BNL-104868-2014-TECH

AGS/AD/Tech Note No. 452;BNL-104868-2014-IR

REVISITINGTHE DEAD RECKONING OF THE AGS ORBIT MEASURING SYSTEM

L. Ahrens

October 1996

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

DISCLAIMER

For Internal Distribution Only

Accelerator Division
Alternating Gradient Synchrotron Department
BROOKHAVEN NATIONAL LABORATORY
Upton, New York 11973

Accelerator Division
Technical Note

AGS/AD/Tech. Note No. 452

REVISITING THE DEAD RECKONING OF THE AGS ORBIT MEASURING SYSTEM

L. Ahrens

October 30, 1996

Revisiting the Dead Reckoning of the AGS Orbit Measuring System

L.A. Ahrens

Introduction:

This note is an update to an AGS tech note (#183) written in 1982. The subject is the offset between the "raw" beam position reported by the AGS equilibrium orbit measuring system and the true position of the beam. The components contributing to this offset are described. The steps - the procedures - both to measure these components and to apply the results to the raw numbers for AGS operations are then given. Over the 15 years since the above report appeared several significant changes have been made to the orbit acquisition or "pick-up" electrode (PUE) system including a mechanical rework of the PUE plates themselves. The resulting system is inherently simpler and somewhat cleaner from a high frequency point of view. An even more significant change, the upgrade of the electronics, is coming soon.

The system remains relevant to AGS operations. Until the electronics upgrade, the dynamic range with which the system can cope is significantly less than the range over which the AGS can operate for the physics programs. Nevertheless, at least over a range of from 1 to 5 $x10^{12}$ protons accelerating in AGS, the system gives good orbit information. The "relative" information - difference orbits - from the system is not the primary subject of this note, but the fact that such data can be taken, and absolute gain calibrations extracted from with-beam experiments allows a basis for moving to absolute measurements for which the offsets of this note are essential. Absolute orbits, the pue's best estimate of where the beam center lies in the machine aperture, combined with information from the loss monitor system and the surviving beam intensity measurements give Operations a description of how well the theoretical aperture is being utilized - for high intensity proton acceleration and, with the future electronics upgrade, for heavy ion acceleration.

One rather basic motivation for this note is to provide definitions for the jargon used in implementing the offsets. Despite the existence of a mechanism for generating and applying the offset tables, over the interval from 1992 to 1995 this mechanism was either not used or misused resulting in some misinformation being extracted from the absolute positions given by the orbit system - which reduced confidence in the system. This note, including the appendices, will contain and explain prescriptions for generating the offset numbers, and suggest checks to see if the numbers being used are appropriate. In particular in each offset type has an associated appendix which describes the last round of data handling. Back in the 1980's the number organizing task was done in the AGS PDP10, and the transfer of the offsets to the AGS orbit application code was internal to the structure. Those days are long gone. For this round, the (rather tedious, trivial, and easily done wrong) analysis is done within "Lotus 123", and the transfer to the application code is "by hand". Surely the next round will move to yet another mechanism, but the pieces will be about the same.

The Offsets:

Three categories of offsets for a given pue station are identified in tech note #183: **I)** those resulting from electrical differences between the pairs of contributing plates, **II)** those resulting from a physical offset of the pue center line from the ideal line in the enclosing vacuum can, and **III)** those resulting from the location of the vacuum can relative to the guide magnetic field for the beam, or equivalently relative to the main ring magnets. The values for these three offsets for each of the 72 pue assemblies are derived from three tables of correction measurements. This generation of offsets references the reported beam position to R_0 - the ideal orbit in the AGS lattice. Previous generations of offsets (prior to the 1995 -1996 physics run) references to the "beam code axis". The three offset sources and the associated measurements are briefly described below. The appendices further explain the mechanics of taking and entering new measurements and of extracting and applying new offsets to the orbit system.

Type I offsets account for channel to channel differences in the handling of the electrical signals generated from the beam. A beam centered on the pue structure will induce equal charge on the two horizontal and on the two vertical plates. In this situation the voltage seen across the high impedance electronics connected between each plate and the vacuum chamber "ground" will be slightly different from plate to plate to the extent that the plate assemblies have different capacitances. The digitization of a processed version of these voltages (not the induced charge itself) gives the data from which the raw beam position is extracted, so any difference in the front end capacitance will result in a false offset.

The capacitance values, four entries per pue station (for the two horizontal and two vertical plate/cable assemblies), are measured (in the ring) and listed in the "capacitance" table. The first order consequence of a capacitance difference between say the two horizontal plates at A2 is to produce a false offset proportional to that difference divided by the sum of the two capacitances. The proportionality constant is just the pue geometric factor that also relates the measured voltage (difference divided by sum) to the offset of the beam, which is a length of approximately 7 cm. Because the normalization for the system uses a global externally derived "sum" signal rather than the sum from these two plates, a gain factor is also required to the extent that the capacitance at a given station differ from the average of all the capacitances contributing, and that factor is also extracted. A global calibration factor (extracted from 'with beam' measurements) is applied in addition to this channel specific factor to take care of the normalization of the external sum signal. The average offset from this source is necessarily zero. The spread over the channels is of order 1 mm. The gain correction is typically a few percent though it is as large as 10% for a few channels. More details on the storage of this data and its processing into gain and offset changes are given in appendix I.

It should be noted that any differences in signal handling from the input to the impedance "matching" transformers (in the ring) through the cables between the transformers and the upstairs electronics, or differences in the electronics is presently ignored. Setup procedures strive to minimize such differences though these procedures are for the most part too time consuming to be attempted. Future modifications may allow or require an additional electronics correction to be applied to the data processing. Modification of this "capacitance" table section of the data handling would be a logical place to add such information.

Type II offsets, the mechanical offsets between pue center line and the vacuum chamber center line, have a rather rich history but an almost trivial future. The need for such a category results from the fact that this offset is not directly observable - it is hidden inside the vacuum chamber once the pues are installed. Any measurement procedure to provide a relevant table of offset numbers is clearly a rather separate task. Historically that task was done only once, and involved lugging a small x-ray machine around the ring and photographing all of the pue stations (see tech note #183). The mechanical rework completed in 1991 simplified the geometry of the plates relative to the vacuum can. Prior to that rework, the axis of the pue plates (and of the concentric ground cylinder in which they are lodged) was intentionally offset (position and angle!) in the horizontal plane from the axis of the cylindrical vacuum chamber in which the assembly is enclosed. This offset moved the pue center line onto the "beam code" axis.

Why was this done? To minimize the sensitivity of the orbit system to gain errors anywhere in the system, it is desirable to have the beam close to the center of the electrical structure. Also the linearity of the pue is best at its geometric center. So it would be reasonable to put the pues on the "best" orbit. In a separated function machine (i.e. the Booster) that best place is obvious, the pues are centered with great accuracy right in the lattice quadrupoles. In the AGS, with its alternating "C" combined function magnets the most desirable position is a bit less obvious. That position corresponds to an orbit referred to as "R_0" (see Ed Bleser's AGS Tech Note #217, "Optimal Central Orbit in the AGS"). The beam traveling on R_0 optimally exploits the aperture of the AGS and behaves in a simple way in the straight sections. Further, other magnetic elements (e.g. the high field quadrupoles and sextupoles) are centered on this "R_0" orbit.

In fact the size of the pues relative to their vacuum chamber cans prevented shifting the assembly all the way over to R_0. (The orbit correcting dipoles nest around the vacuum chamber cans; increasing the can size would result in weaker correctors. Decreasing the PUE size creates potential beam aperture situations.) Instead the pues were shifted about half way to R_0, onto another well defined line mentioned above called the Beam Code Axis. The 1991 rework abandoned the "beam code axis" centering approach, with its complex spring suspension, its cam-positioned system and subtle procedures for getting the position right in favor of a simple rigid positioning of the pue assembly concentric with the vacuum chamber. This of course moves the pue centerline farther away from the R_0 ideal, but results in a well defined robust PUE position. The actual location of the pues inside the cans is essentially eliminated as a source of error. The type II offset table (which was labeled "x-ray" for reasons given above) has not disappeared at this time. Rather it is used to carry the offsets between the pue positions and R_0 , which reduce to one of two values (of about 1 cm) for the different pue stations, except for a couple which are for some reason "different". For this geometry the offset to be applied depends on the longitudinal location of the pue in the straight section because R_0 and the vacuum chamber center line are not parallel. The details of this translation are given in appendix II.

Type III offsets involve the positioning of the pue vacuum can relative to the main ring magnets. The pue vacuum can is rigidly attached to the downstream end of an AGS main ring magnet vacuum chamber. The pue position has considerable "slop" since the AGS vacuum chambers enjoy somewhat unconstrained positioning - sliding into gradient C magnets - and the pue is located at one end of the long vacuum chamber - magnifying any small positioning errors inside the magnet. The pue vacuum can offset is measured using a substantial "jig" described in appendix IV. A set of jig measurements was taken after the vacuum chamber work was completed in 1991; and another set was taken in the fall of 1995. There had been few intentional movements of the ring vacuum chambers during this interval, so a comparison of the positions measured in 1991 and 1995 gives an indication of how much the chambers are moving around "by themselves" and/or how repeatable the jig measurements are. Figures 1 and 2 give a scatter plot of the 1991 and 1995 data. Were there no motion between measurements and were the jig and its "execution" perfect, the results would fall exactly on a line with unity slope. In fact in both planes this tendency is the most obvious feature of the data. A slight systematic deviation from equality may be a consequence of a change made to the jig fixture. The bases of the measuring "pins" were modified to make them magnetic, which simplified using the jig. This could inadvertently have changed the pin length and affected all the '95 readings for a given plane equally. This systematic effect (see the offsets in figures 3 and 4 - histograms of the differences between measurements for the two years) is about 20 mils (.5mm). Beyond this global shift the differences for a given PUE between the years is less than a millimeter (2 boxes in figures 3 and 4) for most of the stations. The clumps (8 and 9 stations) at the extremes in figures 3 and 4 represent for the most part chambers which were moved in association with magnet coil refurbishment between '91 and '95. This four year comparison data is consistent both with the measurements being accurate at the sub-mm level and with the idea that the chamber position is stationary with time at the same level -both satisfactory results. The actual variation around the ring as measured in 1995 (figures 5 and 6) is about 4mm in the vertical and 8 mm in the horizontal; so the correction is large relative to the four year variation. That the vertical spread is smaller than the horizontal is not surprising since the vertical chamber motion is more tightly constrained by the magnets and gravity. More details and the tables and procedures used to generate the offset tables are given in appendix III.

One final comment on the jig, for those who know too much. This fixture (described in painful detail in the appendices) is obsolete as of the shutdown summer 1996 redo of the AGS low field correction magnet system. The new correction magnets do not have the "pin" holes that the old magnets had, so the old jig no longer works. Instead the new magnets have "pin" holes rotated 45^0 relative to the old holes. A new jig is being fabricated to essentially make the same measurements as the old. The correction magnet swap is being done without affecting the vacuum chamber positions but at some point in the future the new jig will be used. Then a comparison to the data presented here will be very interesting.

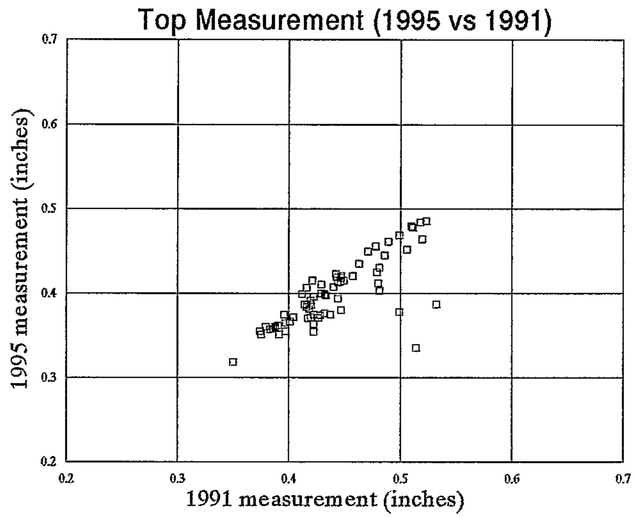


figure1

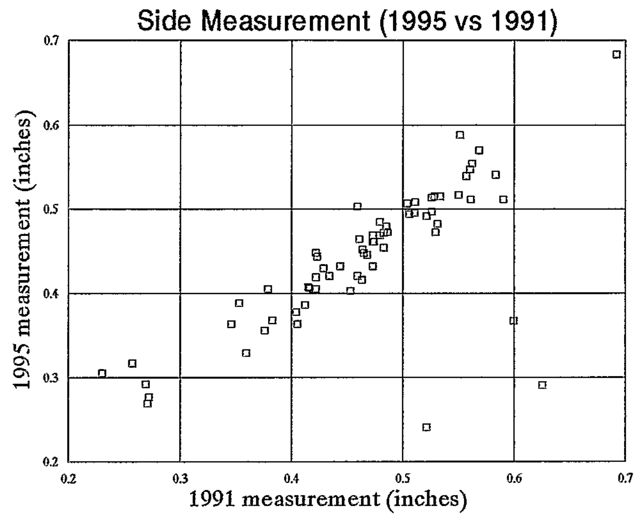


figure 2

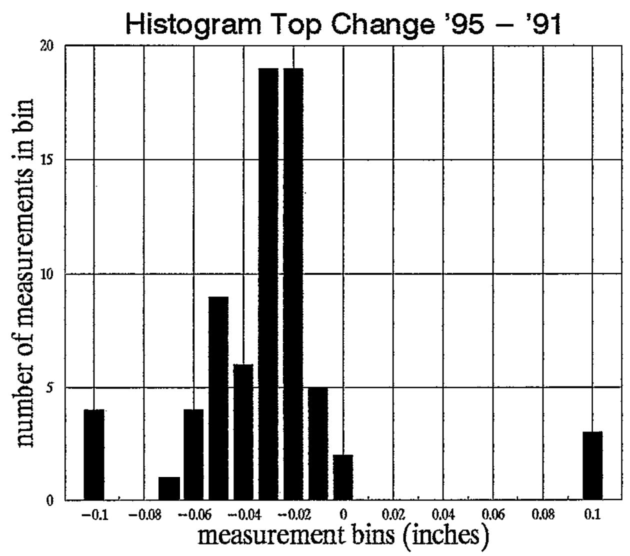


figure 3

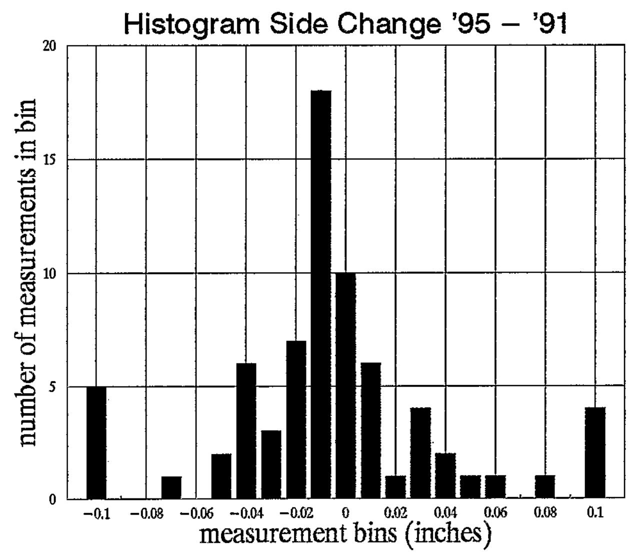


figure 4

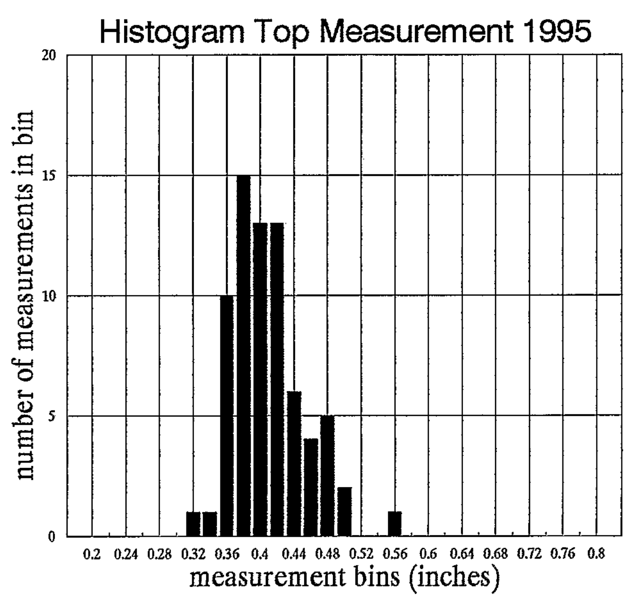


figure 5

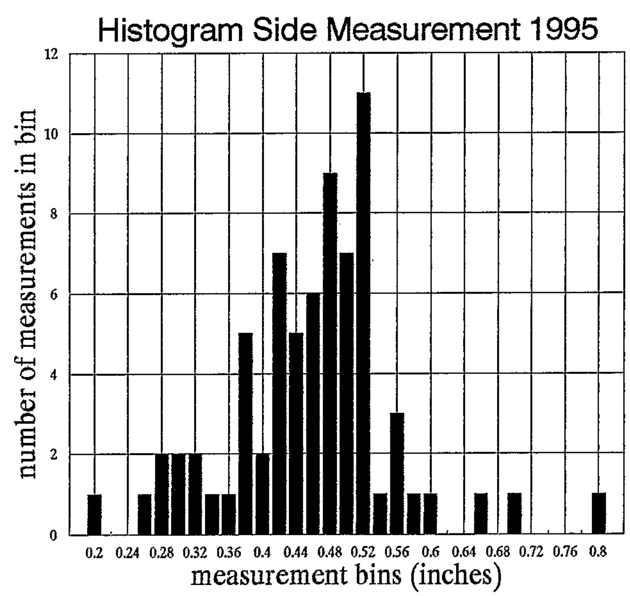


figure 6

Appendix I Capacitance (Electrical) Offsets

The magnitude of the capacitance of the (plate plus internal connecting cables plus feedthrough plus external cable to the impedance matching transformer) has changed over the years. A large (500 pF) capacitor was included in each line in the original design. This capacitor effectively swamped the channel to channel capacitance variation giving all the channels nearly equal gain. The upstream channel capacitance in those days was about 90 pF with channel to channel variation at the 10 pF level. Needless to say, there was another less pleasant effect from the 500 pF capacitance namely an 80% reduction of the signal size. Given that a major source of noise for the system in the late 1970's was rf 'noise' picked up on the cables downstream of the transformer box, the presence of these equalizing but attenuating capacitors did more harm than good. The large capacitors were removed; their function replaced by careful measurement of the input capacitance for all the channels in the yearly system prebeam setup and inclusion of the results in the system offset table. This change occurred prior to the writing of tech note #183 and is covered in more detail there. One side effect of the mechanical rework of the plate assembly completed in 1991 was an increase in the average input capacitance (as a result of the detailed cabling inside the vacuum cans and the new vacuum feed throughs). The 90 pF average increased to 133 pF with a sigma of 5 pF.

Nuts and Bolts: Here we describe specifically how the data is collected and handled. In the ring, each pue station includes four coaxial cables, each running between the vacuum chamber feed through and the transformer box. For the measurement first one cable is disconnected at the transformer box end. The capacitance of that cable and associated "inside the vacuum chamber" stuff is measured - with a portable capacitance meter. The cable is reconnected and the exercise repeated for the next cable. Some care is taken to maintain the 'in ring' cabling such that the labeling both to and from the transformer box is ("1,2,3,4") going from top to bottom. Record the measured capacitance for cables (1,2,3, and 4). These number are to be entered into the spreadsheet page devoted to capacitance. However that page wants its input as (in, out, up, and down), not (1,2,3,4). The mapping between these two sets is done at the electronics in 911B. Each set of four wires from a ring pue station goes into an electronics module. The downstream electronics which "reads" this module assumes that the inputs are arranged from top to bottom as (in, out, up, down). Check and note the cable number going to each location in order to know how to enter the data. This may seem terribly convoluted - why not just connect the "up" pue plate to the "up" cable in the ring? The trouble is you cannot see which pue is connected to which cable. A rather painful history indicates that the best indicator of which plate is 'up' or 'out' is beam measurements. Responding to beam information - namely "the reported position from pue A2 horizontal decreases when all the others increase (and the beam frequency increases at a point in the acceleration cycle below transition) and therefore the horizontal plates are connected backwards and should be reversed " - is done in 911B, without a ring access. As a result the cable pattern there is the best indication of truth - provided no one is also "fixing" things in the ring.

Back to the data crunching. The spreadsheet associated one pue station with each line. The four capacitance values are entered on this line in adjacent columns. Having entered the (72x4) capacitance values in the spreadsheet (presently in locations (B-E)X(5-76)), elsewhere across each line will appear offset and gain corrections, horizontal and vertical, for the 72 pue stations. The capacitance generated offsets and gains must then be transferred (as numbers) to the "Totals" spreadsheet page for inclusion in new complete offsets and gains.

For completeness, the calculations used to translate capacitances into offsets and gains is given next. Each pair of capacitance readings for a pair of plates (e.g. C1 = 'in' and C2 = 'out' for A2 pue) is treated nearly independently. The quantity (C1-C2)/(C1+C2) [=Cr in this discussion] is calculated. It goes into another column (for each plane, and for each pue station) on the spreadsheet. The raw position of the beam at A2 is given by {g x (V1-V2)/(V1+V2)}, where the V's are the voltages measured on the plates, and 'g' is the pue geometric constant whose value is about 7 cm . [Again for this discussion using an analogous notation, the voltage ratio will be referred to as Vr]. The true beam position is (Q1-Q2)/Q1+Q2) [=Qr], where Q1 means the charge on plate 1, and V1=Q1/C1. To predict the **beam position** we **need** the (Q ratio) = **Qr**; we **have** the (V ratio) = **Vr** **and** the capacitance ratio = **Cr**. With a little algebra we can write

$$\mathbf{Qr = (Vr+Cr) \times (1+Vr\,Cr)^{-1}} = (Vr+Cr) \times (1-VrCr+ (VrCr)^2 - ...) =$$
$$Vr +Cr - Cr\,Vr\,Vr - Cr\,Cr\,Vr + \text{higher order terms}$$

Now how big are these terms? From the last round of capacitance measurements the largest Cr = .05 and most are less than .01. For a 3 cm true beam offset (definitely large but not impossible - this is the beam offset from the center of the pue structure - which is located about 1 cm outside of R_0) and taking the geometry factor as 7 cm, Qr is 3/7 = .4. Even for the largest (worst) Cr, this will also be the approximate size for Vr. So Vr=.4, Cr<.05, CrVrVr < .008, and CrCrVr<.001. We then get a good (error less than .6 mm) estimate for Qr even for a 3 cm offset by correcting Vr only by the "offset" given by Cr times the geometry factor (which correction comes out to less than 1 mm for most of the stations, but to a few mm for a few). For stations with typical Cr's (.01), the term quadratic in Vr would introduce about a .4mm (uncorrected) error at a 5 cm beam offset.

This would end the discussion of the effect of the station capacitance if it were not for the fact (mentioned before) that in the present AGS system the voltage "sum" signals assumed above are not available. An attempt to get these signals was made during the last decade, but did not close. Instead, the "normalization" has always been done using an independent signal proportional to the beam intensity - a normalized current transformer reading. The overall calibration of the system is then measured by noting the average beam position change reported by the pue orbit system when the beam is shifted in radius (really momentum) at a fixed magnetic field. The pues are assumed to lie (on average) at points of average "dispersion" to close this argument. However, only one number is extracted for the system. The variation in the size of the capacitors will introduce an error for individual stations to the extent that the capacitors are different from the average. For this reason an additional factor is put into the program to correct the "gain" associated with each pue pair. This is just the sum of the two capacitors for a given plane divided by the average of all the capacitors in that plane in the full system. If a station's capacitors are larger than average, its voltages will be smaller than average, the reported position will be too small. This is the other column in the spreadsheet.

The geometric factor mentioned above, which otherwise would drop out of the argument in fact must be explicitly included in these corrections, since the normalization comes from an external device. This constant lives on this spreadsheet page, as do the calculated sums for the two planes.

Appendix II PUE Offsets inside the Vacuum Chamber

The mechanical rework of the pue assemblies in 1991 removed the primary reason for this category of correction - the x-ray results. Nevertheless this hook is still used, as a place to introduce the now very substantial (horizontal only) offsets between the pue center line and the R_0. This appendix will give the reasoning used to derive these offsets, as a reference. Further, the mechanics for changing these numbers will be described. The primary reason for touching this part of the offset determination would be a change in the AGS vacuum (e.g. the A2 pue is unique), or to correct an error in this analysis. None of this affects the pue results in the vertical plane. In this plane if the vacuum chamber is correctly centered the pues will be centered on the perfect orbit.

Nuts and bolts: this set of numbers lives on the x-ray page of the spreadsheet - for historic reasons which you may now understand. Unless there is a mistake in this page, which is not impossible, or better information is obtained for some of the spacing, or a physical change is made somewhere in the ring, this page will not change. If it is changed, the output needs to be carried over to the Totals spreadsheet page to be used in generating the bottom line set of offsets and gains.

One input for this analysis is the basic construction of the (2,4,8,12,14, and 16) straight sections in the AGS, where the pues are located (our reference here is Bleser's tech notes #215, "Where are the AGS Magnets?", and #217, "The Optimum Central Orbit in the AGS"). The magnets upstream of #2 and #12 are "short" magnets, the magnets upstream of # 4, #8, #14, and #18 are "long" magnets. The other input is the actual positioning of the pues in the vacuum chambers. As has been said, the pues lie on extensions of the upstream magnet socket line (assuming a properly positioned chamber). However, this magnet socket line and the R_0 line in the straight section are not parallel. So for example if the beam is reported as centered in the pue (equal voltages from the two plates), its distance from R_0 depends on just how far into the straight section the pue lies. And in order to do this calculation we must pick the point longitudinally along the pue structure which is the effective center of the pue. (The old geometry avoided this question by turning the pue axis horizontally till it lay on the beam code axis - still not parallel to R_0 however.)

So now the details as applied. The spreadsheet x-ray page includes a row for each pue station. On each row there are effectively three "input" numbers, and one "calculated" horizontal position which gets passed along to the totalizing page. Two inputs come from the Bleser notes. The first is the angle between the magnet socket line (the pue center line) and R_0 in the straight section. This depends only on whether the (upstream) magnet is "long" or "short", the angle being 13.9825 mrad for the long and 11.7512mrad for the short. The other number we need is the distance alone the socket line from the intersection of the "straight section" R_0 line and the magnet socket line to the pue center. The part of this to the magnet steel again can be extracted from Bleser's notes. The rest comes from drawings or measurements. What we actually find in the Bleser note is the distance between R_0 and the socket line, perpendicular to the socket line, at the "edge of the fringe field" (which edge is defined as being 2 inches out from the edge of the steel). Here again there are only two possibilities, one for the long magnets (.21906 inches), and one for the short (.15472) inches. From this distance and the angle, the required distance can be calculated. The third input is the distance along the socket line between the end of the magnet steel and the horizontal pue center. What to use for this number is a bit of a challenge to find. One has to decide where the pue assembly is positioned, relative to the magnet steel, and then decide where the center of the horizontal plates should be located. What is used in the spreadsheet for most of the pues is 14.90 inches. This comes from the estimate for the (steel to chamber end) at 16.65 (+/- .01) inches, the end of the horizontal plate as .43 inches upstream of the chamber end, and the effective center position of the pue along its plates as (1/3 of 3.97 inches).

These numbers are used for all the pues except two. At "A2" the pue assembly is really mounted on the upstream end of the A3 magnet rather than on the downstream end of A2. The calculation then must be done relative to the A3 magnet - which is a long magnet, and also has one other difference namely the pue can ends 1.5 inches farther (upstream) from the A3 steel than the cans for the normal configurations end (downstream). At H8 the (new) assembly - larger pue to give larger aperture and make a pue here possible - was constructed with the horizontal plates upstream of the vertical putting the horizontal plates about 4 inches closer to the upstream steel.

The offsets given in the table are very large (.8 or 1 cm for the two normal cases). However the answer is not terribly sensitive to the details of the last paragraphs. Even the rather huge position shift for H8 results in a change in offset of only 1.5 mm.

Appendix III Vacuum Chamber to Magnet Offsets

The spreadsheet page labeled jig introduces the jig survey numbers. First some general comments. The page has a row for each pue station. The vertical and horizontal data are handled separately in separate series of columns. One philosophy here and elsewhere is to require that the raw data go directly into the table. In fact we violate this a bit. Data taken with the jig "reversed" is entered with a negative sign - just as an indicator. The micrometers in both planes are set up to decrease as the pin advances - which for the vertical means goes down, which is logical enough for the vertical. The jig was originally built to bring the micrometers to .500 just as the pins hit the pue can if all is perfect.

First consider the vertical numbers. That situation slipped away from (.500 = correct) state because of problems with the micrometers, but the original situation is recovered by subtracting 1.028 from the vertical micrometer readings. This mostly explains the first (purely raw (micrometer) readings, and second (correcting for this offset) vertical columns. The additional offset for A2 is required because a spacer plate is needed for this unique pue (really in A3) which reduces the reading. Next the .500 "perfect" position reading is subtracted, the then the number is converted from inches to centimeters.

The horizontal readings again have a "raw" column. One feature of the jig is its ability to rotate the horizontal arm through 180^0 around a vertical axis to measure the pue can from the other side - from the aisle side or from the catwalk side. The feature allows measurements to be made which otherwise would be impossible where injection or extraction beam pipes block outside entry, but also allow a check (returned to below) on the jig geometry by measuring a given pue in both orientations. As mentioned above the raw data taken in the reverse position is 'arbitrarily' entered with a negative sign. The next spreadsheet column processes this data a bit. First, all readings are increased by .005, because it was noticed that the push of the micrometer on the pue would actually move the jig away from the pue about this much before the micrometer would “free wheel”. The micrometers decrease as they go in; their readings must be increased to correct for this. The reverse readings are also transformed to the values they would have had if taken in the forward geometry. The formula to do this is 1.-(-raw+.005). The (-) in front of the raw just removes the (-) put there to identify that this is a reverse reading. The .005 is again accounting for the jig to be tilted by the pin and micrometer. The (1-) out front comes from the geometry and construction of the jig. For a perfectly positioned can, the normal and reversed readings both should give .500. As the can moves to the inside. The normal reading decreases, and the reverse reading increases by the same amount. So subtracting the reverse reading from 1.000 just transforms it into the number one would get for a normal reading.. On the last pass with the jig four pue cans were measures with the horizontal arm both out and in. This is a check! The result for the sum of the two readings was .994 with a total spread of +/- .01. The A2 pue has an additional correction again because the reading must be taken with a spacer plate - which was .094 inches thick for this measurement.

Three more steps are still required for this horizontal data. The jig geometry is set up to be perfect for the #4 or #14 magnet geometry. The micrometer should hit the pue can exactly at .500 there. Just because of the differences in the machine lattice, a perfect pue can at a #2 or #12 would report an offset of -.066 inches; and similarly at #8 or #18 the measured offset would be .033 inches. These built in offsets are removed on this page. The .500 “perfect” position must also be subtracted, and the measure converted from inches to centimeters.

Appendix IV Putting the Pieces Together

Working now on the totals spreadsheet page: all of the final columns from the three cases are carried to this page - preferably just as numbers. In the vertical plane, the jig and capacitor contributions are added, and that is it. The only contribution to the vertical gain comes from the capacitor values. In the horizontal the situation is the same except that the “x-ray” offsets also get added in. Again the only contribution to the channel gain comes from the capacitors. All of these contributions have been arranged to have the same sign, and the sign appropriate to adding these final numbers to the positions reported by the AGS orbit acquisition program. Needless to say, if one gets the sign wrong, one would be better off to have stayed home.

An additional “summary” sheet takes the bottom line - 72x4 numbers to a separate page. These numbers want to be the same as the numbers in the active AGS orbit system offset/gain file.

A separate spreadsheet - I was having memory trouble - used the Totals sheet only and generates some plots of offset contributions from the various sources. This sort of presentation allows any crazy entries to be notices (and corrected if appropriate). As a final figure, these plots for the ‘95-’96 offsets are included.

Appendix V The Survey Jig

Description:

A rather substantial measuring fixture or "jig" has been used to relate the position of each pue ("pick up electrode") "can" to the adjacent main ring magnets. The pue vacuum can holds the plates making the beam position measurement. The jig comprises a long horizontal "longitudinal" beam below which is mounted a shorter perpendicular "transverse" arm both arms being instrumented with micrometer driven reference pins. The philosophy behind the fixture is that the position of the pue "can" (whose diameter and length are both about 7.5 inches) is known a priori to perhaps a quarter of an inch. Then the fixture measurements provide the exact position. All cans are assumed to be identical.

The fixture is referenced (in space) transversely by the adjacent main magnet socket holes and vertically by the reference "flats" in which these socket holes are drilled. Specifically the longitudinal beam of the fixture rests on the upstream magnet "flat" and picks up the upstream magnets downstream socket hole using a round ended thick pin fixed to the beam which snugly fits into the socket hole. Similarly the downstream end of this beam picks up the upstream socket hole of the downstream main magnet including its vertical "flat. To avoid an over constrained situation, this downstream connection is made using a free thick pin snugly fitted in the socket hole and then snugly fitted into a slot in the longitudinal beam.

A micrometer with vertical travel is rigidly attached to this horizontal fixture beam at the position which allows a rigid but relatively thin (.2 inch diameter by 5 inch in length) "pin" driven by the micrometer to maneuver down through an observation hole in the correction magnet windings which surround the pue outer can and to make physical - and audible - contact with the top of the can. The sensing pin must be separable from the arm to allow the positioning to be accomplished. During the measurement the pin is held parallel with the micrometer drive direction while still maintaining some transverse flexibility using two flat 2 inch diameter disks mounted perpendicular to the drive direction. One disk is effectively attached to the micrometer, the other to the pin. The two disks can slide against each other allowing the pin to move relative to the micrometer shaft but transverse to the micrometer direction of motion. This freedom is required because the magnet coil assembly arrangement is sloppy, sometimes shifting the access hole by a fraction of an inch.

The second arm, the "transverse" arm', is mounted below and perpendicular to the longitudinal arm just described. This arm also carries a micrometer and sensing pin arrangement nearly identical to that carried by the longitudinal beam. However the micrometer moves this pin horizontally and the pin is positioned so as to pick up the side of the pue can. An additional feature is the inclusion of the flexibility to rotate this side arm by 180 degrees around the vertical axis which is the shaft that ends in the longitudinal arms' sensing pin. Using this rotation degree of freedom, the transverse arm's sensing pin can be arranged to come in to the pue can from the outside or to come out to the pue can from the inside. This freedom is required to allow horizontal measurements to be made at all (most) of the pue locations in the ring. Specifically measurements from the inside are required at the injection channel (L18), the extraction channels (F12, F14; H12, H14), shielding at I14, and magnet buss work at (G2, G4, and G8). (The situation at (F14 and H14) is actually worse as in these two locations neither in nor out measurements were physically possible in 1995-6.)

The transverse arm is rigidly connected to the longitudinal beam by four vertical bolts in slightly oversized holes. The additional constraint that the transverse arm be a snug fit to the substantial vertical shaft of the longitudinal beam together with the fact that in either orientation horizontal micrometer moves nearly perpendicular to the can surface being measured makes this unpinned connection quite acceptable and it is simple.

While the levelness of the fixture longitudinally is "guaranteed" by the fact that it rests on the magnets, the transverse arm must be explicitly "leveled". Indeed the pressure exerted by the side micrometer when contact with the pue can is made and before the micrometer "free wheels" causes the fixture to tilt a bit, and the bubble of the level to respond. Because assurance of good contact with the can is important, this effect is taken as a feature rather than a bug. With the pressure required to freewheel in the '95 measurements, the horizontal measurements overestimate the distance to the can - by about 5 mils. This is corrected on average in the final data.

The fixture described above was designed and construction under the direction of Nick Parinello back in 1982. Recently (1995) Viorel Badea simplified its use in two ways. The attachment of the pin disk to the micrometer disk mentioned above had been done using a pair of mechanical clips. These are replaced by a magnet embedded in one disk and a magnetic flat on the other. The second improvement was the lightening of the beam structures by removing some of the metal without measurably reducing the rigidity of the structure. These changes significantly reduced the effort required to make the measurements.

A Listing of the Kit of Parts:

The two beams, and the separable vertical axis rod are stored in a large (3'x4'x1') wooden box. In addition the kit contains:

two 5" "pins", the "red" one is to be used for the side measurement.

two 6" Starrett levels - one a spare when the first is dropped.

one 3"x(5/8)" "pin" or dowel for the downstream magnet socket hole

two "leveling" screws, (3.5" long with large hex heads) which fit threaded holes in the longitudinal beam and allow the leveling of the transverse arm by pushing against the top of the main magnet.

two 3"x3"x2" painted lead blocks, with slots, which are needed to counterbalance the transverse arm at half of the measuring positions - (12, 14, and 18 if arm on the outside).

four ((3/8)" x 1.5") bolts, each with two washers and a nut, for attaching the transverse arm to the horizontal arm.

one "c" clip to hold the vertical shaft in the horizontal beam.

one tool for opening the "c" clip

Assembly Instructions:

Do the following physically reasonably near where the fixture is to be used. The assembled jig can be carried in a car or truck, but only with care. The relatively delicate micrometers are exposed when the assembled fixture is carried around.

Loosely attach the transverse arm to the longitudinal (longer with T end) arm using four bolts with washers on both sides on each bolt. Arrange the transverse arm to extend **out** (longitudinal micrometer handle up, T end to left, T lying in horizontal plane, transverse arm extending toward you) or **in** as desired. The "out" position is used for most of the can measurements.

Attach the vertical shaft through the transverse arm and through the longitudinal beam using a "c" clip.

Tighten the four bolts with the edges of the butting surfaces reasonably lined up.

To reverse the transverse arm, the vertical shaft need not be removed. The four bolts are removed, and the arm rotated by 180 degrees. Then the bolts are reattached. Tighten gradually, and check the reasonable alignment of the butting surfaces.

Use Instructions:

With the fixture assembled in the desired configuration, transport it to the magnet to be measured. You will also need: the two pins, the socket hole thick pin, the level, a pen and paper (= data sheet), a cleaning cloth. In addition if working with the arm to the outside, you will need the two counter weight blocks at pue's #12, 14, and 18. A stool or other support is appreciated at these locations also.

For the outside measurements, climbing onto the magnets is not necessary.

Climb up so you can see the socket holes. Wipe around the holes where the fixture will rest. Insert the free socket pin into the socket hole in the downstream magnet, pointed end up. Lift the fixture up into approximately the correct position. Gently align the upstream pin into the upstream socket hole. Lift the fixture and position so that the downstream pin meets the slot in the fixture. Slightly tilt the fixture until the pin slips into the slot.

Check the longitudinal beam for levelness by placing the level on the top surface flats. There is nothing to be done, if the surfaces are clean except to document any discrepancies from level. Move the level to the side flats on the transverse arm. Adjust the leveling screw on the T arm of the longitudinal beam till the bubble is centered.

Insert the vertical and horizontal can measuring pins and magnetically attach them to their micrometer shafts. Slide the pins in by hand until they hit the pue can. If a pin does not clearly hit the metal can (feel and sound) slide the pin disk along the micrometer disk till a good hit is accomplished. If possible slide longitudinally - along the pue can axis. This will not affect the answer. If it is necessary to slide the pin transversely note how much (roughly) on the data sheet.

With the pins against the can, run in the two micrometers till they are against the pins and "freewheel". Record the measured positions.

Back off both micrometers. Reverse the level on the flat. Relevel the fixture. Again check that the pins hit the can, and push them in. Again run in the micrometers till they freewheel. Record the measurements.

That's it for this pue. The two measurements are a check against some systematics. The level may be biased. The average of the two horizontal readings is the best estimate. Hopefully they are close - within 10 mils. The vertical should agree to 1 mil.

Be very careful before lifting down the fixture. **Remove the level.** Back off the micrometers and **remove the pins.** This turns out to be very hard to remember every time. If the level falls, it will not be the same.

Other associated measurements:

The micrometers have the bad feature that if retracted far enough, they lose their reference. And of course they must be retracted nearly that far to remove the pins after each measure. **Don't retract the micrometer end out of sight into the micrometer.** Further, check occasionally that such an event has not occurred by measuring the position just as the micrometer end comes out from its holder - hold something against the micrometer end and retract till it just touches. This reading should always be the same. For the data taken in 1995, the vertical micrometer read 2.270" when just retracted, the horizontal read 1.130". In fact this reference was not lost, so the problem is only there if the micrometer is inadvertently over retracted. Nevertheless, if the reference is seen to be changed, all readings taken since the last check are suspect and probably must be redone.

Appendix V The Survey Jig

Description:

A rather substantial measuring fixture or "jig" has been used to relate the position of each pue ("pick up electrode") "can" to the adjacent main ring magnets. The pue vacuum can holds the plates making the beam position measurement. The jig comprises a long horizontal "longitudinal" beam below which is mounted a shorter perpendicular "transverse" arm both arms being instrumented with micrometer driven reference pins. The philosophy behind the fixture is that the position of the pue "can" (whose diameter and length are both about 7.5 inches) is known a priori to perhaps a quarter of an inch. Then the fixture measurements provide the exact position. All cans are assumed to be identical.

The fixture is referenced (in space) transversely by the adjacent main magnet socket holes and vertically by the reference "flats" in which these socket holes are drilled. Specifically the longitudinal beam of the fixture rests on the upstream magnet "flat" and picks up the upstream magnets downstream socket hole using a round ended thick pin fixed to the beam which snugly fits into the socket hole. Similarly the downstream end of this beam picks up the upstream socket hole of the downstream main magnet including its vertical "flat. To avoid an over constrained situation, this downstream connection is made using a free thick pin snugly fitted in the socket hole and then snugly fitted into a slot in the longitudinal beam.

A micrometer with vertical travel is rigidly attached to this horizontal fixture beam at the position which allows a rigid but relatively thin (.2 inch diameter by 5 inch in length) "pin" driven by the micrometer to maneuver down through an observation hole in the correction magnet windings which surround the pue outer can and to make physical - and audible - contact with the top of the can. The sensing pin must be separable from the arm to allow the positioning to be accomplished. During the measurement the pin is held parallel with the micrometer drive direction while still maintaining some transverse flexibility using two flat 2 inch diameter disks mounted perpendicular to the drive direction. One disk is effectively attached to the micrometer, the other to the pin. The two disks can slide against each other allowing the pin to move relative to the micrometer shaft but transverse to the micrometer direction of motion. This freedom is required because the magnet coil assembly arrangement is sloppy, sometimes shifting the access hole by a fraction of an inch.

The second arm, the "transverse" arm', is mounted below and perpendicular to the longitudinal arm just described. This arm also carries a micrometer and sensing pin arrangement nearly identical to that carried by the longitudinal beam. However the micrometer moves this pin horizontally and the pin is positioned so as to pick up the side of the pue can. An additional feature is the inclusion of the flexibility to rotate this side arm by 180 degrees around the vertical axis which is the shaft that ends in the longitudinal arms' sensing pin. Using this rotation degree of freedom, the transverse arm's sensing pin can be arranged to come in to the pue can from the outside or to come out to the pue can from the inside. This freedom is required to allow horizontal measurements to be made at all (most) of the pue locations in the ring. Specifically measurements from the inside are required at the injection channel (L18), the extraction channels (F12, F14; H12, H14), shielding at I14, and magnet buss work at (G2, G4, and G8). (The situation at (F14 and H14) is actually worse as in these two locations neither in nor out measurements were physically possible in 1995-6.)

The transverse arm is rigidly connected to the longitudinal beam by four vertical bolts in slightly oversized holes. The additional constraint that the transverse arm be a snug fit to the substantial vertical shaft of the longitudinal beam together with the fact that in either orientation horizontal micrometer moves nearly perpendicular to the can surface being measured makes this unpinned connection quite acceptable and it is simple.

While the levelness of the fixture longitudinally is "guaranteed" by the fact that it rests on the magnets, the transverse arm must be explicitly "leveled". Indeed the pressure exerted by the side micrometer when contact with the pue can is made and before the micrometer "free wheels" causes the fixture to tilt a bit, and the bubble of the level to respond. Because assurance of good contact with the can is important, this effect is taken as a feature rather than a bug. With the pressure required to freewheel in the '95 measurements, the horizontal measurements overestimate the distance to the can - by about 5 mils. This is corrected on average in the final data.

The fixture described above was designed and construction under the direction of Nick Parnello back in 1982. Recently (1995) Virel Badea simplified its use in two ways. The attachment of the pin disk to the micrometer disk mentioned above had been done using a pair of mechanical clips. These are replaced by a magnet embedded in one disk and a magnetic flat on the other. The second improvement was the lightening of the beam structures by removing some of the metal without measurably reducing the rigidity of the structure. These changes significantly reduced the effort required to make the measurements.

A Listing of the Kit of Parts:

The two beams, and the separable vertical axis rod are stored in a large (3'x4'x1') wooden box. In addition the kit contains:

two 5" "pins", the "red" one is to be used for the side measurement.

two 6" Starrett levels - one a spare when the first is dropped.

one 3"x(5/8)" "pin" or dowel for the downstream magnet socket hole

two "leveling" screws, (3.5" long with large hex heads) which fit threaded holes in the longitudinal beam and allow the leveling of the transverse arm by pushing against the top of the main magnet.

two 3"x3"x2" painted lead blocks, with slots, which are needed to counterbalance the transverse arm at half of the measuring positions - (12, 14, and 18 if arm on the outside).

four ((3/8)" x 1.5") bolts, each with two washers and a nut, for attaching the transverse arm to the horizontal arm.

one "c" clip to hold the vertical shaft in the horizontal beam.

one tool for opening the "c" clip

Assembly Instructions:

Do the following physically reasonably near where the fixture is to be used. The assembled jig can be carried in a car or truck, but only with care. The relatively delicate micrometers are exposed when the assembled fixture is carried around.

Loosely attach the transverse arm to the longitudinal (longer with T end) arm using four bolts with washers on both sides on each bolt. Arrange the transverse arm to extend **out** (longitudinal micrometer handle up, T end to left, T lying in horizontal plane, transverse arm extending toward you) or **in** as desired. The "out" position is used for most of the can measurements.

Attach the vertical shaft through the transverse arm and through the longitudinal beam using a "c" clip.

Tighten the four bolts with the edges of the butting surfaces reasonably lined up.

To reverse the transverse arm, the vertical shaft need not be removed. The four bolts are removed, and the arm rotated by 180 degrees. Then the bolts are reattached. Tighten gradually, and check the reasonable alignment of the butting surfaces.

Use Instructions:

With the fixture assembled in the desired configuration, transport it to the magnet to be measured. You will also need: the two pins, the socket hole thick pin, the level, a pen and paper (= data sheet), a cleaning cloth. In addition if working with the arm to the outside, you will need the two counter weight blocks at pue's #12, 14, and 18. A stool or other support is appreciated at these locations also.

For the outside measurements, climbing onto the magnets is not necessary.

Climb up so you can see the socket holes. Wipe around the holes where the fixture will rest. Insert the free socket pin into the socket hole in the downstream magnet, pointed end up. Lift the fixture up into approximately the correct position. Gently align the upstream pin into the upstream socket hole. Lift the fixture and position so that the downstream pin meets the slot in the fixture. Slightly tilt the fixture until the pin slips into the slot.

Check the longitudinal beam for levelness by placing the level on the top surface flats. There is nothing to be done, if the surfaces are clean except to document any discrepancies from level. Move the level to the side flats on the transverse arm. Adjust the leveling screw on the T arm of the longitudinal beam till the bubble is centered.

Insert the vertical and horizontal can measuring pins and magnetically attach them to their micrometer shafts. Slide the pins in by hand until they hit the pue can. If a pin does not clearly hit the metal can (feel and sound) slide the pin disk along the micrometer disk till a good hit is accomplished. If possible slide longitudinally - along the pue can axis. This will not affect the answer. If it is necessary to slide the pin transversely note how much (roughly) on the data sheet.

With the pins against the can, run in the two micrometers till they are against the pins and "freewheel". Record the measured positions.

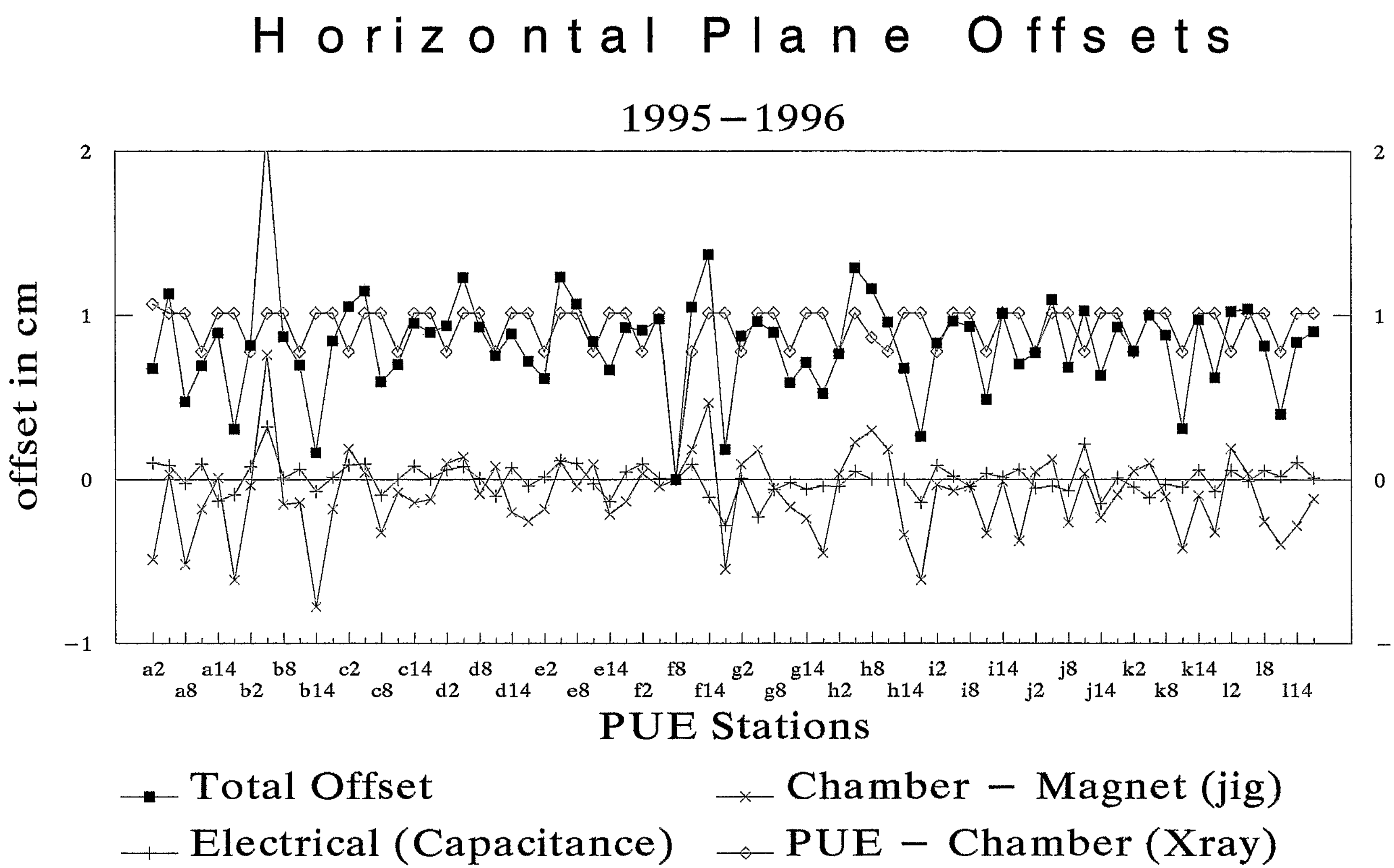
Back off both micrometers. Reverse the level on the flat. Relevel the fixture. Again check that the pins hit the can, and push them in. Again run in the micrometers till they freewheel. Record the measurements.

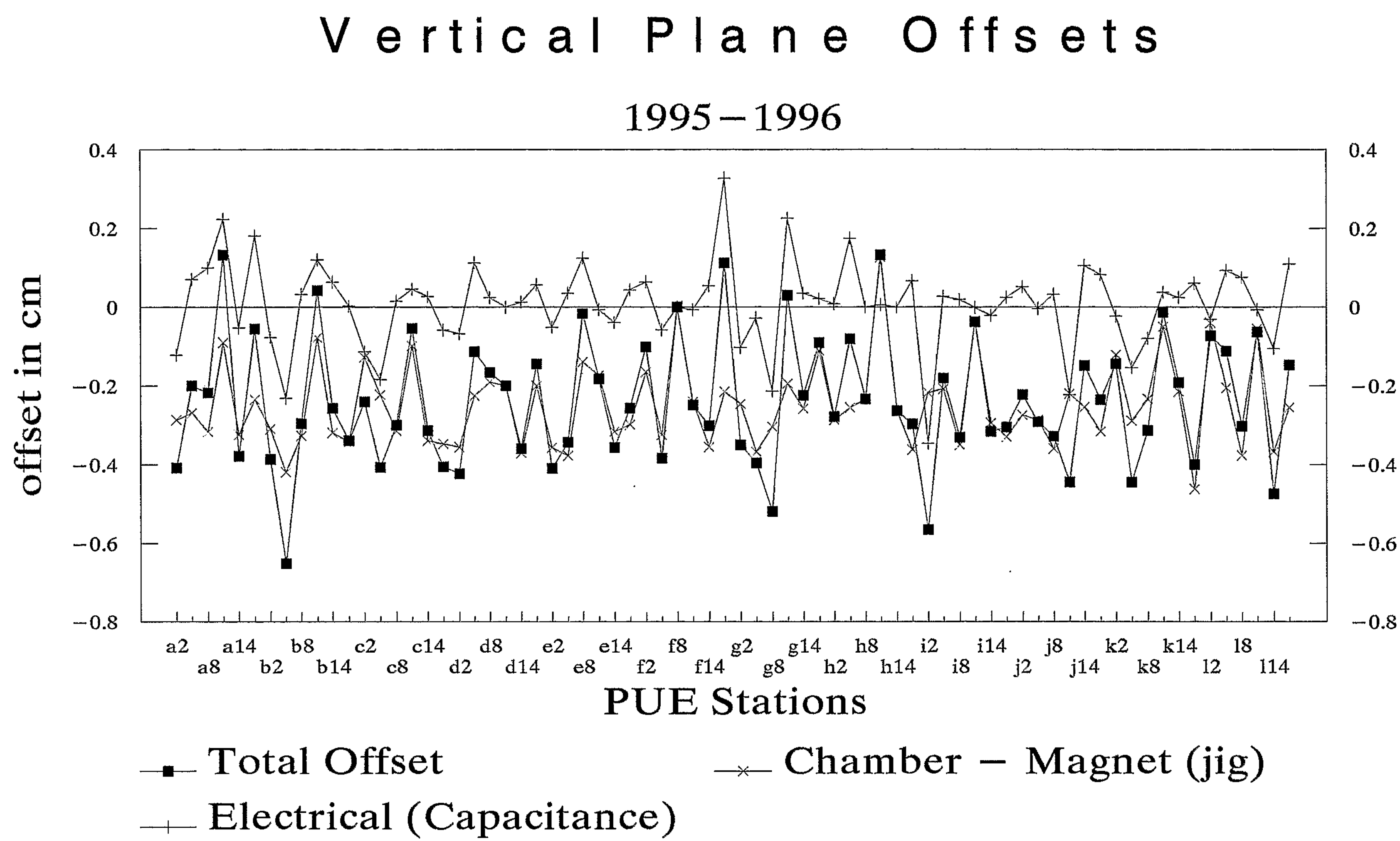
That's it for this pue. The two measurements are a check against some systematics. The level may be biased. The average of the two horizontal readings is the best estimate. Hopefully they are close - within 10 mils. The vertical should agree to 1 mil.

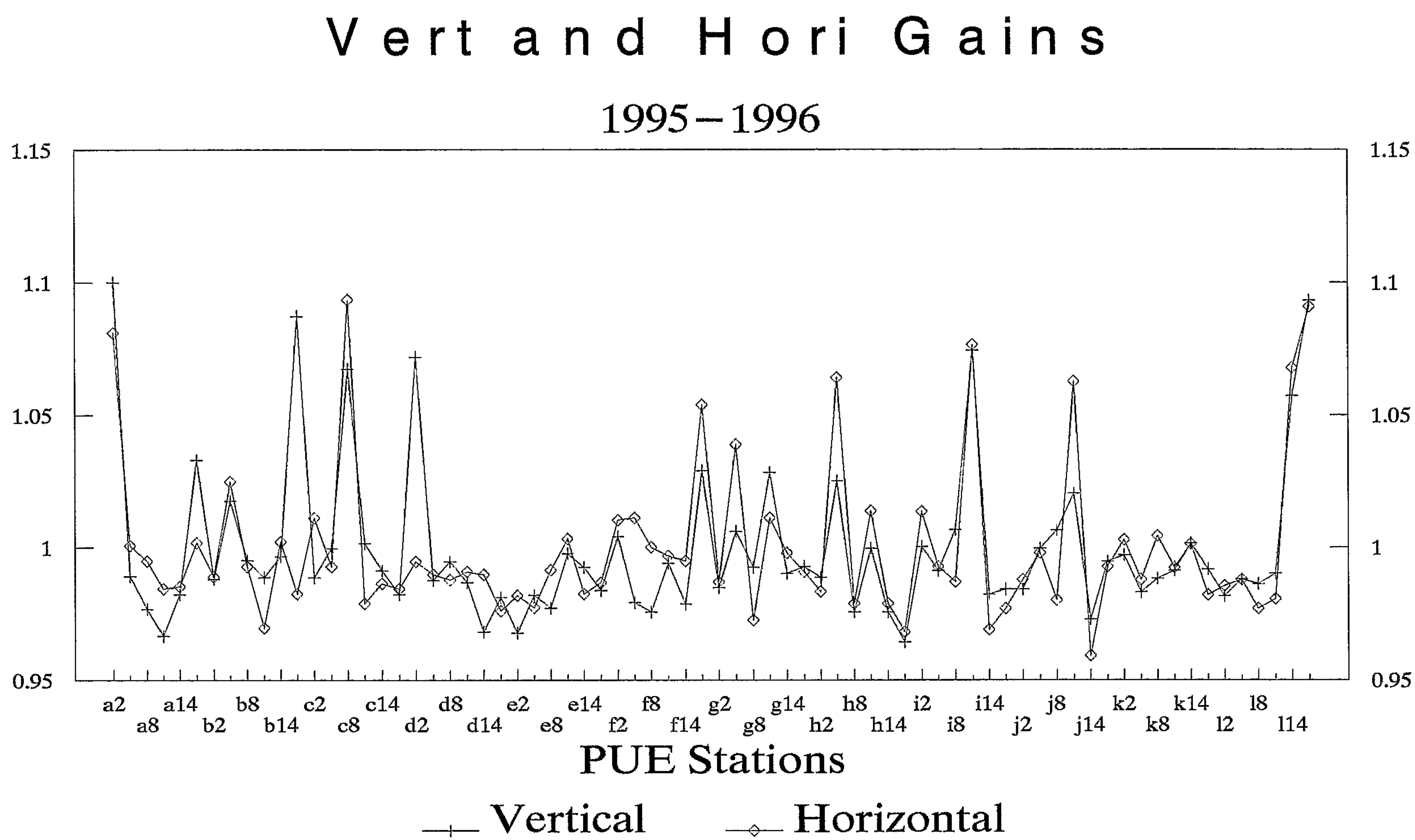
Be very careful before lifting down the fixture. **Remove the level.** Back off the micrometers and **remove the pins.** This turns out to be very hard to remember every time. If the level falls, it will not be the same.

Other associated measurements:

The micrometers have the bad feature that if retracted far enough, they lose their reference. And of course they must be retracted nearly that far to remove the pins after each measure. **Don't retract the micrometer end out of sight into the micrometer.** Further, check occasionally that such an event has not occurred by measuring the position just as the micrometer end comes out from its holder - hold something against the micrometer end and retract till it just touches. This reading should always be the same. For the data taken in 1995, the vertical micrometer read 2.270" when just retracted, the horizontal read 1.130". In fact this reference was not lost, so the problem is only there if the micrometer is inadvertently over retracted. Nevertheless, if the reference is seen to be changed, all readings taken since the last check are suspect and probably must be redone.


Horizontal Plane Offsets
1995–1996
offset in cm
2
1
0
−1
a2 a8 a14 b2 b8 b14 c2 c8 c14 d2 d8 d14 e2 e8 e14 f2 f8 f14 g2 g8 g14 h2 h8 h14 i2 i8 i14 j2 j8 j14 k2 k8 k14 l2 l8 l14
PUE Stations
Total Offset
Chamber – Magnet (jig)
Electrical (Capacitance)
PUE – Chamber (Xray)


Vertical Plane Offsets
1995–1996
offset in cm
0.4
0.2
0
–0.2
–0.4
–0.6
–0.8
a2 a8 a14 b2 b8 b14 c2 c8 c14 d2 d8 d14 e2 e8 e14 f2 f8 f14 g2 g8 g14 h2 h8 h14 i2 i8 i14 j2 j8 j14 k2 k8 k14 l2 l8 l14
PUE Stations
Total Offset
Chamber – Magnet (jig)
Electrical (Capacitance)



Vert and Hori Gains
1995–1996
1.15
1.1
1.05
1
0.95
a2 a8 a14 b2 b8 b14 c2 c8 c14 d2 d8 d14 e2 e8 e14 f2 f8 f14 g2 g8 g14 h2 h8 h14 i2 i8 i14 j2 j8 j14 k2 k8 k14 l2 l8 l14
PUE Stations
Vertical
Horizontal