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THE DEAD RECKONING OF THE AGS RING PUE SYSTEM

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The AGS equilibrium orbit measuring system is composed of 72 electrode (PUE) sets each of which produces a vertical and horizontal position for the beam centroid for that azimuthal position around the ring. Each PUE set consists of two horizontal and two vertical plates rigidly fixed within a metal shield tube which itself is appropriately positioned within the vacuum chamber. The plates couple capacitively to the passing beam bunches. Position is deduced by taking differences between the signals measured on the plates (V1, V2) normalized to the sum, with an overall proportionality constant fixed by the geometry: POS=K*(V1-V2)/(V1+V2). K is approximately 5cm for the ring PUE's.

Discrepencies between the deduced positions and the true beam positions can be interpreted as an offset, a (linear) gain error, and higher order terms. In fact the plates are positioned such that a beam centered in the aperature is also centered in the PUE structure to a few millimeters so the above expansion is appropriate. That is, even if the gains of a PUE pair are not quite equal, the system still gives approximately valid information when used in a nulling mode. Quantitatively, if the gain of one side differs from the other by the factor (1+E), the resulting offset is E*(K/2). A 10% gain difference causes an apparent offset of 2.5mm.

This note is concerned with offsets caused by errors in the system upstream of the electronics. These offsets are essentially impossible to distinguish from real offsets in the equilibrium orbit--the latter of course being the information one is after. Therefore these erroneous offsets must be removed by a dead reckoning procedure— either correcting the cause in the hardware or the resulting effects in the software. For practical considerations the software correction course is adopted here. As a useful byproduct the magnitudes of the effects are measured.

Three offset sources are considered: a) the plates may be improperly positioned within the vacuum chamber, b) the vacuum chamber may be improperly positioned within the magnets, and c) the capacitances of the two plates contributing to a measurement may not be equal. Cause c) is a gain inequality whose effect is identical to that of a gain inequality in the electronics. It is considered here because as configured the system does not allow this component to be measured while the beam is up. These three contributions have been measured for the system, ((a) for the vertical is not yet done), and the resulting predicted errors are corrected in measured orbits using a table stored in the computer. The remainder of the note will very briefly describe the methods used to measure the three effects and present the resulting offsets.

Error (a) is in the first place minimized by using a precision jig to align the plates relative to the vacuum chamber. The curved plates and the enclosing shield tube are offset from the chamber center line to a center on the beam code axis. The magnitude of the offset is different for the three different lattice positions held by the PUEs, and is of order 5mm. As a result of a simplification in the assembly procedure, the jig must be rotated by 180 degrees about the beam axis in going from PUEs in the first half of a superperiod to those in the second half. If this rotation is forgotten, or if a chamber is moved from the second half to the first half without realignment, an offset error of approximately 10mm will result.

The method to check this position after assembly is not obvious since breaking the ring vacuum and pulling chambers and magnets to allow access would almost certainly do more harm than good. Following a suggestion of Dr. A. Maschke the use of a portable x-ray machine to image the plates on a film was investigated and found to be feasible. In this way the horizontal plate positions have been measured. For a subset of PUEs, pictures of both the inside and outside plates, and the adjacent shield tube and chamber edge were taken, allowing an independent estimation of the accuracy of the procedure, given the known chamber and shield tube radii. The measurement error distribution width was approximately 0.5mm (rms). From this data three PUEs were found to be mispositioned by approximately 10mm, and in the direction expected by the above mentioned possible jig misuse. The rest were distributed with an rms variation of 0.8mm about a mean offset of 1mm. These data are given in figure 1 and table 1. The results imply an average jig positioning error approximately equal to the error in the measurement technique. The mean offset is not clearly understood. However, the x-ray results use the edge of the shield tube at its extreme downstream edge as the position reference, while the jig picks up the center line of one of the attached plates. At any rate, an over all radial offset of the PUEs is of small consequence being equivalent to a momentum shift. The procedure will be applied to the vertical PUEs during the coming year.

Error source (b), the position of the vacuum chamber holding the PUE assembly relative to the magnets, has recently been measured using a substantial jig which references from the nearest upstream and downstream magnet socket holes. Pins driven by micrometer heads pick up the top and sides of the vacuum chamber outside the PUE. The method gives reproducible results to within a few mils, the largest error being associated with the leveling of the assembly. The interpretation of the measurement assumes that the two magnets involved are positioned relative to one another according to the survey data. Figures and tables 2 and 4 give the results from this work. The chambers are found to be systematically low - they rest on the bottom of the magnet gaps- but the vertical spread is narrower than the horizontal, the vertical being more tightly constrained by the magnet geometry.

Finally error (c), the capacitance inequality, is considered. The capacitance in each plate system, upstream of the impedance matching transformer, is approximately 90 pf. Originally this capaciance was put in parallel with a precision 500 pf. capacitor effectively causing small variations in the plate system to be swamped out, but reducing the available voltage by the same factor (X5). It was judged preferable to remove the large capacitor and take both the gain increase and the increased sensitivity to capacitance variation. Monitoring of the capacitors requires the maintainance of a (4 x 72) element table but also gives some information about the stability of the system which may have independent value. Using the relation listed early on, a one picofarad variation away from the table values in the difference between the plates involved in one measurement corresponds to a spurious offset of (1/180)*5cm.= .25mm. Difference reproducibility at this level for healthy channels has been obtained for measurements taken over a period of a year. Figures and tables 3 and 5 report the corrections required by the capacitance measurements.

In conclusion, three sources of PUE offset errors have been measured and can be corrected for in generating beam equilibrium orbits using tables in the software. A summary of the results is given in table 6. A pessimist would point out that for the applied corrections to be valid these tables must be right to begin with (one sign error is twice as bad as doing nothing), and must remain up to date as changes occur in the ring. Even he would presumably grant that the order of magnitude of the errors resulting form the three effects investigated has been established, which in itself has significance in predicting the overall accuracy to be expected of the system.

Many AGS personnel have contributed to these measurements. In particular, Mr. Nick Parnello and his staff have been extremely helpful both in the organization and execution of the x-ray work and in the creation of the magnet referencing jig. The x-ray unit itself came from and was manned by B.N.L. quality control personnel, and in particular Mr. Fred Conners was essential in working out the set up parameters.

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Figures and Tables

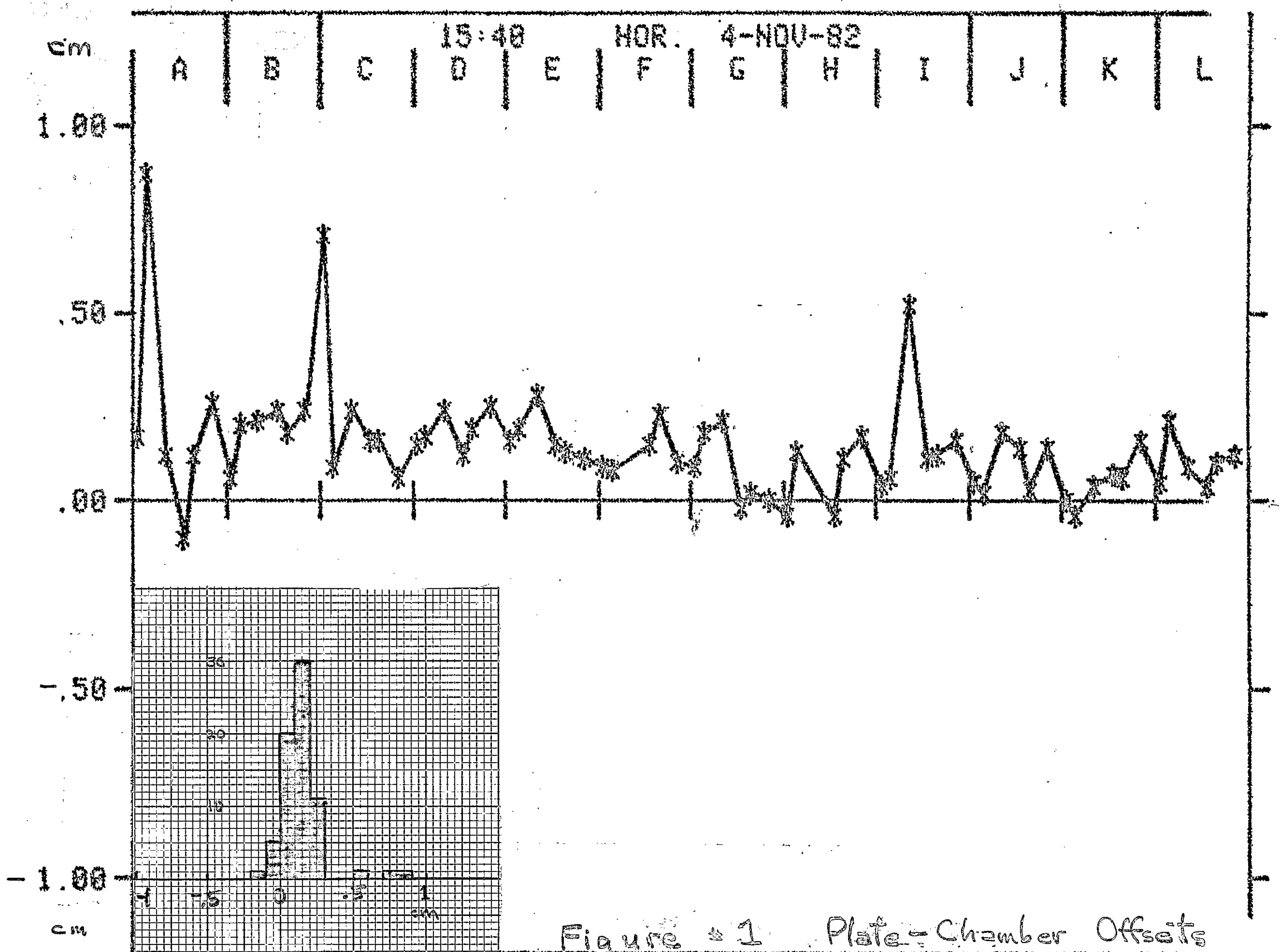

Figure #1 Plate-Chamber Offsets
horizontal

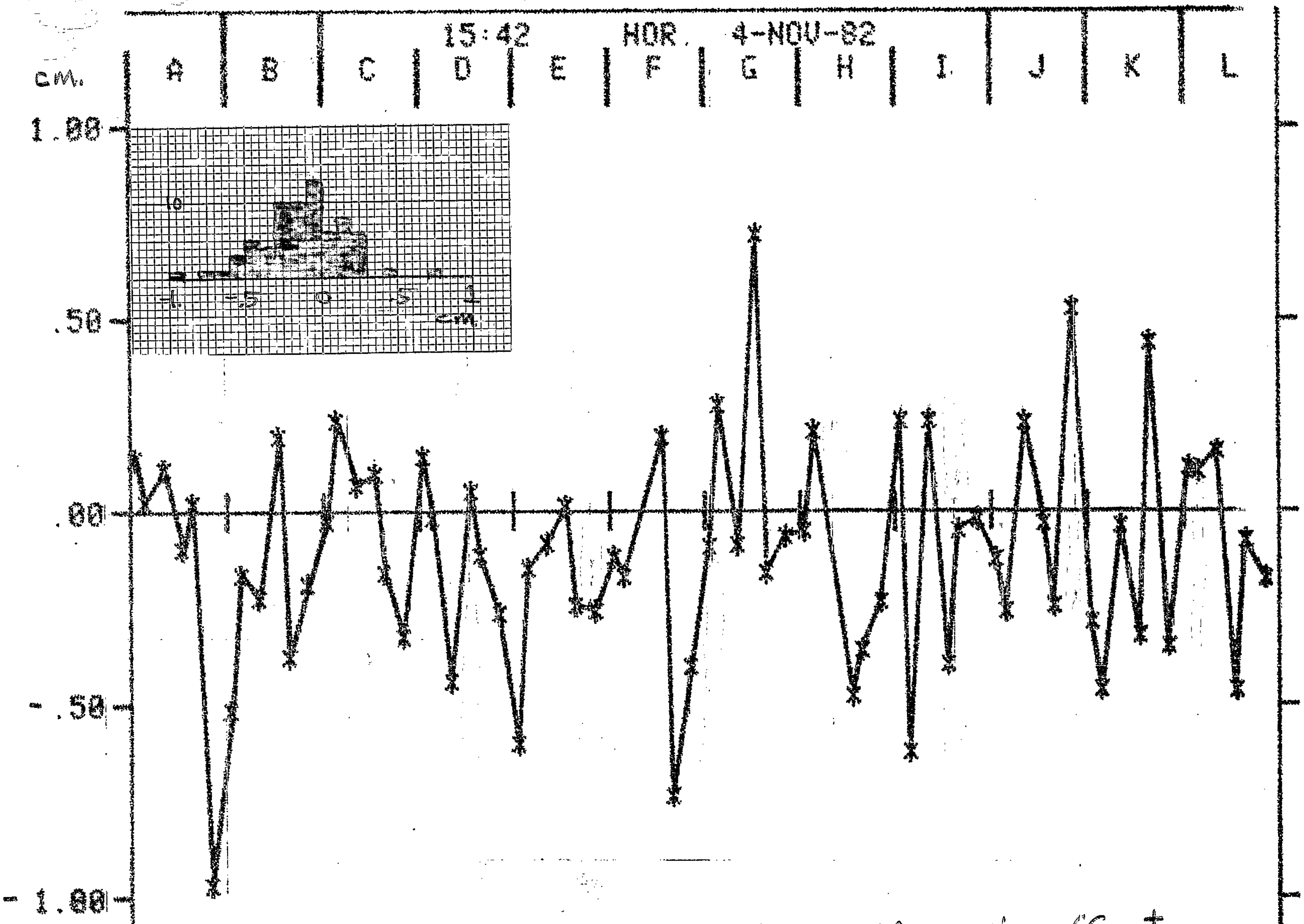

Figure 2 Chamber - Magnet offset horizontal

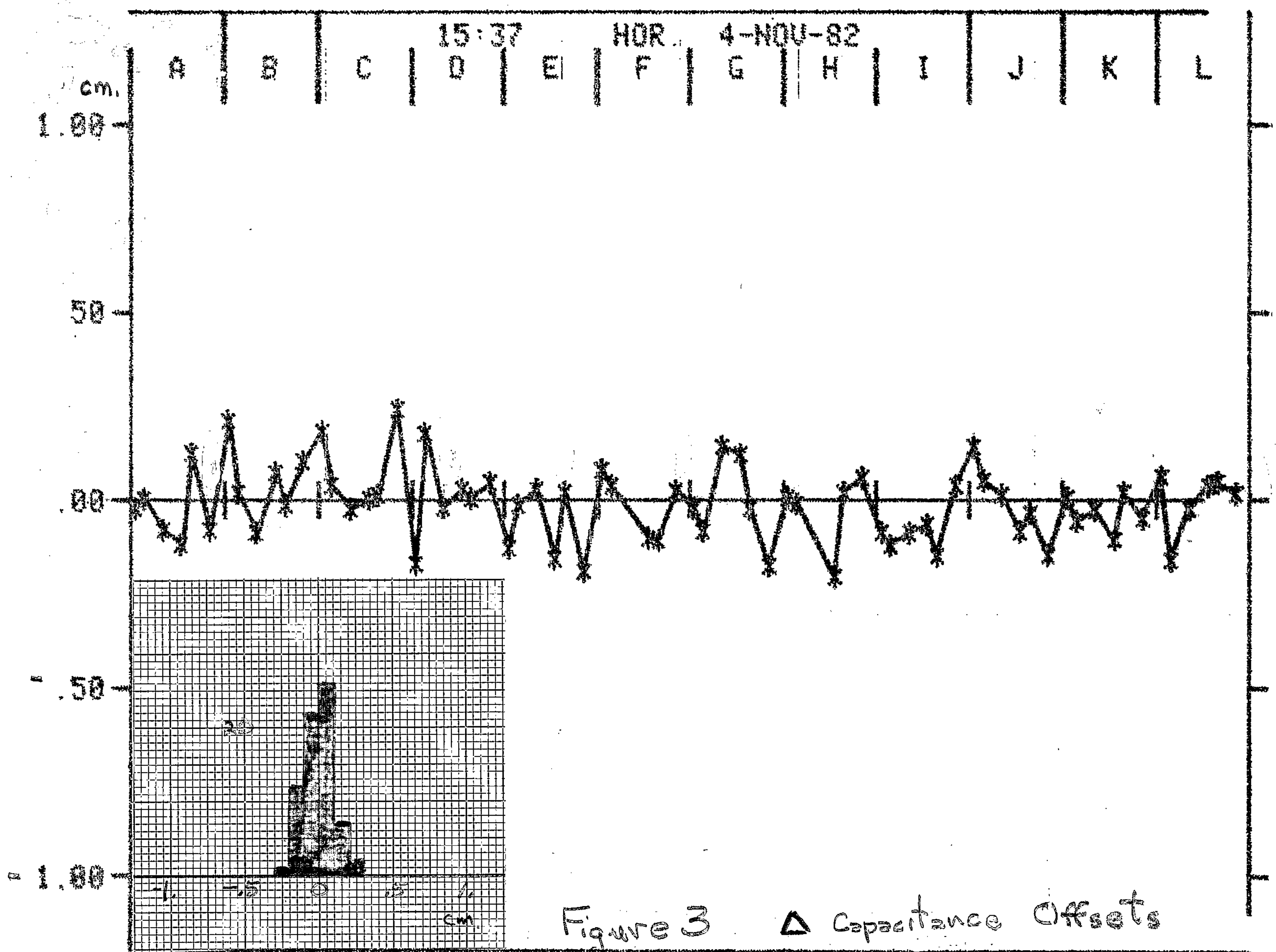

Figure 3 Δ Capacitance Offsets horizontal

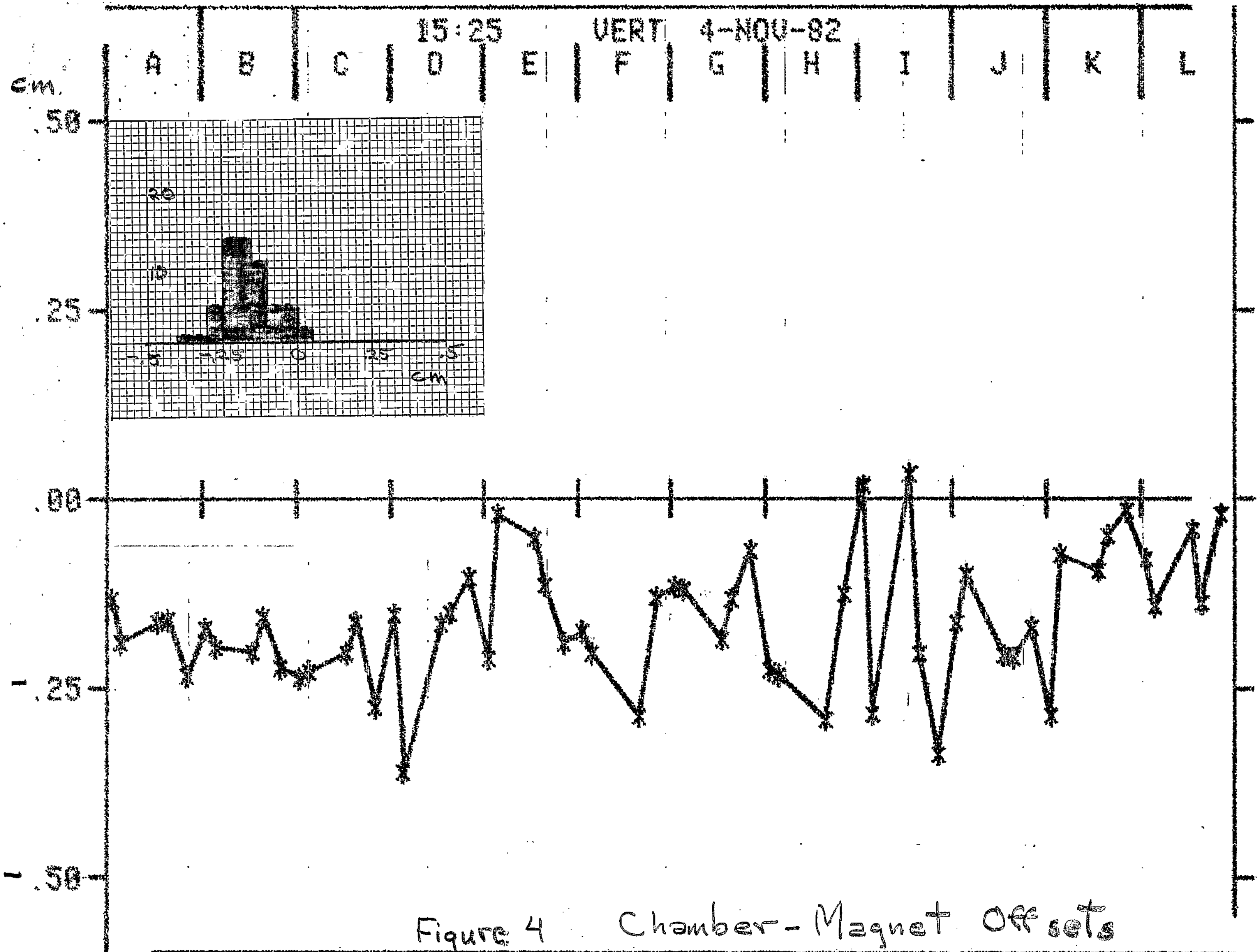

Figure 4 Chamber-Magnet Offsets

Vertical

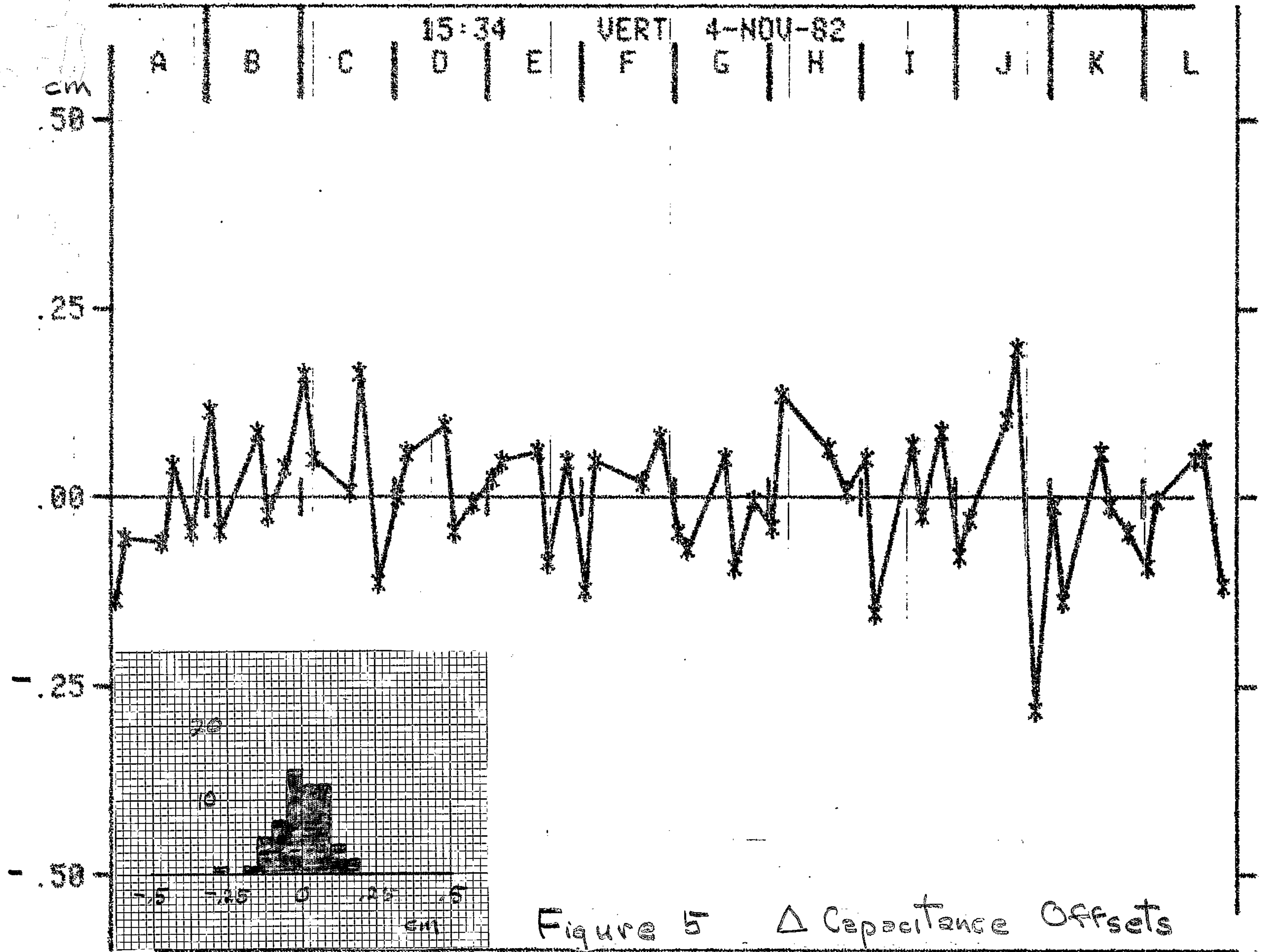

Figure 5 Δ Capacitance Offsets Vertical

Table 1 PUE Plate – Chamber Offsets horizontal (cm.)

A 2	0.170	A 4	0.870	A 8	0.120	A12	-0.100	A14	0.120	A18	0.260
B 2	0.060	B 4	0.200	B 8	0.210	B12	-0.240	B14	0.180	B18	0.240
C 2	0.710	C 4	0.090	C 8	0.240	C12	0.160	C14	0.160	C18	0.060
D 2	0.150	D 4	0.170	D 8	0.240	D12	0.120	D14	0.190	D18	0.250
E 2	0.160	E 4	0.190	E 8	0.280	E12	0.150	E14	0.130	E18	0.110
F 2	0.090	F 4	0.080	F 8		F12	0.150	F14	0.230	F18	0.100
G 2	0.090	G 4	0.180	G 8	0.210	G12	-0.020	G14	0.020	G18	-0.000
H 2	-0.040	H 4	0.130	H 8		H12	-0.040	H14	0.110	H18	0.170
I 2	0.040	I 4	0.060	I 8	0.520	I12	0.110	I14	0.120	I18	0.160
J 2	0.050	J 4	0.020	J 8	0.180	J12	0.140	J14	0.030	J18	0.140
K 2	0.000	K 4	-0.040	K 8	0.040	K12	0.070	K14	0.060	K18	0.160
L 2	0.050	L 4	0.210	L 8	0.090	L12	0.040	L14	0.100	L18	0.120

AVER FOR 70 ELECTRODES = 0.14

Table 2 Chamber – Magnet offsets horizontal (cm.)

A 2	0.140	A 4	0.025	A 8	0.111	A12	-0.094	A14	0.020	A18	-0.963
B 2	-0.513	B 4	-0.163	B 8	-0.221	B12	0.196	B14	-0.373	B18	-0.188
C 2	-0.025	C 4	0.237	C 8	0.069	C12	0.097	C14	-0.157	C18	-0.323
D 2	0.142	D 4	-0.015	D 8	-0.439	D12	0.053	D14	-0.112	D18	-0.264
E 2	-0.599	E 4	-0.147	E 8	-0.081	E12	0.015	E14	-0.241	E18	-0.256
F 2	-0.117	F 4	-0.165	F 8		F12	0.196	F14	-0.734	F18	-0.401
G 2	-0.087	G 4	0.277	G 8	-0.084	G12	0.719	G14	-0.155	G18	-0.064
H 2	-0.051	H 4	0.208	H 8		H12	-0.475	H14	-0.356	H18	-0.234
I 2	0.233	I 4	-0.620	I 8	0.236	I12	-0.394	I14	-0.046	I18	-0.018
J 2	-0.122	J 4	-0.257	J 8	0.231	J12	-0.030	J14	-0.241	J18	0.526
K 2	-0.284	K 4	-0.460	K 8	-0.036	K12	-0.320	K14	0.437	K18	-0.345
L 2	0.114	L 4	0.104	L 8	0.158	L12	-0.462	L14	-0.074	L18	-0.173

AVER FOR 70 ELECTRODES = -0.11

Table 3 Offsets due to capacitor differences = horizontal (cm)

A 2	-0.019	A 4	0.004	A 8	-0.077	A12	-0.116	A14	0.124	A18	-0.078
B 2	0.211	B 4	0.023	B 8	-0.084	B12	0.073	B14	-0.012	B18	0.106
C 2	0.184	C 4	0.040	C 8	-0.022	C12	0.004	C14	0.016	C18	0.241
D 2	-0.169	D 4	0.176	D 8	-0.020	D12	0.028	D14	0.004	D18	0.047
E 2	-0.125	E 4	-0.012	E 8	0.028	E12	-0.155	E14	0.023	E18	-0.187
F 2	0.080	F 4	0.039	F 8		F12	-0.099	F14	-0.104	F18	0.028
G 2	-0.021	G 4	-0.083	G 8	0.142	G12	0.121	G14	-0.022	G18	-0.172
H 2	0.008	H 4	-0.008	H 8		H12	-0.201	H14	0.020	H18	0.059
I 2	-0.084	I 4	-0.119	I 8	-0.085	I12	-0.065	I14	-0.146	I18	0.040
J 2	0.143	J 4	0.051	J 8	0.016	J12	-0.081	J14	-0.031	J18	-0.144
K 2	0.008	K 4	-0.055	K 8	-0.027	K12	-0.101	K14	0.021	K18	-0.045
L 2	0.064	L 4	-0.158	L 8	-0.024	L12	0.040	L14	0.048	L18	0.020

AVER FOR 70 ELECTRODES = -0.01

Table 4 Chamber - Magnet offsets vertical (cm)

A 2	-0.132	A 4	-0.188	A 8		A12	-0.162	A14	-0.160	A18	-0.234
B 2	-0.170	B 4	-0.196	B 8		B12	-0.203	B14	-0.155	B18	-0.224
C 2	-0.236	C 4	-0.228	C 8		C12	-0.203	C14	-0.163	C18	-0.274
D 2	-0.152	D 4	-0.361	D 8		D12	-0.165	D14	-0.150	D18	-0.104
E 2	-0.211	E 4	-0.021	E 8		E12	-0.051	E14	-0.115	E18	-0.190
F 2	-0.175	F 4	-0.203	F 8		F12		F14	-0.287	F18	-0.130
G 2	-0.117	G 4	-0.119	G 8		G12	-0.185	G14	-0.132	G18	-0.069
H 2	-0.226	H 4	-0.234	H 8		H12		H14	-0.290	H18	-0.124
I 2	0.018	I 4	-0.282	I 8		I12	0.033	I14	-0.203	I18	-0.335
J 2	-0.163	J 4	-0.099	J 8		J12	-0.206	J14	-0.209	J18	-0.170
K 2	-0.284	K 4	-0.074	K 8		K12	-0.094	K14	-0.048	K18	-0.015
L 2	-0.079	L 4	-0.139	L 8		L12	-0.041	L14	-0.137	L18	-0.020

AVER FOR 58 ELECTRODES = -0.16

Table 5 Offsets due to capacitance differences - vertical (cm.)

A 2	-0.134	A 4	-0.054	A 8		A12	-0.060	A14	0.042	A18	-0.044
B 2	0.113	B 4	-0.043	B 8		B12	0.085	B14	-0.024	B18	0.041
C 2	0.162	C 4	0.051	C 8		C12	0.008	C14	0.165	C18	-0.112
D 2	0.000	D 4	0.059	D 8		D12	0.095	D14	-0.044	D18	-0.008
E 2	0.025	E 4	0.048	E 8		E12	0.060	E14	-0.086	E18	0.048
F 2	-0.124	F 4	0.048	F 8		F12		F14	0.020	F18	0.079
G 2	-0.046	G 4	-0.069	G 8		G12	0.052	G14	-0.092	G18	-0.004
H 2	-0.039	H 4	0.134	H 8		H12		H14	0.064	H18	0.008
I 2	0.050	I 4	-0.153	I 8		I12	0.070	I14	-0.024	I18	0.087
J 2	-0.076	J 4	-0.028	J 8		J12	0.103	J14	0.196	J18	-0.280
K 2	-0.012	K 4	-0.136	K 8		K12	0.058	K14	-0.012	K18	-0.045
L 2	-0.090	L 4	-0.004	L 8		L12	0.050	L14	0.063	L18	-0.117

AVER FOR 58 ELECTRODES = 0.00

TABLE 6

	Horizontal (mm)		Vertical (mm)	
	Ave Offset	RMS Variation	Ave Offset	RMS Variation
(a) Plate-Chamber Offset (x-ray)	1.44	1.46	———	———
Plate-Chamber Error with A4, C2, 18 excluded	1.19	0.83	———	———
(b) Chamber-Magnet Offset	-1.06	2.86	-1.60	0.84
(c) Offset due to Capacitance Inequality	-0.10	0.96	0.02	0.87