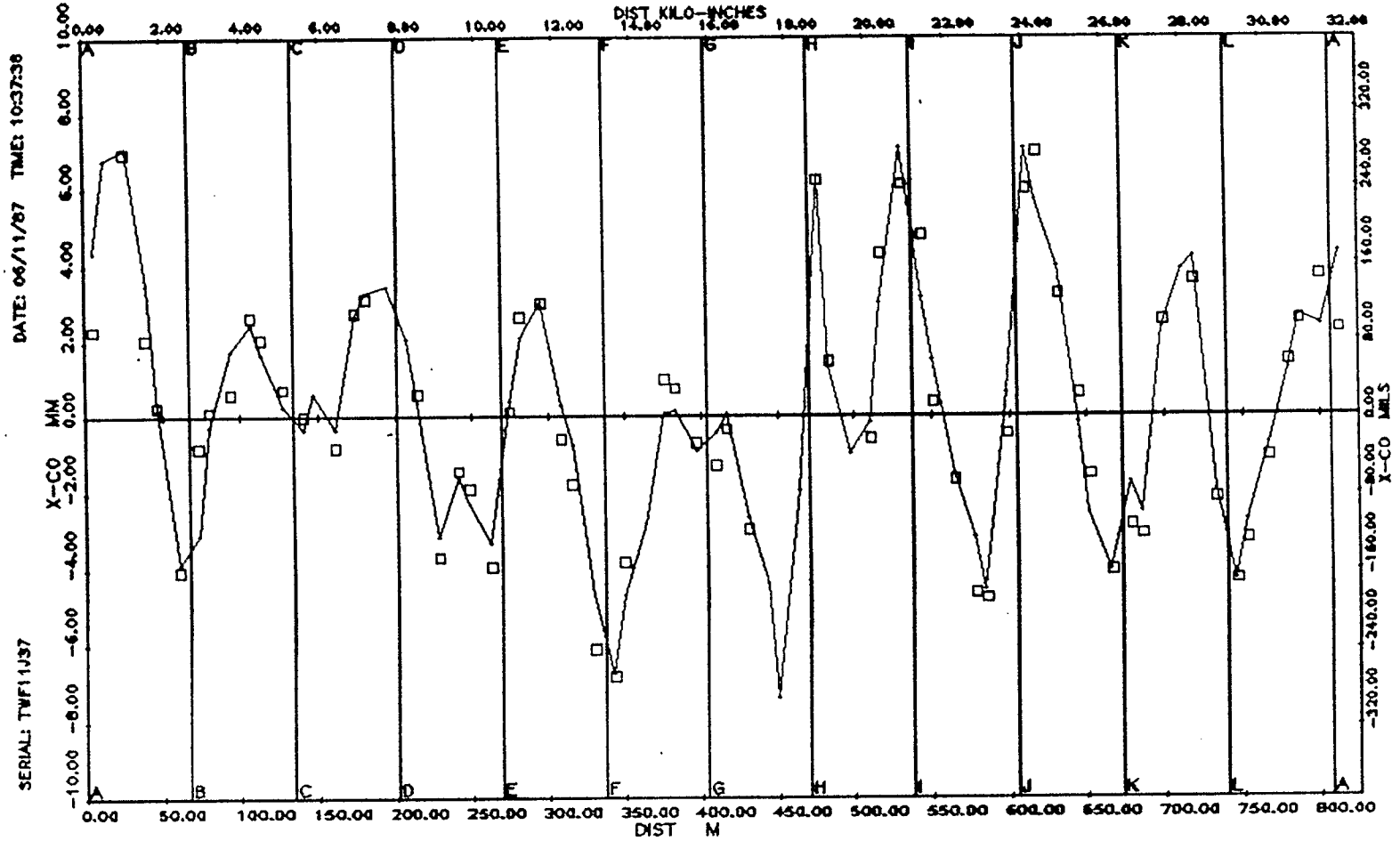

DIST KILO-INCHES
DATE: 06/11/87 TIME: 10:37:38
SERIAL: TWF11J37
X-CO MM
X-CO MILS
DIST M

Figure 6

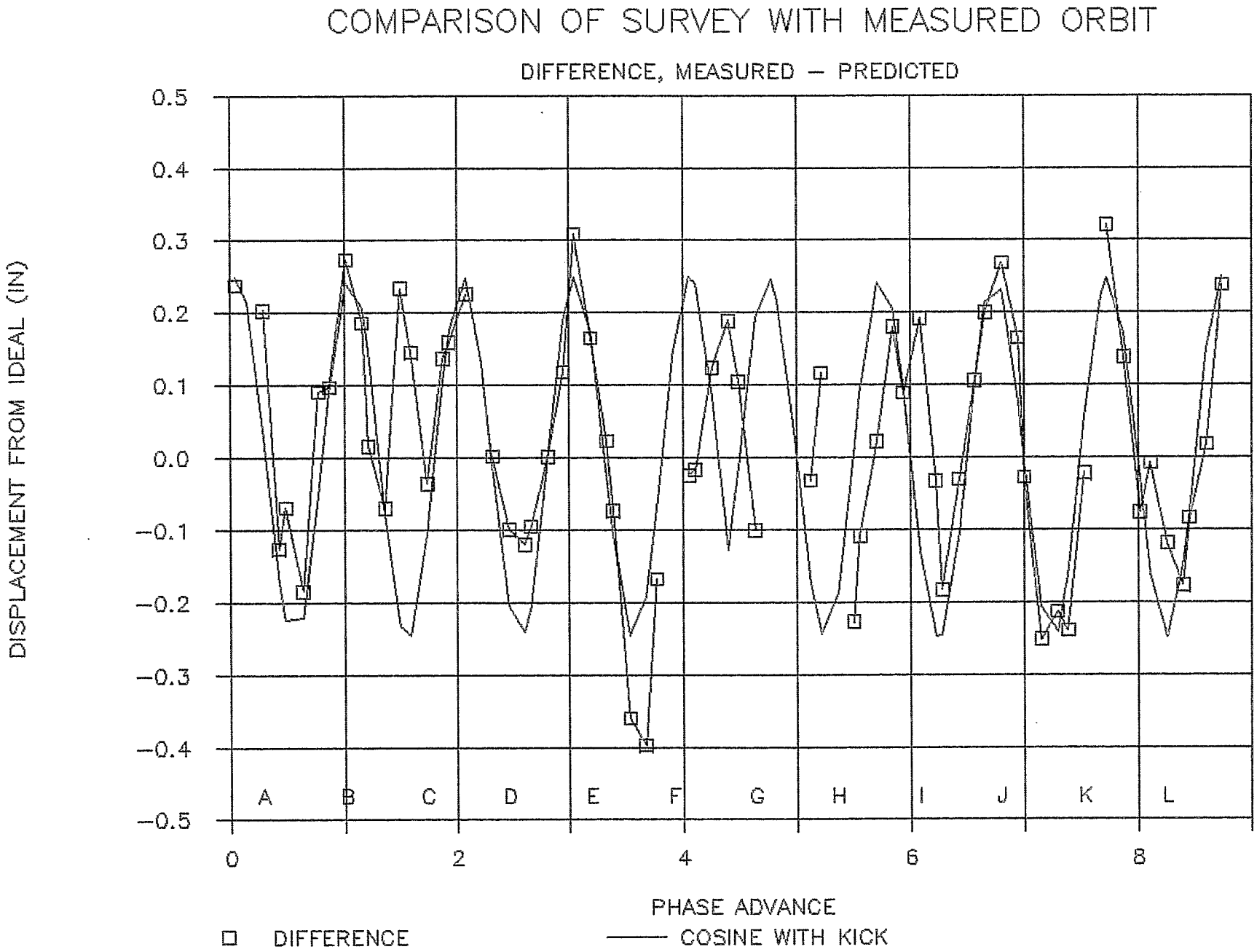
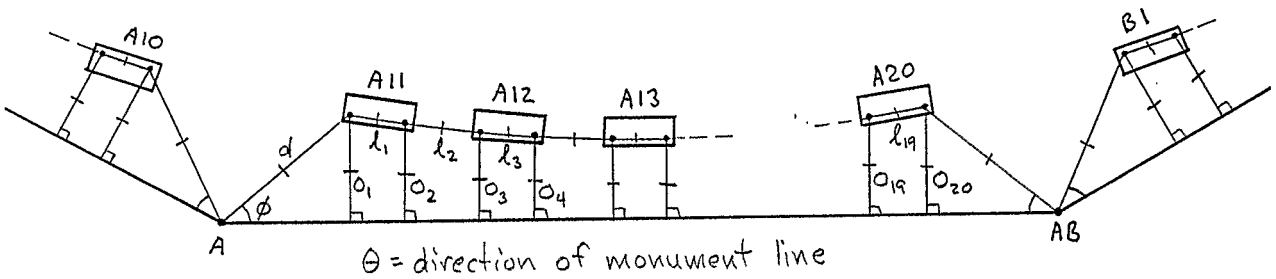
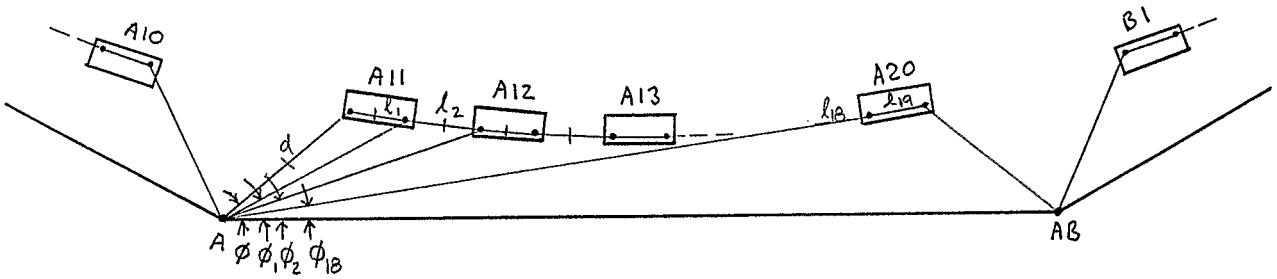

COMPARISON OF SURVEY WITH MEASURED ORBIT
DIFFERENCE, MEASURED – PREDICTED
DISPLACEMENT FROM IDEAL (IN)
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.4
−0.5
A
B
C
D
E
F
G
H
I
J
K
L
0
2
4
6
8
PHASE ADVANCE
DIFFERENCE
COSINE WITH KICK

Figure 7

a.


A10
A11
A12
A13
A20
B1
d
ϕ
l_1
l_2
l_3
l_{19}
O_1
O_2
O_3
O_4
O_{19}
O_{20}
A
AB
θ = direction of monument line

b.


A10
A11
A12
A13
A20
B1
d
l_1
l_2
l_{18}
l_{19}
A
ϕ ϕ_1 ϕ_2 ϕ_{18}
AB

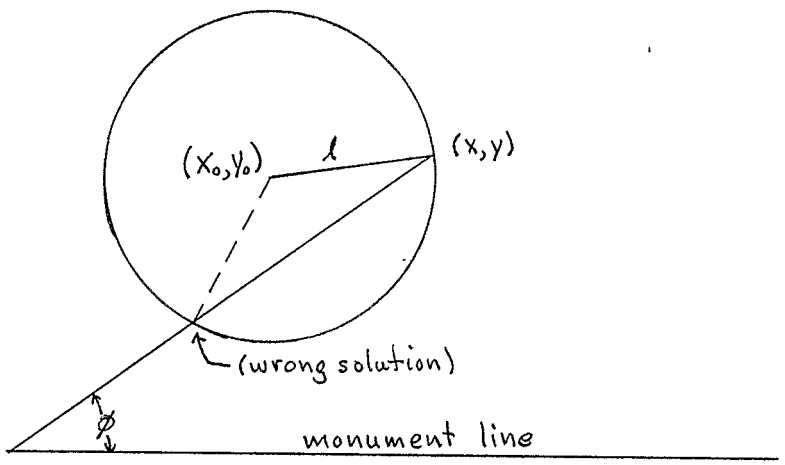

(X_o, Y_o)
l
(x, y)
(wrong solution)
ϕ
monument line

Figure A1