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THE 1987 VERTICAL SURVEY OF THE AGS: I

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Collider Accelerator Department

Brookhaven National Laboratory

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Accelerator Division
Technical Note

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THE 1987 VERTICAL SURVEY OF THE AGS: I

E. Bleser, E. Auerbach, S. Tanaka, R. Thern

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I. Introduction

In 1985 we surveyed and realigned the AGS main magnets vertically and developed an understanding of the limitations of our then used techniques.[1] In 1986 we surveyed the AGS again and started to develop some improved procedures.[2] In 1987 we have fully developed a set of new procedures, we have carried out a complete vertical survey, and we have carried out the first phase of a complete vertical realignment. This note records the work completed so far in 1987. The remaining work to be done involves a fine tuning of the vertical alignment based on the measured beam orbit and is scheduled to take place during machine turn on this fall. The goals of this effort are to maximize the aperture in the AGS, to reduce the number of resonances which affect the polarized proton beam, and to simplify and standardize the high field orbit.

II. The Vertical Monument System

The vertical monument system consists of a set of stainless steel pins mounted in the pile caps which are on top of the 50-foot pilings used to support the AGS magnets. We have standardized on a set of 40 pins spaced every 6 magnets around the ring, starting at SS A-02. In some instances new pins were installed to improve accessibility, so there is not a one-to-one comparison with the 1986 survey. The pin elevations were measured using the standard procedures, but with considerable care, taking about one day to complete an orbit.

Five complete orbits were run and the results averaged to give the pin elevations listed in Table 1 and plotted in Figure 1. (We have defined the elevation of pin A-02 as 0.616 inches, which then enables us to set the pad height of the magnets to 56.000 inches.) As is customary, the closing errors were corrected for by distributing them linearly around the ring. Table 2 summarizes the results of a statistical analysis of the data. The distribution of the errors in measuring the change in height from one pin to the next was analyzed from the 200 measurements that were made, and has a standard deviation of 0.00177 inches. Four of the measurements were rejected as being more than 3.5 standard deviations from the mean. The standard deviation per instrument sighting is just the previous number divided by the square root of two. The standard deviation on the pin elevation found by averaging over five runs is just that for a single measurement divided by the square root of five. The closing errors should be distributed around zero with a standard deviation given by the square root of 40 times the standard deviation per step.

The results are very good, except for the one mysterious fact that the closing errors average to +0.024 inches when we would expect them to average to 0.000 ± 0.005. This appears to be significant and suggests a systematic 0.0005 inch error per pin, which can be ignored on an individual basis and which we correct for on an overall basis, but the procedures are designed to eliminate such a bias; we have at present no idea where it comes from. However, we note that all these circuits were made one way around the AGS and that the original workers[3] always matched clockwise and counterclockwise circuits, a procedure we may have to adopt.

To emphasize the necessarily statistical nature of the vertical survey, we plot in Figures 2 through 6 the deviation of each run from the average value of all 5 runs, displaying, as we have in previous papers, the random walk effect.

III. Is the AGS Moving?

The elevation of the vertical monuments (pins) around the ring is found by defining the elevation for the first (n = 0) pin and then adding in sequence the steps in elevation from pin to pin. The accuracy with which we know the elevation of the nth pin is given by the square root of n, times the standard deviation per pin. Since we close the ring and tie the first point to the last, we actually do much better than this, and the proper value for the standard deviation of the absolute value of the elevation of the nth pin, $\sigma(n)$, is given by:

$$\frac{1}{\sigma^2(n)} = \frac{1}{n\,\sigma^2} + \frac{1}{(40-n)\sigma^2}$$

where σ is the standard deviation per pin elevation. Figure 7 shows two envelopes plotted from this formula. The outer one is an envelope one standard deviation wide, for single measurements around the ring. It is to be compared with Figures 2 through 6 and seems reasonable. The inner envelope is plotted for an average of 5 runs and purports to show the absolute accuracy with which we know the elevations of the vertical monuments, 0.003 inches in the worst case.

To confirm this rather spectacular claim, we can look at the results from 1986, where we have a certain number of pins which overlap the present set, measured the equivalent of three times. Figure 8 shows our estimate of a one standard deviation envelope between the two results and the data points resulting from subtracting the 1986 data from the 1987 data. The agreement is not very good, but it is not clear that there is a statistically significant effect here. However, in our judgment, the precision of our data is pretty good, and we feel that the suggested disagreement in Figure 8 is due to the earth moving. Thus, the simplest and most reasonable statement to make at the present time is:

> Some parts of the ring are moving up and some parts of the ring are moving down. These are long-term (the order of 12 months) motions and their rate is as high as 0.001 inches per month.

This statement is the simplest explanation of the data and is a reasonable geological statement since we have recently observed 0.040 inches of motion in a few days as the roof beams are moved,[1] and earlier work saw motions similar to that postulated here.[3] By repeating this year's measurements next year, we should have two sets of data of precision considerably greater than the postulated earth movements, and we might hope to have a good answer to the question posed in this section.

For the general operation of the AGS, this motion is inconsequential. However, the polarized proton runs are sensitive at the 0.005 inch level, and the postulated motions may have to be taken into account.

IV. The Magnet Elevations

The magnet elevations were determined by locating the survey instrument midway between two pins, sighting each pin, using the pin elevations tabulated above, averaging these two measurements to get the instrument elevation, and then measuring the magnet elevations, using all three pads on each magnet. These data indicate where the magnets have been for the past two years and are discussed at length below. Without moving the instrument, the magnets were then realigned vertically so that all three pads on each magnet were set to a fixed elevation. Thus, our data now indicate that the ring is flat to one or two thousands of an inch. This is not so of course, the dominant error being the random walk in the pin elevations, which we project to have a standard deviation of 0.003 inches. There is also the reading error on each pad, which we project to be nearly 0.002 inches per pad. There is also the possibility of some blunders creeping in. However, we do not deem it meaningful or efficient to resurvey the ring to check the accuracy of our work. Our expectation is that the ring is in general very smooth and that the most efficient procedure is to measure the orbit of the circulating proton beam and move selected magnets to improve it. This will be carried out this fall.

V. Analysis of Magnet Elevations

Figures 9 and 10 show the elevations of the downstream pads on each magnet as measured in 1986 and 1987. The 1986 data are in general confirmed by the 1987 data, the deviations being largely accounted for by changes in pin elevations discussed above. Also, the magnets were realigned radially[4] in June of 1987 before the vertical measurements were made.

Table 3 lists the elevation of the downstream pads on the magnets, the roll of the magnets, and the pitch of the magnets, as measured in July of 1987 before realignment. Figures 11 and 12 show the distribution of the pitch and the roll. The roll of a magnet is defined as positive when the magnet is rotated in a clockwise direction looking along the beam, that is when the aisle side of the magnet is low. The numerical value is the difference between the elevation of the middle pad and the mean of the elevations of the upstream and downstream pads in inches. The pad separation is 22 inches so the roll in radians can be found by dividing the tabulated number by 22. the pitch is the downstream elevation minus the upstream elevation in inches.

The vertical realignment set the elevation, the pitch, and the roll of each magnet to zero within our accuracy so any plots of the present distributions are essentially meaningless, however, just for fun we show in Figure 13 a before and after plot of the magnet elevations.

VI. Overall Program

During the summer of 1987 we have undertaken a complete realignment of the AGS. The initial radial realignment was carried out early in June.[4] The vertical realignment, reported here, was completed by early July. The time-consuming effort of realigning the 5 and 10 foot straight sections, based on the current magnet positions, will be completed in August. At this point the ring should be mechanically aligned very well. Any orbit distortions will presumably be due to a distribution of very small errors in the magnet placements and in the magnetic fields. Therefore, the final step in smoothing the high field orbit, both vertically and horizontally, will assume that the ring is well enough aligned and will use the measured beam orbit to select several dozen magnets for moving to reduce the principal observed harmonics. Thus, this final fine tuning will make no effort to deal with the magnets that are actually the source of the orbit distortions, since they are very hard to find, but will rather introduce some small displacements from the optimum survey positions. With the AGS alignment optimized, it will then be useful to devise techniques for measuring the dynamic aperture around the ring and maximize it. It will also be useful to define the Pick-Up Electrode centers to agree with the magnet centers, and finally come up with a simple well centered standard orbit.

VII. Acknowledgments

As always when we report on the survey results, we are pleased to acknowledge the people who actually do the work, Frank Karl and the Survey Group, in particular John Sullivan, Don Kazmark, and Joe Roecklein. We would like to also acknowledge that this note was greatly expedited by the fact that we received the data from them already entered into a spreadsheet program on a PC, a great boon.

IX. References

1. E. Bleser, K. Brown, R. Thern. Accelerator Division Technical Note No. 237, January 23, 1986.
2. E. Bleser. AGS/AD/Tech. Note No. 275, February 4, 1987.
3. O.S. Reading. AGS Internal Report OSR-5, July 15, 1964.
4. R. Thern, et al., to be issued.

TABLE 1. VERTICAL MONUMENT ELEVATION

AVERAGE of 5 RUNS, 6/22-7/7/87

A-02 set to 0.616 inches

Number	Station	ELEVATION
1	A-02	0.616 inches
2	A-08	0.164
3	A-14	0.253
4	A-20	0.550
5	B-06	1.022
6	B-12	0.602
7	B-18	0.716
8	C-04	0.935
9	C-10	0.536
10	C-16	0.857
11	D-02	0.713
12	D-08	0.933
13	D-14	0.977
14	D-20	0.825
15	E-06	1.037
16	E-12	0.721
17	E-18	0.443
18	F-04	0.685
19	F-10	0.914
20	F-16	0.145
21	G-02	0.283
22	G-08	0.415
23	G-14	0.424
24	G-20	0.464
25	H-06	0.502
26	H-12	0.635
27	H-18	0.547
28	I-04	0.696
29	I-10	0.957
30	I-16	0.930
31	J-02	0.986
32	J-08	1.042
33	J-14	0.794
34	J-20	0.935
35	K-06	1.012
36	K-12	0.799
37	K-18	0.725
38	L-04	0.519
39	L-10	0.611
40	L-16	0.235

TABLE 2. STATISTICAL ANALYSIS

FOR ONE RUN

STANDARD DEVIATION

PER PIN ELEVATION	1.77 *0.001 inches
PER SIGHT	1.25 *0.001 inches

CLOSING ERRORS

PREDICTED

MEAN	0
STANDARD DEVIATION	11 *0.001 inches

FOR AVERAGE OF 5 RUNS

STANDARD DEVIATION

PER PIN ELEVATION	0.79

CLOSING ERRORS

PREDICTED

MEAN	0
STANDARD DEVIATION	5 *0.001 inches

MEASURED

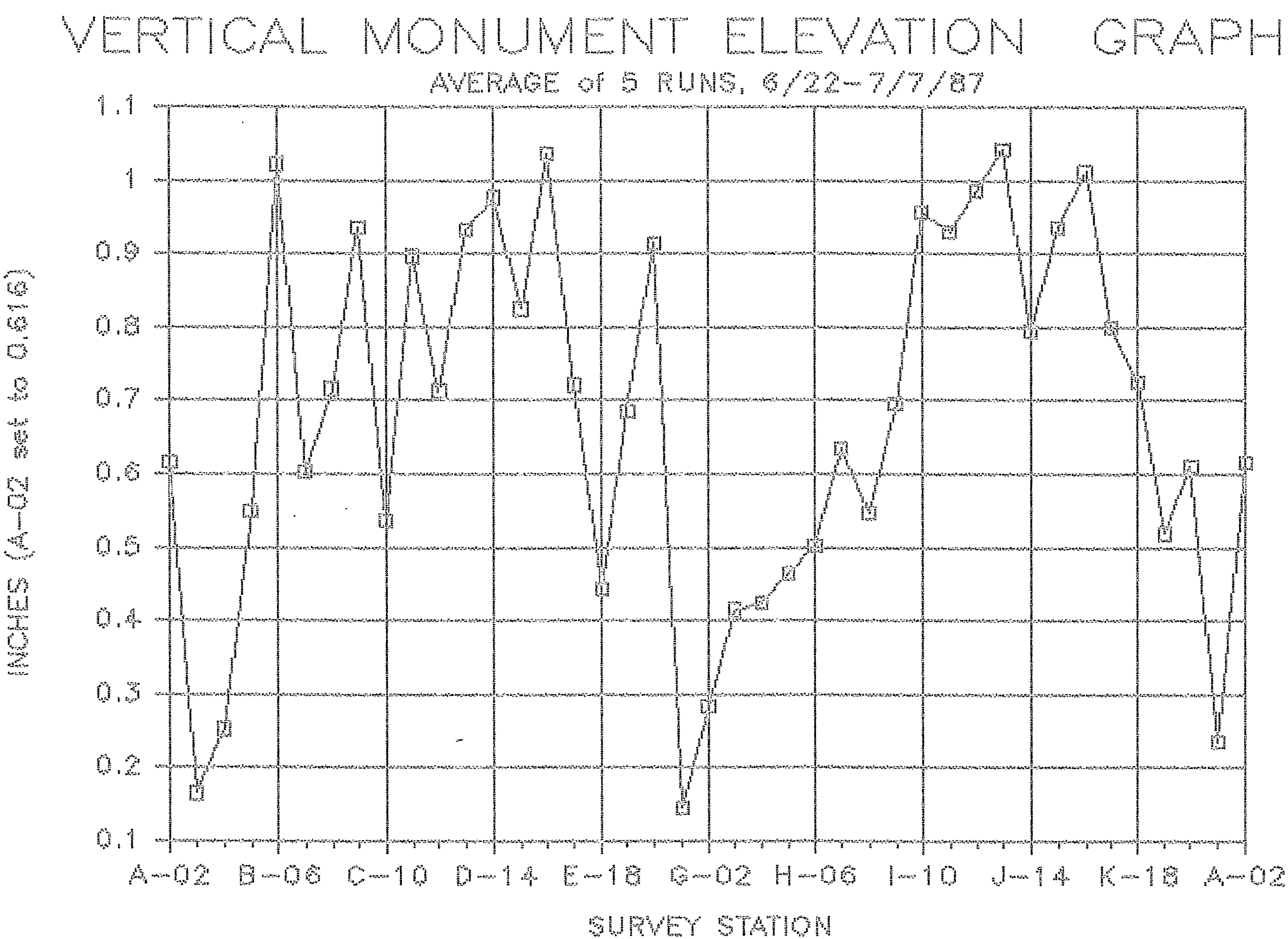
MEAN	24 *0.001 inches
STANDARD DEVIATION	7 *0.001 inches

TABLE III. MAGNET ELEVATIONS, PITCHES, and ROLLS; JUNE 1987

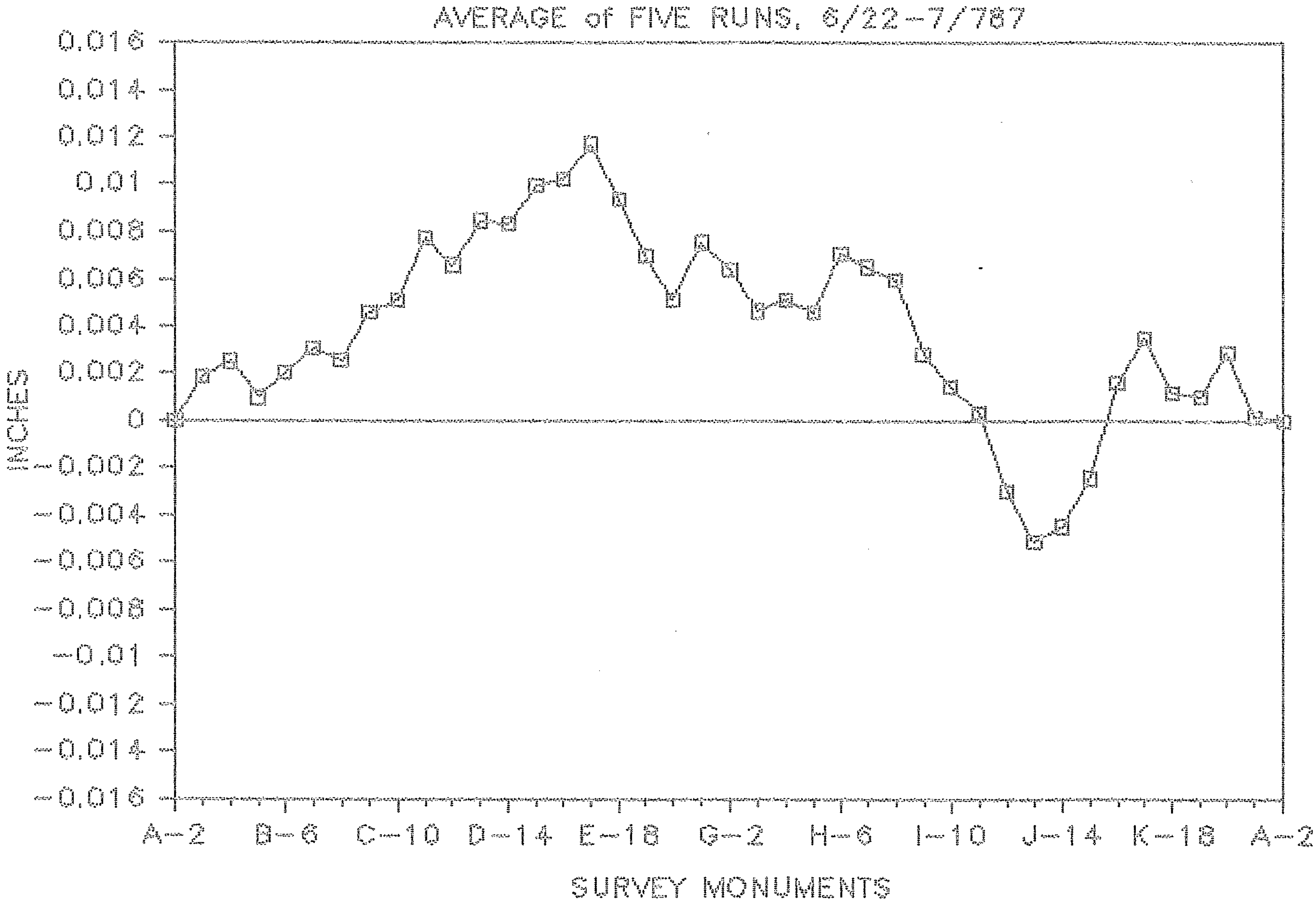
MAGNET	ELEVATION	PITCH	ROLL	MAGNET	ELEVATION	PITCH	ROLL
A-01	0.000	-0.003	0.002	C-01	-0.021	-0.002	.000
A-02	-0.008	-0.010	0.003	C-02	-0.017	0.001	-0.003
A-03	0.002	-0.013	0.004	C-03	-0.026	-0.004	-0.006
A-04	0.007	0.011	.000	C-04	-0.032	0.001	-0.009
A-05	-0.002	-0.007	0.001	C-05	-0.024	0.015	0.002
A-06	0.004	0.003	-0.002	C-06	-0.017	0.012	0.003
A-07	-0.009	-0.011	0.001	C-07	-0.026	0.004	-0.009
A-08	-0.015	-0.006	-0.004	C-08	-0.030	-0.008	.000
A-09	-0.011	0.004	-0.008	C-09	-0.024	-0.003	0.005
A-10	-0.009	-0.005	-0.002	C-10	-0.027	0.004	-0.002
A-11	-0.005	0.009	-0.017	C-11	-0.026	0.004	0.002
A-12	-0.016	-0.001	-0.002	C-12	-0.041	-0.003	-0.009
A-13	-0.014	-0.001	.000	C-13	-0.025	0.006	0.001
A-14	-0.027	0.007	-0.005	C-14	-0.025	0.004	0.002
A-15	-0.026	0.001	0.003	C-15	-0.027	0.000	0.000
A-16	-0.027	0.000	0.004	C-16	-0.010	0.015	0.003
A-17	-0.024	-0.001	-0.004	C-17	-0.019	-0.003	-0.007
A-18	-0.019	-0.001	0.001	C-18	-0.007	0.014	-0.003
A-19	-0.023	0.000	0.000	C-19	-0.012	-0.013	-0.010
A-20	-0.033	-0.002	-0.001	C-20	-0.005	0.002	0.001
B-01	-0.028	-0.001	.000	D-01	-0.004	0.007	-0.001
B-02	-0.028	0.000	0.000	D-02	-0.013	0.000	-0.006
B-03	-0.020	-0.011	0.005	D-03	-0.005	0.003	0.002
B-04	-0.022	0.001	-0.003	D-04	0.004	-0.001	-0.005
B-05	-0.034	-0.010	0.001	D-05	0.006	0.005	.000
B-06	-0.026	0.008	-0.003	D-06	0.005	-0.002	0.004
B-07	-0.035	-0.004	-0.001	D-07	0.007	0.000	-0.002
B-08	-0.032	-0.015	0.003	D-08	0.007	-0.002	0.001
B-09	-0.025	-0.002	0.002	D-09	0.014	0.008	0.002
B-10	-0.031	-0.005	0.000	D-10	0.017	0.000	0.000
B-11	-0.028	0.003	0.002	D-11	0.012	-0.008	0.003
B-12	-0.035	-0.005	0.002	D-12	0.022	-0.007	-0.008
B-13	-0.035	0.004	0.001	D-13	0.013	-0.013	-0.010
B-14	-0.026	0.008	0.006	D-14	0.019	0.003	0.002
B-15	-0.023	0.006	0.004	D-15	0.021	0.006	0.001
B-16	-0.021	0.000	0.010	D-16	0.027	0.005	-0.001
B-17	-0.015	0.001	-0.001	D-17	0.035	0.010	0.005
B-18	-0.044	-0.004	0.002	D-18	0.032	-0.003	-0.016
B-19	-0.050	0.003	0.002	D-19	0.021	0.000	0.000
B-20	-0.044	0.010	-0.001	D-20	0.019	0.001	-0.006

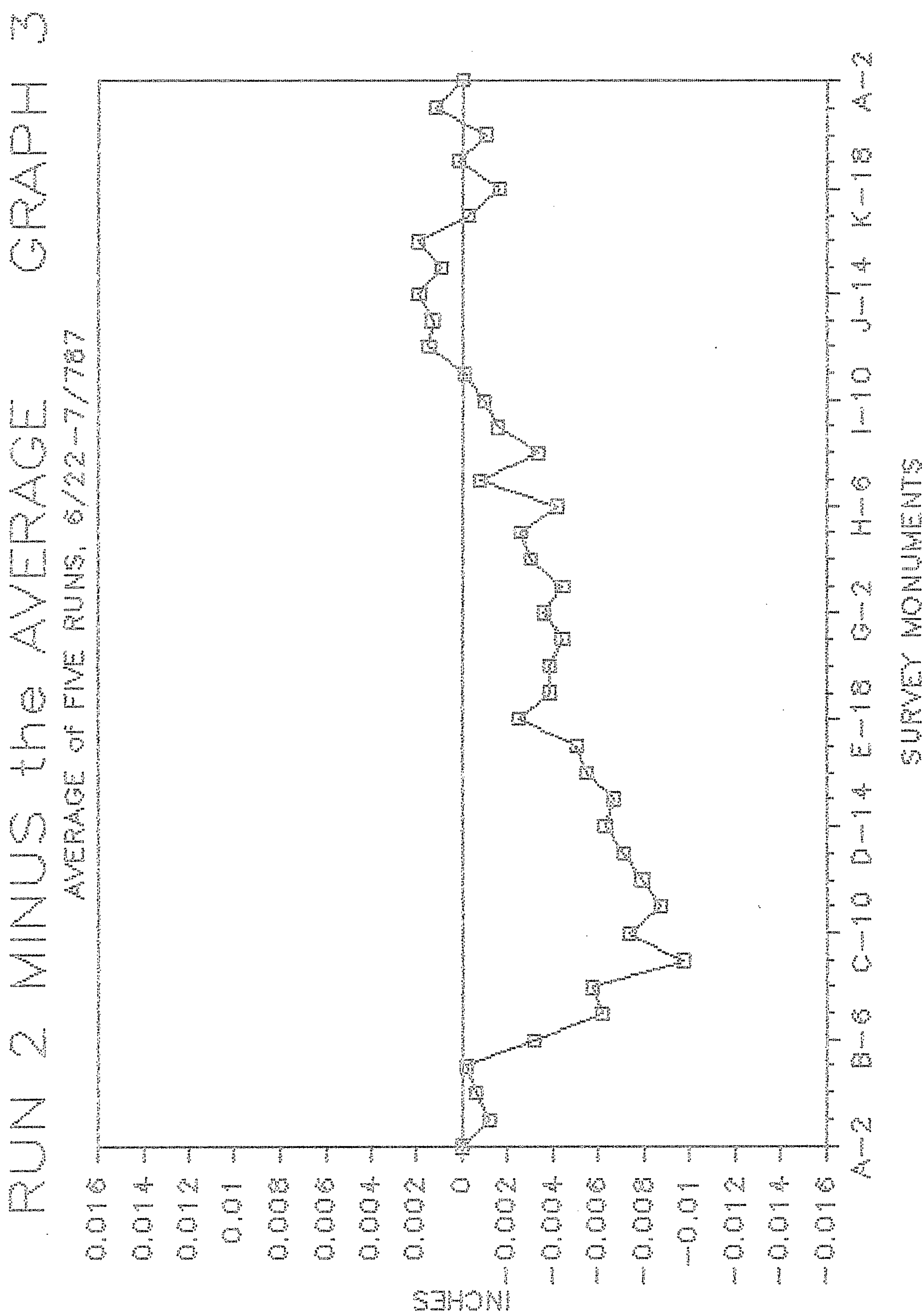
MAGNET	ELEVATION	PITCH	ROLL	MAGNET	ELEVATION	PITCH	ROLL
E-01	0.022	0.008	-0.001	G-01	0.024	-0.005	0.003
E-02	0.031	0.007	0.007	G-02	0.024	-0.006	0.005
E-03	0.029	0.004	-0.002	G-03	0.031	0.019	.000
E-04	0.028	-0.003	0.002	G-04	0.031	0.006	-0.003
E-05	0.023	-0.007	-0.004	G-05	0.026	-0.002	-0.001
E-06	0.020	-0.010	0.008	G-06	0.027	0.002	0.001
E-07	0.022	0.002	0.003	G-07	0.021	-0.002	-0.001
E-08	0.021	0.003	-0.002	G-08	0.023	-0.005	-0.012
E-09	0.025	0.000	-0.001	G-09	0.027	0.000	-0.004
E-10	0.017	-0.011	-0.006	G-10	0.030	0.005	0.002
E-11	0.023	0.001	-0.006	G-11	0.034	0.007	-0.006
E-12	0.012	-0.008	-0.004	G-12	0.027	-0.005	-0.002
E-13	0.016	0.001	-0.005	G-13	0.024	-0.007	-0.003
E-14	0.010	-0.007	-0.003	G-14	0.022	-0.005	.000
E-15	0.011	0.000	0.005	G-15	0.027	0.002	-0.005
E-16	0.016	0.003	-0.003	G-16	0.022	-0.005	0.001
E-17	0.007	0.000	-0.005	G-17	0.029	-0.012	-0.011
E-18	0.002	-0.005	-0.003	G-18	0.025	0.007	-0.009
E-19	0.005	-0.001	0.001	G-19	0.008	-0.005	-0.001
E-20	0.005	0.001	.000	G-20	0.013	-0.003	-0.002
F-01	0.014	0.009	.000	H-01	0.007	0.004	0.008
F-02	0.007	-0.004	-0.001	H-02	-0.010	0.001	-0.003
F-03	0.010	0.001	.000	H-03	-0.009	-0.002	0.001
F-04	0.009	0.000	0.001	H-04	-0.014	-0.005	-0.004
F-05	0.015	0.015	-0.003	H-05	-0.016	-0.004	0.005
F-06	0.016	-0.005	0.002	H-06	-0.020	-0.001	.000
F-07	0.013	-0.001	.000	H-07	-0.023	0.001	.000
F-08	0.013	-0.003	0.002	H-08	-0.017	0.006	-0.003
F-09	0.014	0.001	.000	H-09	-0.011	0.003	0.002
F-10	0.013	-0.001	-0.015	H-10	-0.013	0.004	-0.005
F-11	0.016	0.006	0.003	H-11	-0.018	0.000	0.000
F-12	0.018	0.003	-0.002	H-12	-0.023	-0.002	-0.004
F-13	0.016	0.001	.000	H-13	-0.013	0.001	-0.005
F-14	0.010	-0.009	-0.002	H-14	-0.012	0.003	0.006
F-15	0.019	0.001	.000	H-15	-0.009	0.000	0.000
F-16	0.018	0.003	0.002	H-16	0.004	0.002	-0.002
F-17	0.023	0.009	0.005	H-17	-0.010	-0.013	0.005
F-18	0.023	0.000	0.000	H-18	-0.012	-0.008	.000
F-19	0.025	0.003	0.003	H-19	-0.004	0.001	-0.002
F-20	0.033	0.004	-0.006	H-20	-0.003	-0.008	-0.003

MAGNET	ELEVATION	PITCH	ROLL	MAGNET	ELEVATION	PITCH	ROLL
I-01	0.007	0.000	0.002	K-01	0.015	0.006	0.000
I-02	0.010	-0.002	0.001	K-02	0.016	0.003	0.003
I-03	0.008	0.002	0.008	K-03	0.015	-0.008	0.002
I-04	-0.003	-0.010	0.005	K-04	0.013	-0.004	0.002
I-05	0.006	0.011	0.010	K-05	0.014	-0.001	.000
I-06	0.003	0.005	-0.005	K-06	0.008	-0.002	0.001
I-07	0.009	0.005	0.004	K-07	0.004	0.003	-0.002
I-08	-0.009	-0.023	0.001	K-08	0.002	0.001	-0.006
I-09	0.017	0.008	-0.004	K-09	0.005	0.002	0.001
I-10	0.012	0.001	.000	K-10	0.004	0.002	-0.005
I-11	0.007	-0.004	0.002	K-11	-0.002	0.003	-0.002
I-12	0.019	-0.002	-0.001	K-12	-0.006	-0.003	-0.004
I-13	0.025	0.002	-0.004	K-13	-0.002	0.002	-0.001
I-14	0.028	0.002	-0.001	K-14	-0.002	0.000	0.002
I-15	0.022	-0.001	0.002	K-15	0.001	-0.001	0.005
I-16	0.011	-0.001	0.001	K-16	0.001	-0.006	-0.004
I-17	0.007	-0.004	0.001	K-17	-0.004	-0.001	.000
I-18	0.004	-0.004	0.001	K-18	-0.011	-0.001	0.001
I-19	0.016	0.006	0.003	K-19	-0.011	-0.005	0.005
I-20	0.017	0.001	-0.003	K-20	0.002	0.005	0.003
J-01	0.011	-0.005	-0.001	L-01	0.006	-0.006	0.001
J-02	0.016	0.005	0.006	L-02	0.004	-0.010	-0.003
J-03	0.026	0.007	-0.002	L-03	0.005	-0.015	0.009
J-04	0.025	0.002	0.001	L-04	-0.004	-0.003	0.008
J-05	0.029	0.007	0.002	L-05	-0.008	-0.001	.000
J-06	0.023	0.000	0.000	L-06	0.002	-0.002	0.004
J-07	0.020	-0.002	-0.003	L-07	0.002	0.000	0.008
J-08	0.029	0.000	0.002	L-08	0.005	-0.007	0.001
J-09	0.010	0.002	-0.001	L-09	0.004	0.001	-0.002
J-10	0.019	0.002	0.006	L-10	-0.004	0.003	-0.002
J-11	0.018	0.004	0.002	L-11	-0.001	0.005	0.003
J-12	0.020	0.000	-0.004	L-12	0.008	0.005	0.001
J-13	0.012	0.000	0.008	L-13	0.013	0.002	0.000
J-14	-0.001	0.001	0.020	L-14	0.012	-0.001	-0.003
J-15	0.014	-0.001	0.001	L-15	-0.005	-0.022	-0.011
J-16	0.014	-0.002	0.004	L-16	-0.016	-0.016	.000
J-17	0.015	0.001	-0.001	L-17	-0.014	0.008	0.004
J-18	0.012	0.001	0.005	L-18	-0.002	0.002	-0.001
J-19	0.010	-0.002	-0.001	L-19	0.005	0.004	-0.002
J-20	0.012	0.006	0.003	L-20	0.009	0.002	-0.003


VERTICAL MONUMENT ELEVATION GRAPH 1
AVERAGE of 5 RUNS, 6/22-7/7/87
INCHES (A-02 set to 0.616)
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
A-02 B-06 C-10 D-14 E-18 G-02 H-06 I-10 J-14 K-18 A-02
SURVEY STATION

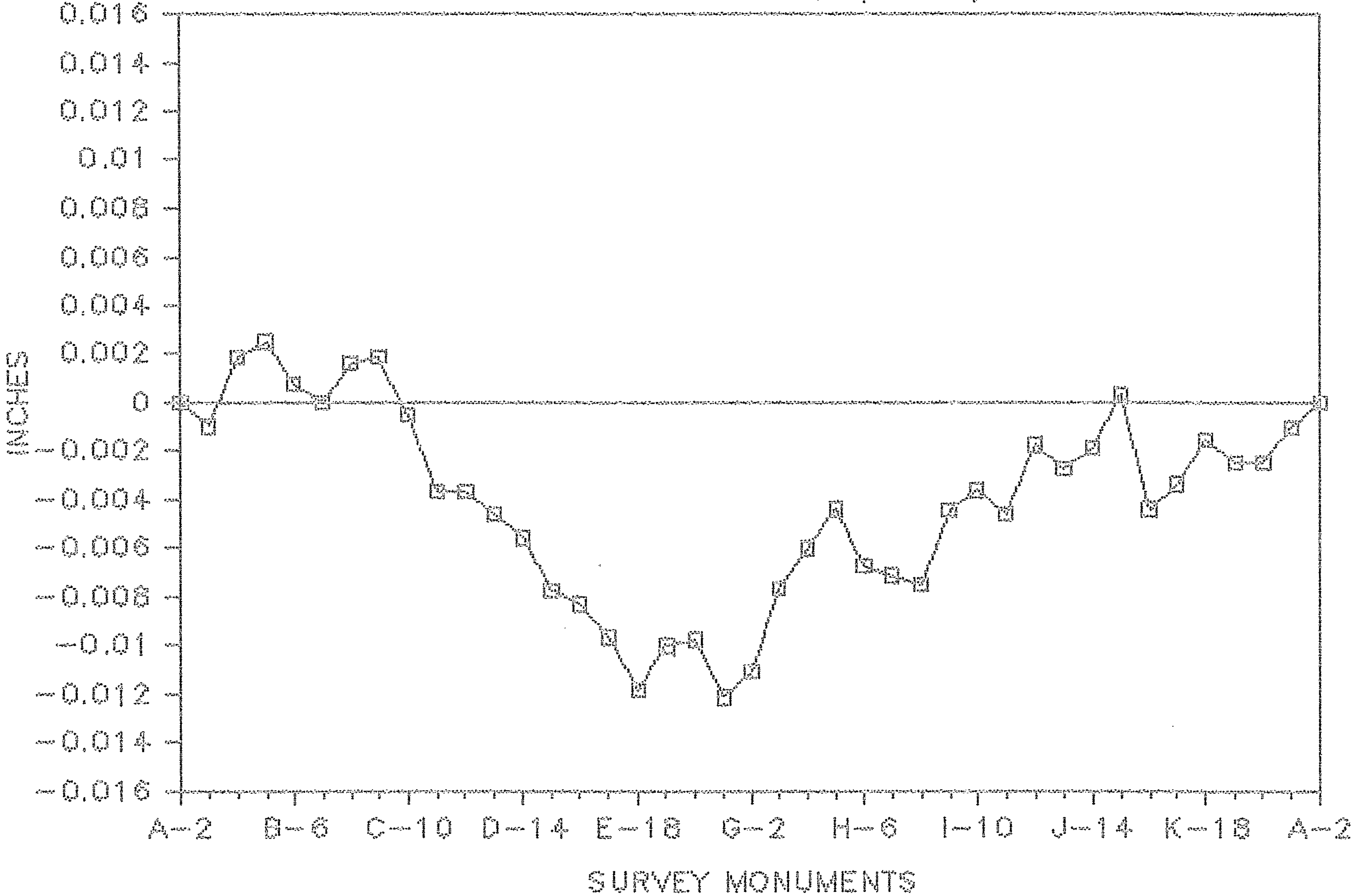
RUN 1 MINUS the AVERAGE GRAPH 2

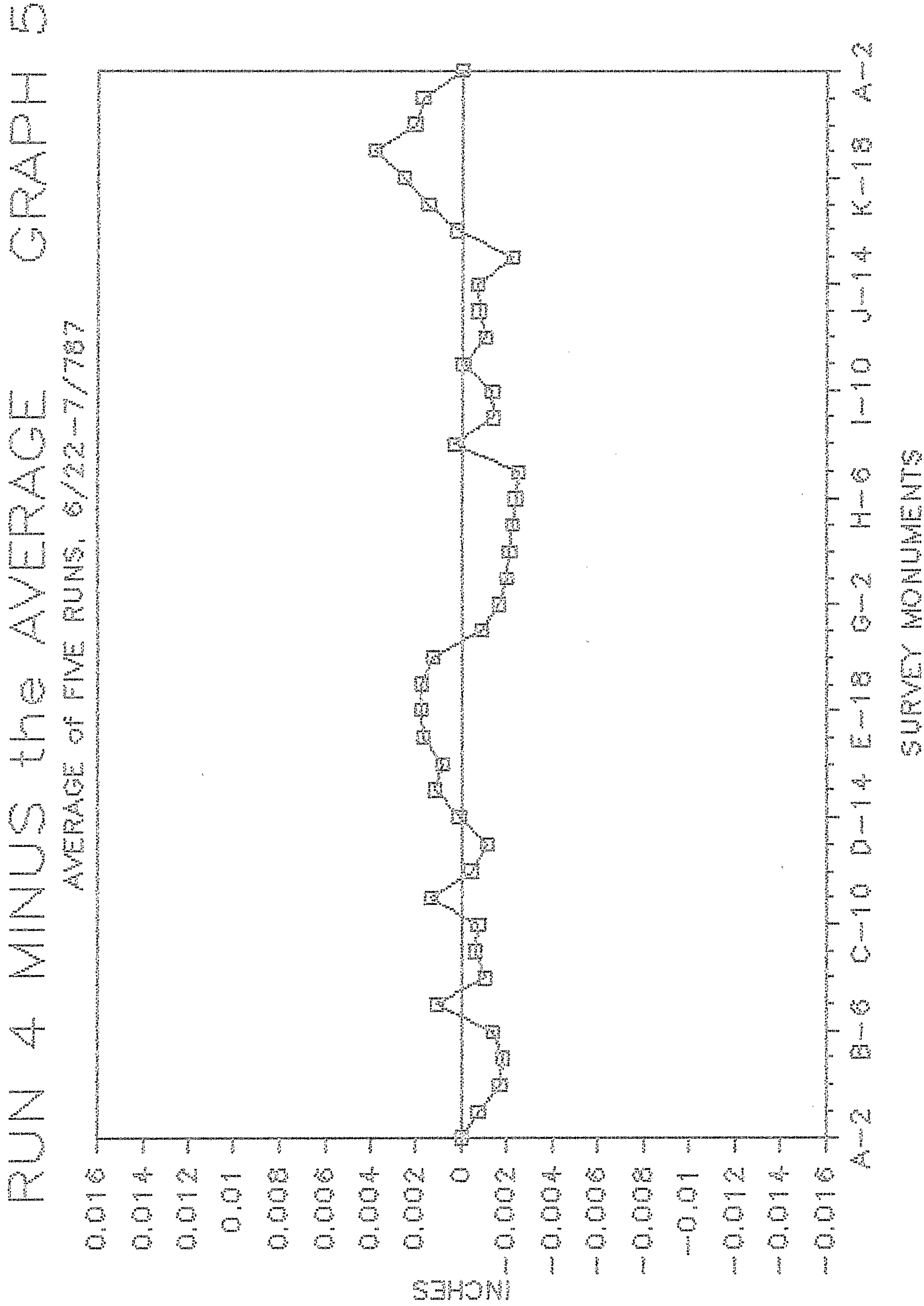


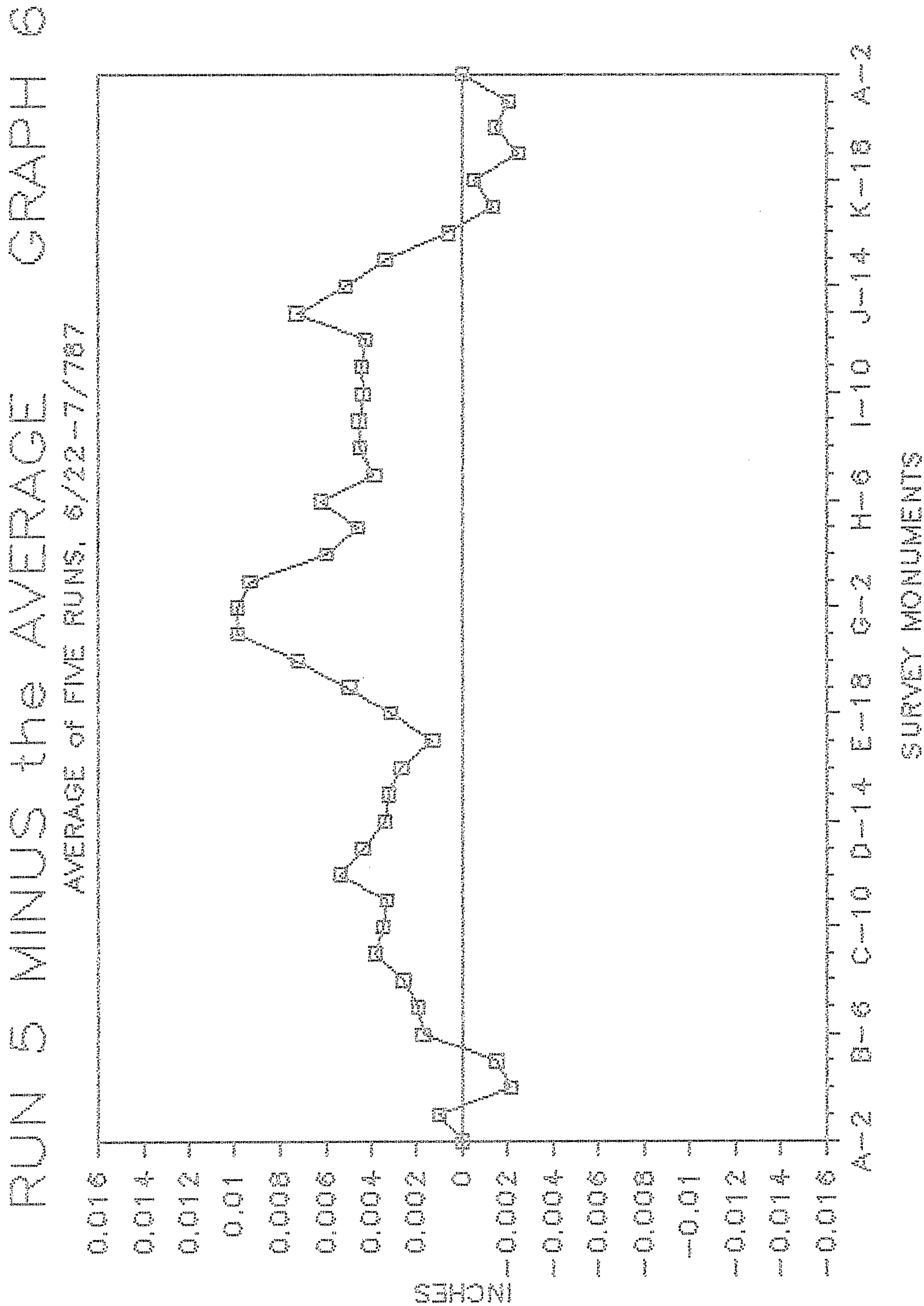

RUN 2 MINUS the AVERAGE GRAPH 3
AVERAGE of FIVE RUNS, 6/22–7/787
INCHES
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
–0.002
–0.004
–0.006
–0.008
–0.01
–0.012
–0.014
–0.016
A–2
B–6
C–10
D–14
E–18
G–2
H–6
I–10
J–14
K–18
A–2
SURVEY MONUMENTS

RUN 3 MINUS the AVERAGE GRAPH 4

AVERAGE of FIVE RUNS, 6/22-7/787

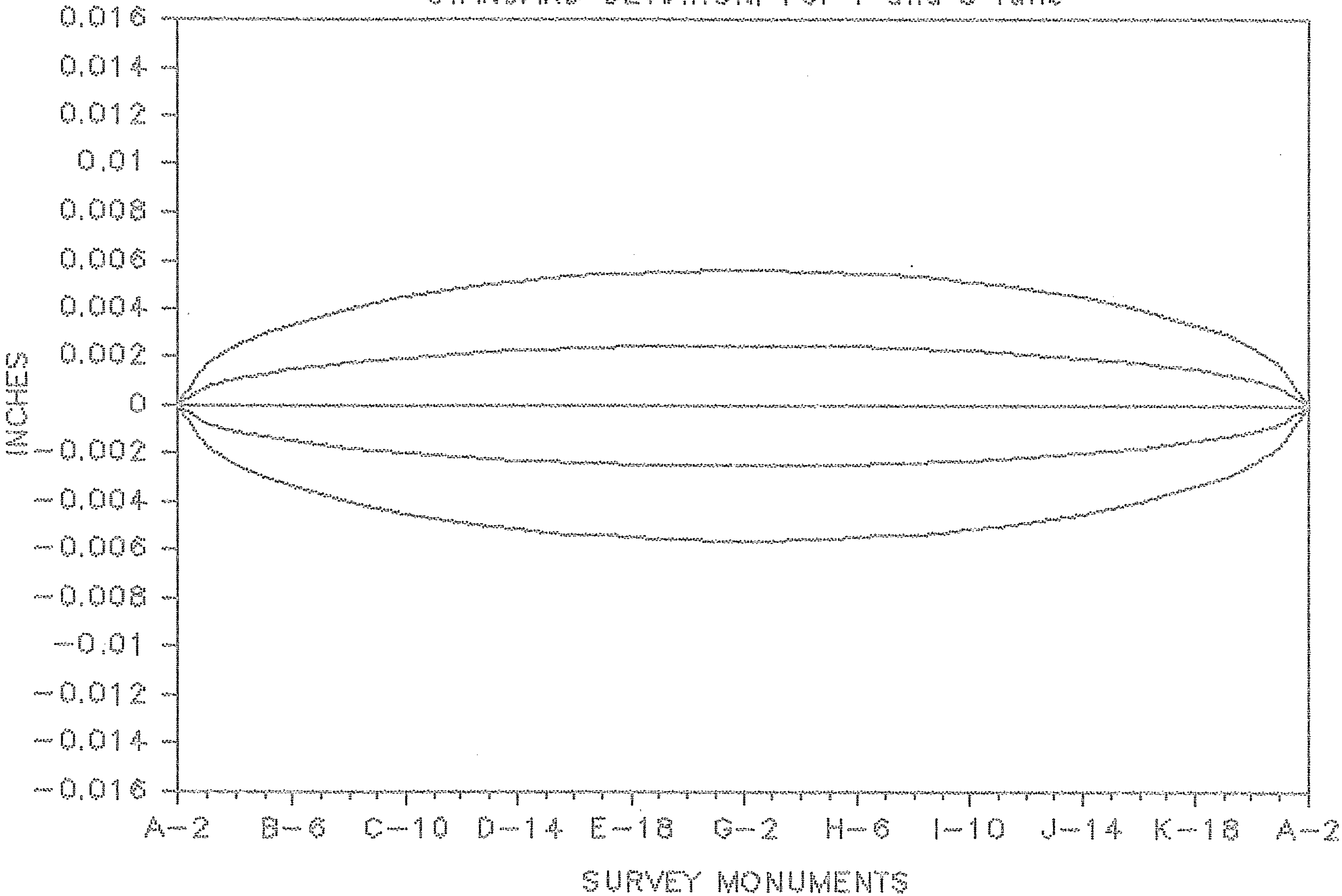


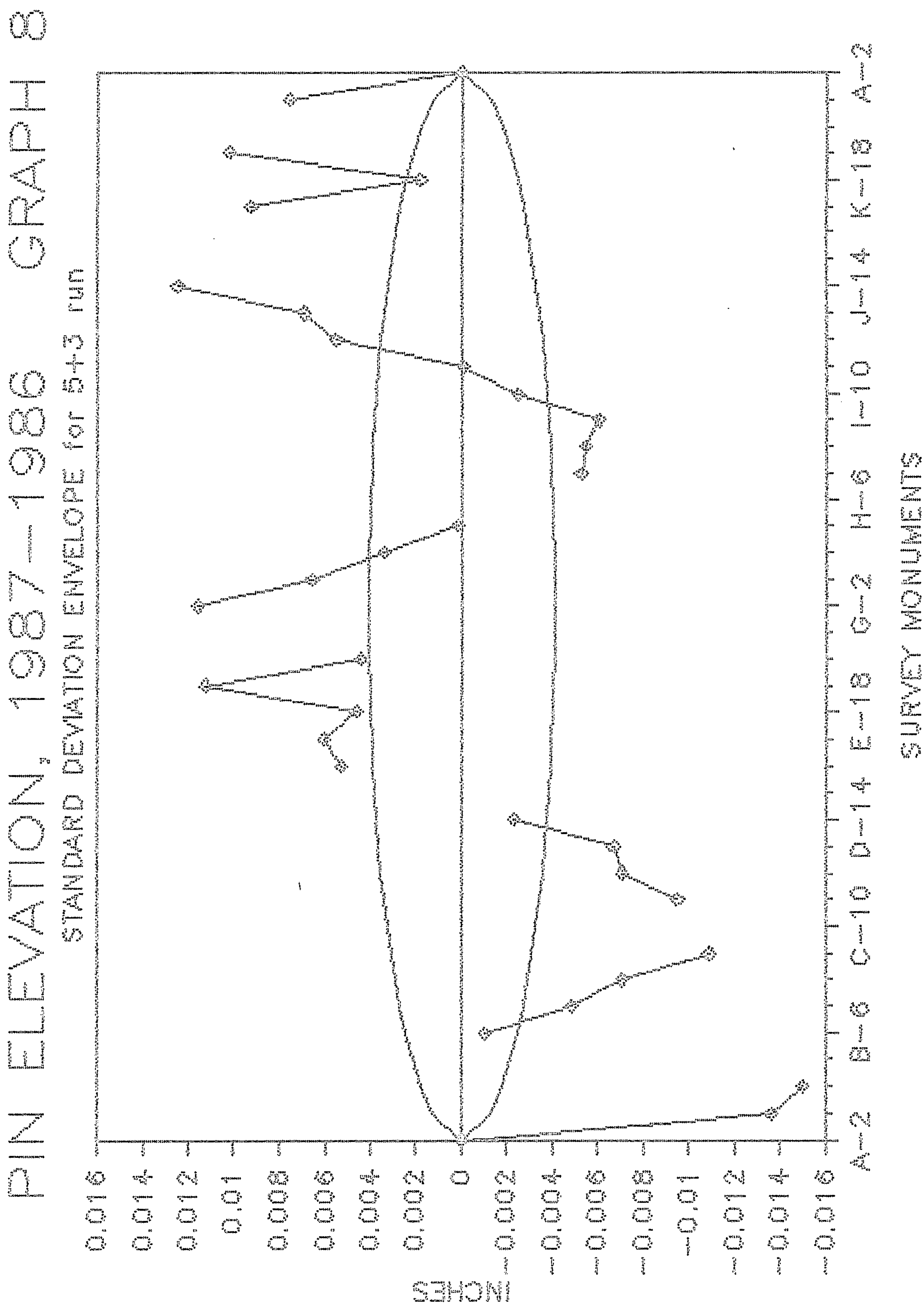

RUN 4 MINUS the AVERAGE GRAPH 5
AVERAGE of FIVE RUNS, 6/22-7/787
INCHES
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.01
-0.012
-0.014
-0.016
SURVEY MONUMENTS
A-2
B-6
C-10
D-14
E-18
G-2
H-6
I-10
J-14
K-18
A-2

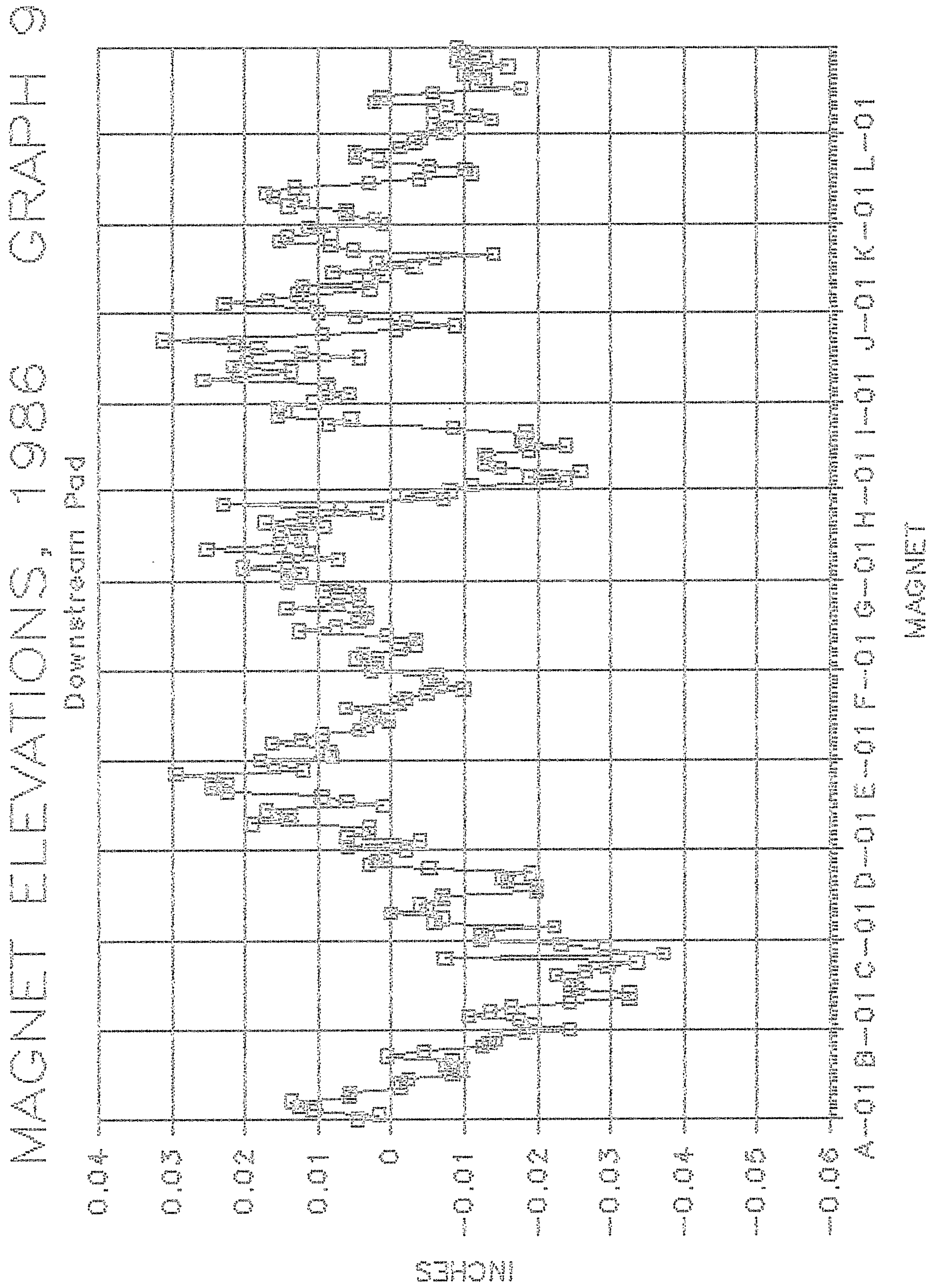

RUN 5 MINUS the AVERAGE GRAPH 6
AVERAGE of FIVE RUNS, 6/22-7/787
INCHES
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.01
-0.012
-0.014
-0.016
A-2
B-6
C-10
D-14
E-18
G-2
H-6
I-10
J-14
K-18
A-2
SURVEY MONUMENTS

ENVELOPE for RANDOM WALKS GRAPH 7

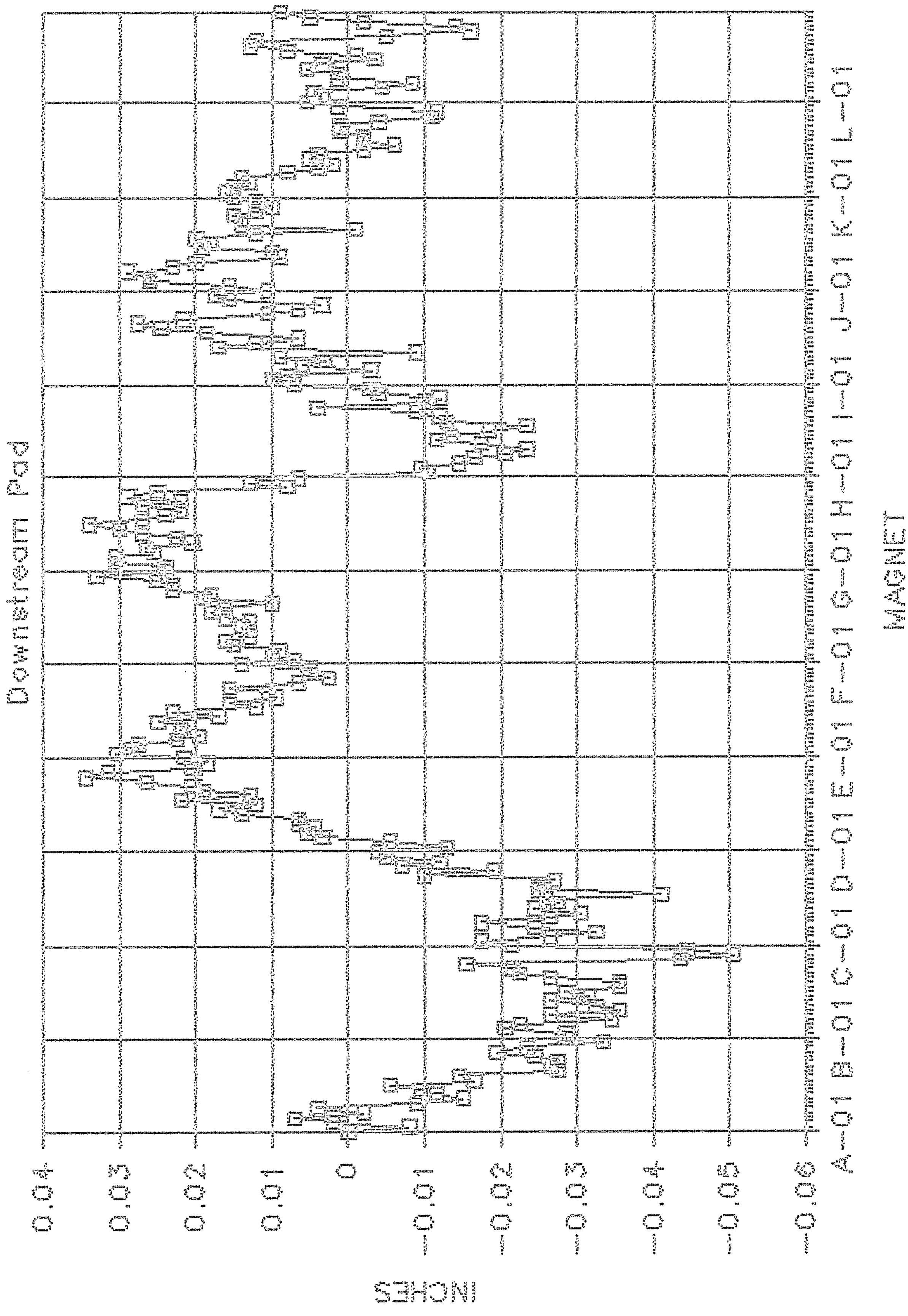
STANDARD DEVIATION, For 1 and 5 runs

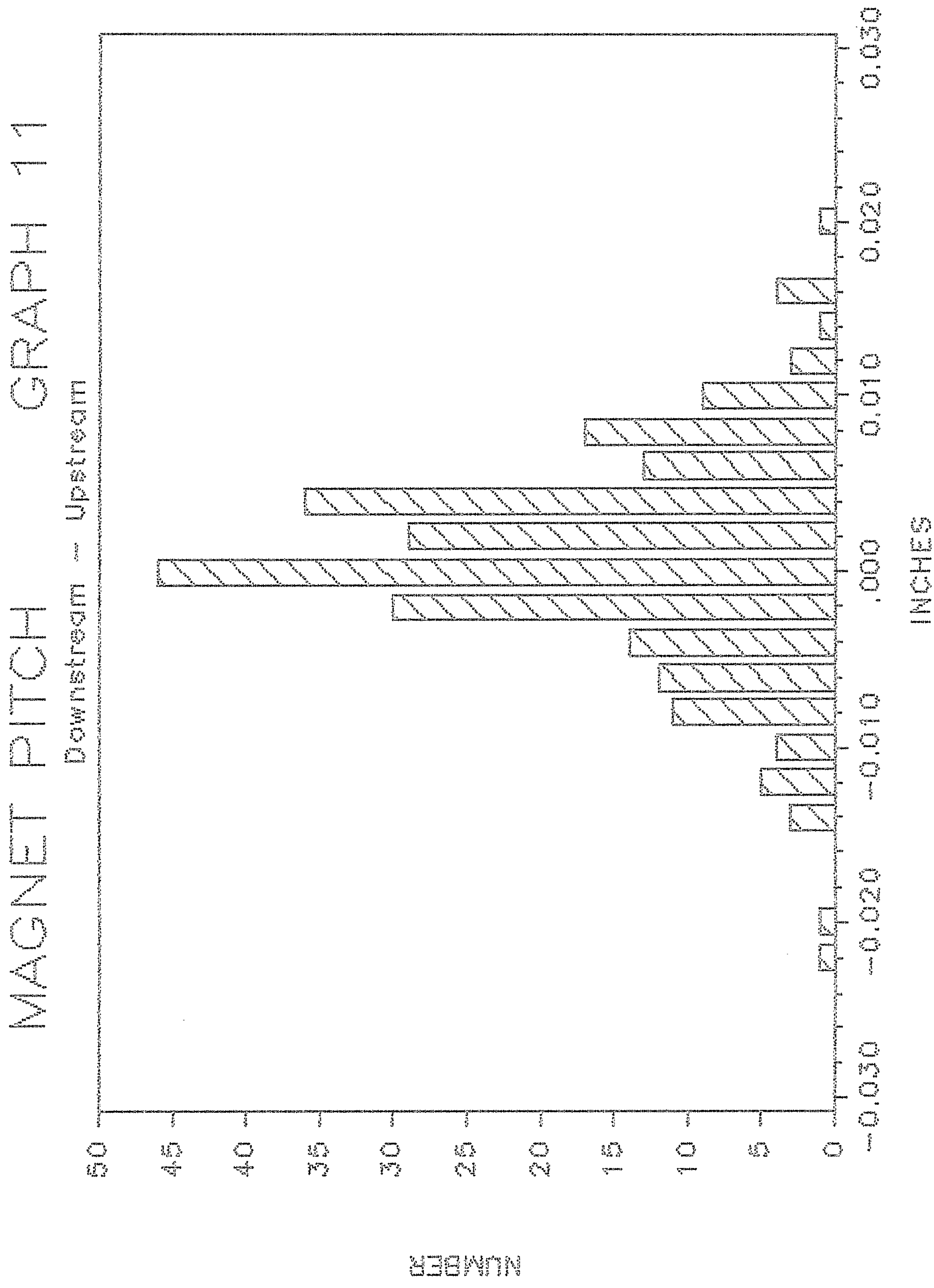


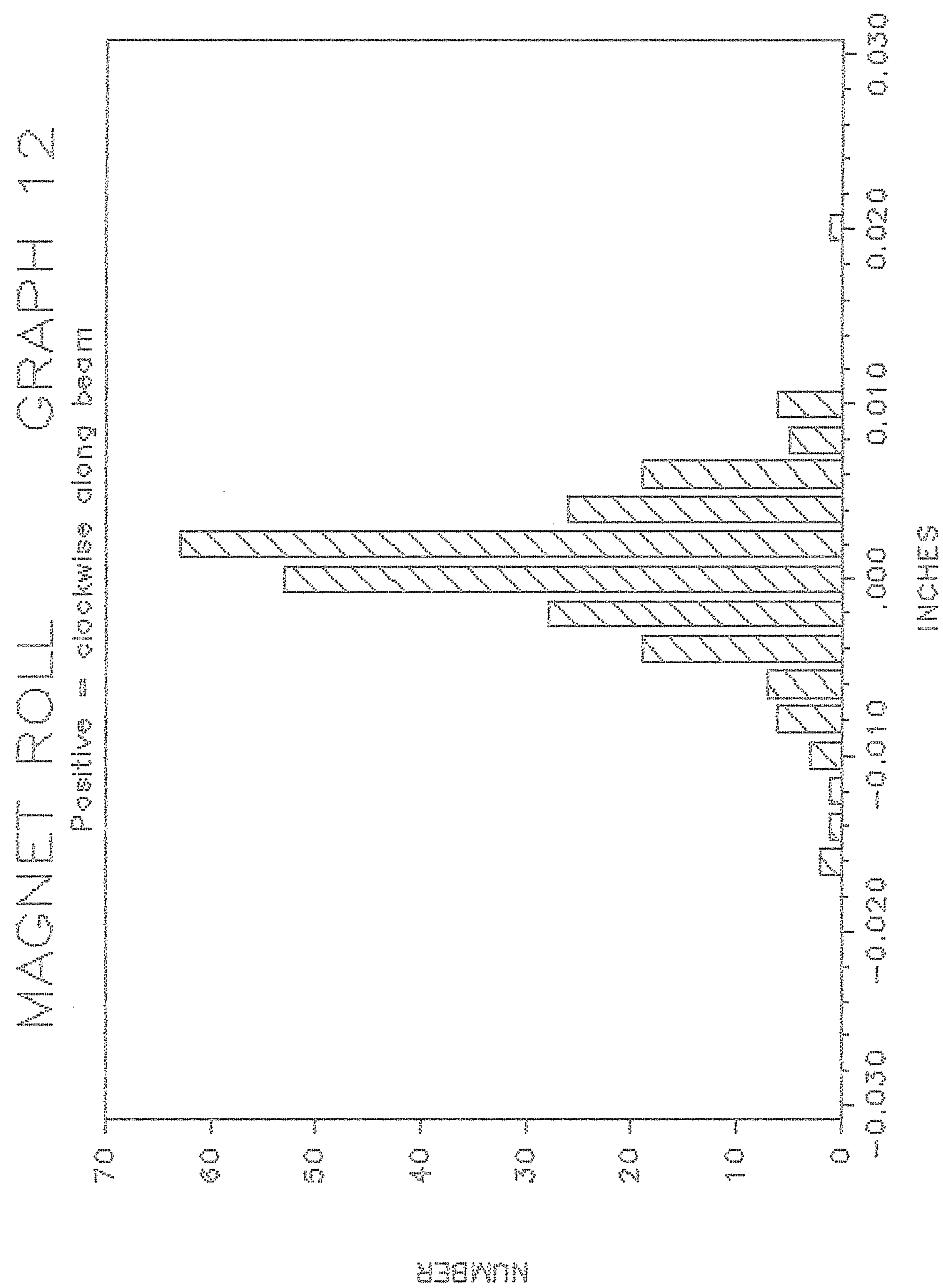

PIN ELEVATION, 1987 — 1986 GRAPH 8
STANDARD DEVIATION ENVELOPE for 5+3 run
INCHES
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.01
-0.012
-0.014
-0.016
A-2 B-6 C-10 D-14 E-18 G-2 H-6 I-10 J-14 K-18 A-2
SURVEY MONUMENTS


MAGNET ELEVATIONS, 1986 GRAPH 9
Downstream Pad
INCHES
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
A-01 B-01 C-01 D-01 E-01 F-01 G-01 H-01 I-01 J-01 K-01 L-01
MAGNET

MAGNET ELEVATIONS, 1987 GRAPH 10




MAGNET PITCH GRAPH 11
Downstream - Upstream
INCHES
NUMBER
-0.030 -0.020 -0.010 .000 0.010 0.020 0.030
0 5 10 15 20 25 30 35 40 45 50


MAGNET ROLL GRAPH 12
Positive = clockwise along beam
INCHES
NUMBER
-0.030
-0.020
-0.010
.000
0.010
0.020
0.030
0
10
20
30
40
50
60
70

MAGNET ELEVATIONS, 1987 GRAPH 13

Before & After Alignment