BNL-104204-2014-TECH

AGS.SN332;BNL-104204-2014-IR

Measurement of the Sextupole String Center on the AGS Injection Porch

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June 1995

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U.S. Department of Energy

USDOE Office of Science (SC)

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Date:11 Jul 95 **AGS Studies Report No.** 332

AGS Complex Machine Studies
(AGS Studies Report No. 332 **)**
Title: Measurement of the Sextupole String "Center" on the AGS Injection Porch
Study Period: 18Jun95 (after HEP run finished)
Participants: L Ahrens, C Whalen, N Williams, B Tamminga
Reported by: L Ahrens, and C Whalen
Machine: AGS
Beam: 2 Tp protons
Tools: Tune meter, Frequency meter, Orbit Acquisition System
Aim: Determine Orbit Zero relative to Sextupole String
'center'. (Data taken in HEP Startup Book IV, pp49-53).

I. Introduction

The primary motivation for this study was to remeasure the radius that the AGS orbit acquisition system reported for the center of the AGS high field sextupole arrays. The sextupole center is defined here as that radius at which the betatron tune of the machine is not affected by changes in the current in the sextupole strings. It is claimed (Ahrens private communication) that the AGS orbit system reports radial positions relative to the "Beam Code axis" which lies on average about 4mm to the outside (larger radius or larger circumference) of R_0. The Sextupoles are surveyed in on R_0. Therefore, if life were simple we would expect to learn that the sextupoles did not affect either horizontal or vertical tune if the radius were set to -4mm according to the Orbit system.

Procedure

We work on the AGS injection porch ($B_{Hall\ probe}$)=905.2 Gauss with less than a .1 Gauss variation over the four samples at the times of the four transfers ... the variation in the up and down Gauss clock counts was **not** measured during the study) which for this study is extended for over two seconds at which time the rf is turned off and the Main Magnet magnetic field is ramped up slightly scraping the beam into the catcher. Four Booster batches are transferred, the four transfer initial intensity is about 2 Tp. The radial loop is closed after the fourth transfer. The sextupole current is shifted to the desired value after the fourth transfer is accomplished. The reference to the radial loop (radial steering function) is then used to adjust the beam momentum. The command given to the radial steering function is the independent variable. The AGS Orbit Acquisition system, in the "high" gain mode (a switch in the electronics racks, 911B) acquires orbits and reports the average of the pue's. Five cycles are averaged for each point. The variation in the reported average is typically .02 cm. The rf frequency is measured averaging over 10 AGS cycles, using a 100us window occurring at the same AGS time line setting as the orbit data is taken. The frequency variation is typically 30 Hz. Further, again at this time in the AGS cycle, the horizontal and vertical betatron tunes are measured, using the AGS tune meter, Again averages are taken. Estimation of the precision of these tune results is less obvious. For this note all the tunes measured are shown.

For each (of four) setting of the sextupole strings (the chromaticities) the radial steering function (or Radial Command) is varied (usually in .5 Volt steps) both inward and outward until significant loss is experienced. Therefore for each sextupole setup a table of radial steering setting and four associated quantities is generated. For both the horizontal and the vertical betatron tunes one expects to obtain four lines of (Tune vs Radius) all intersecting at one radial value - which would then be taken as the radius corresponding to the sextupole center.

Although that was the point of the exercise namely to learn the relative position of the Orbit Acquisition "zero" and the sextupole center, a calibration of the gains of the Orbit system and the radial loop command naturally occur, as does a check on the chromaticity reported by the Chromaticity Control Application code. The beam revolution frequency, or equivalently the rf frequency, provides an absolute measurement of the change in equilibrium orbit circumference as the radial loop reference is varied. The reference or "Radial Command" sent to the radial loop and the average reported by the Orbit system ("Radial Average") both should vary linearly with the frequency. The slope of these data gives the calibration for both systems. Figures 1 and 2 show the data.

These plots in fact include all the data for all four chromaticity settings. The "worst" points in the radial average plot correspond to data taken at the extremes for that setting - where beam was being lost due to the radial shift. This may explain the deviations from the global linearity. The correlation between frequency and radial command is excellent, and better than that between frequency and radial average. The tune shifts inherent in the study did not confuse the loop inputs.

$f_{rf}(\mathrm{MHz})=2.745654+.0013087*R_{cmd}$ $f_{rf}(\mathrm{MHz})=2.752024+.0037165*<R_{ave}>$

describe the lines drawn on the figures.

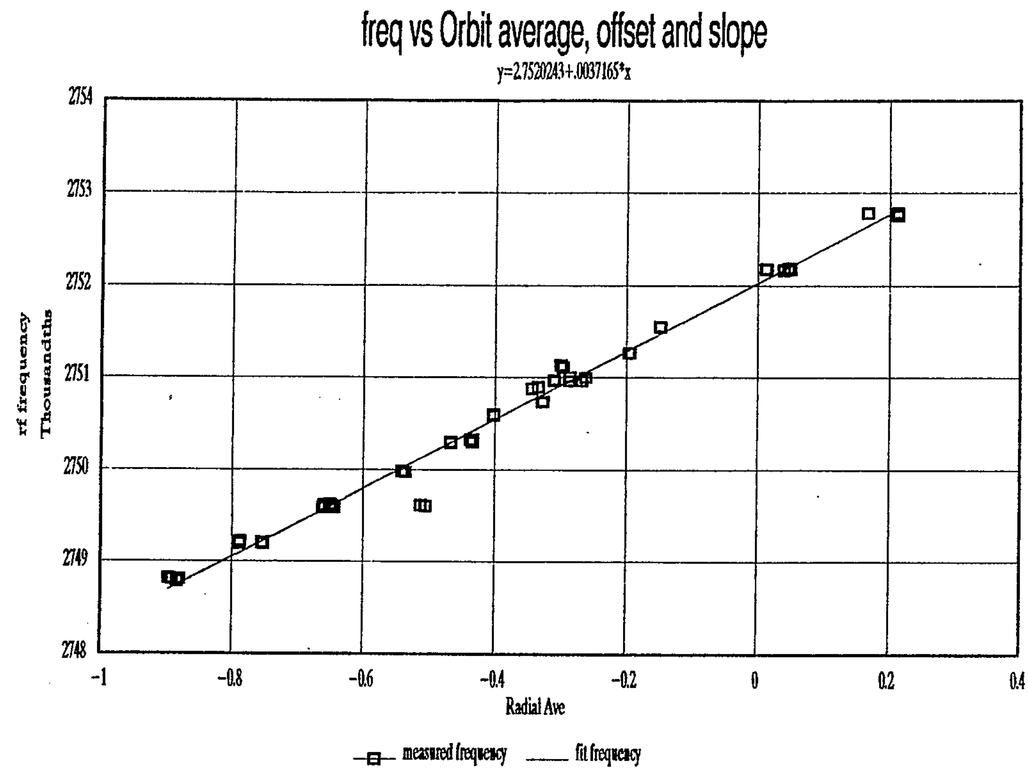

Figure 1. RF Frequency vs Orbit Radial Average

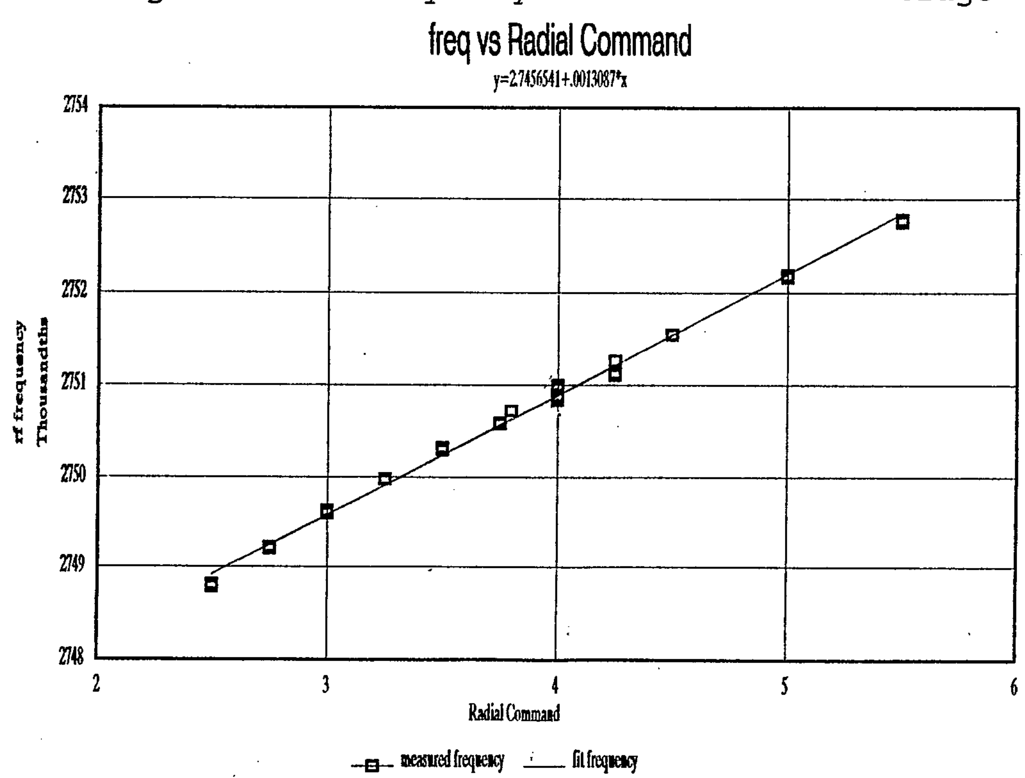

Figure 2. RF Frequency vs Radial Command

From this (given that the magnetic field is fixed, assuming R=12845.4cm, γ_{tr}=8.5, and the differential relation among (B,F, and R) one can extract that the rf frequency should change by 200 Hz per mm average (circumfrence/2pi) change, and hence that:

for the Radial Command, a 1 Volt change gives a .66cm radial shift; and

for the Orbit program,a shift reported as 1 "cm" is really a shift of 1.86cm.

The latter inconsistency reflects what has been an ongoing struggle this run. This calibration is apparently dependent on other variables - at least on the intensity. Further one can combine the equations, eliminating the frequency:

$<R_{avs}>$ ("cm")=-1.714+.352*R_{cmd} (Volts or function units)
(we are being casual in carrying digits - this is a study note.)

Ultimately we will find (this is jumping to the end) that the sextupole center is at about $<R_{ave}>$=-.5 "cm" = -.96 cm, and at R_{cmd}=3.4 Volts.

Figure 3 gives the (tune vs radius) data for the four chromaticity settings. The chromaticity "runs" are labeled by the requested horizontal chromaticity. (+1.,-.5, -4., and -2.6). The four plots all have the same scaling of the axes; the tunes (horizontal and vertical) range from 8.73 to 8.93; the rf frequency from 2.748 MHz to 2.754 MHz. Horizontal tunes are denoted by shaded squares, vertical tunes by open diamonds.

Some comments: (+1) - the available radial motion was most constrained, but the motion in tune space was typical. Both chromaticities are large - the tunes are usually well separated, coupling is not an issue.

(-.5) - Here the tunes were close and interpreting the results from the tune meter was confusing. We do not understand the observed shape. For searching for a horizontal crossing (below) we arbitrarily take only the points at radial ave = 3 and 3.5. In the course of this scan, the VHF cavity was turned off, in an attempt to reduce the momentum spread of the beam.

(-4.) - This was the last point taken, and the "drill" was well established. Further the available radial aperture was largest of the chromaticities explored. In the crossing search, we discard the point at 2.5 because the tunes are close to each other, although the results are not strongly affected. The horizontal chromaticity is not the "set" value of -4. As will be explained later we didn't understand how the program coped with the monopolar power supply.

(-2.6) - This was how we found the machine, and probably corresponds to the high intensity machine. There is little current in either string.

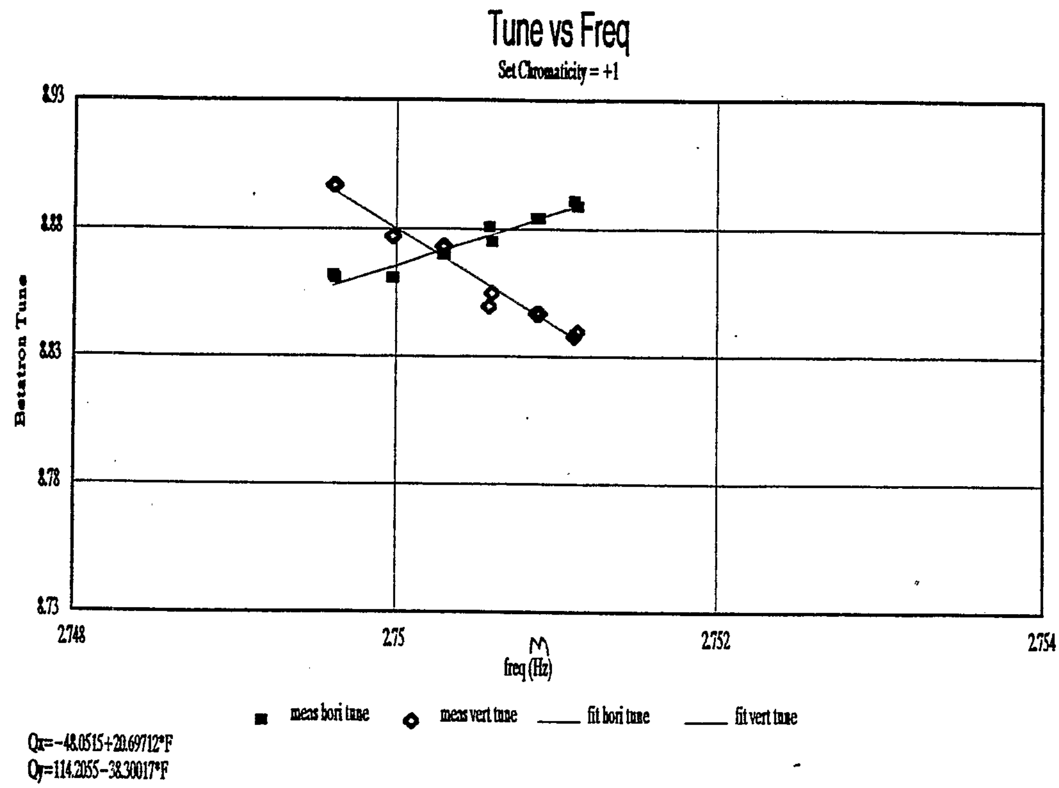

Figure 3a: Horizontal chromaticity set to +1. Measured chromaticities (H,V) = (+.75, -1.38)

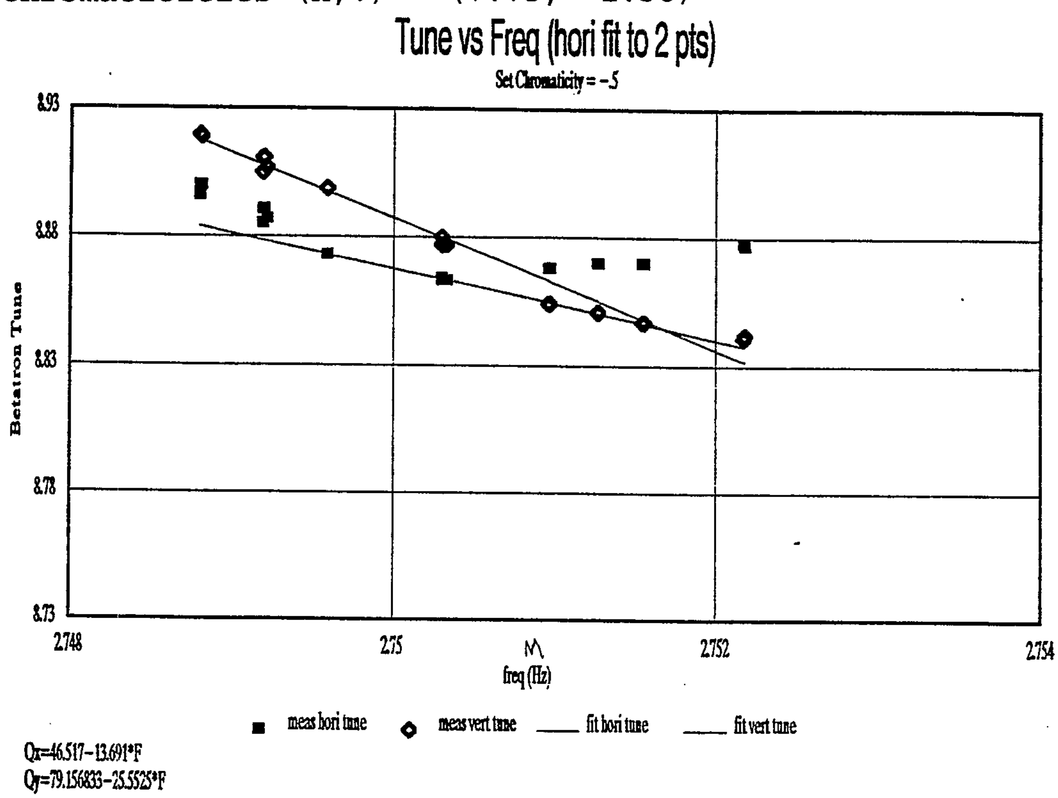

Figure 3b: Horizontal chromaticity set to -.5. Measured chromaticity (at radial cmd = 3) (H,V) = (-.57, -1.02)

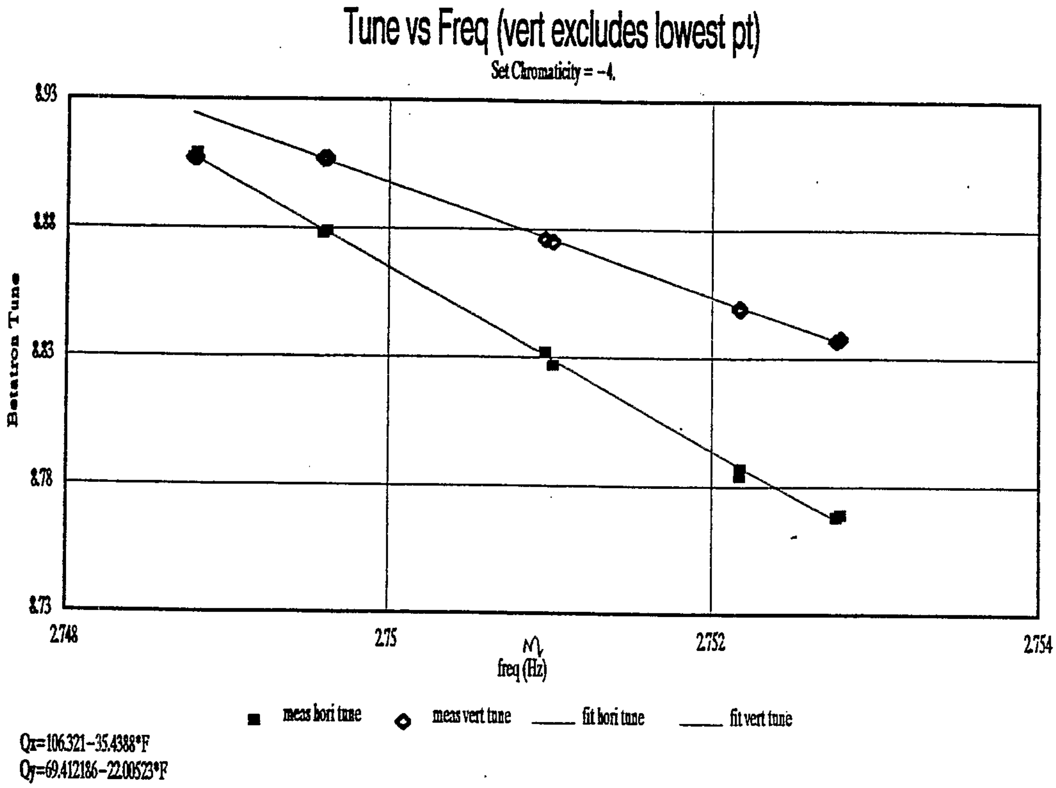

Figure 3c: Horizontal chromaticity set to -4. Measured chromaticity (H,V) = (-1.41, -.84)

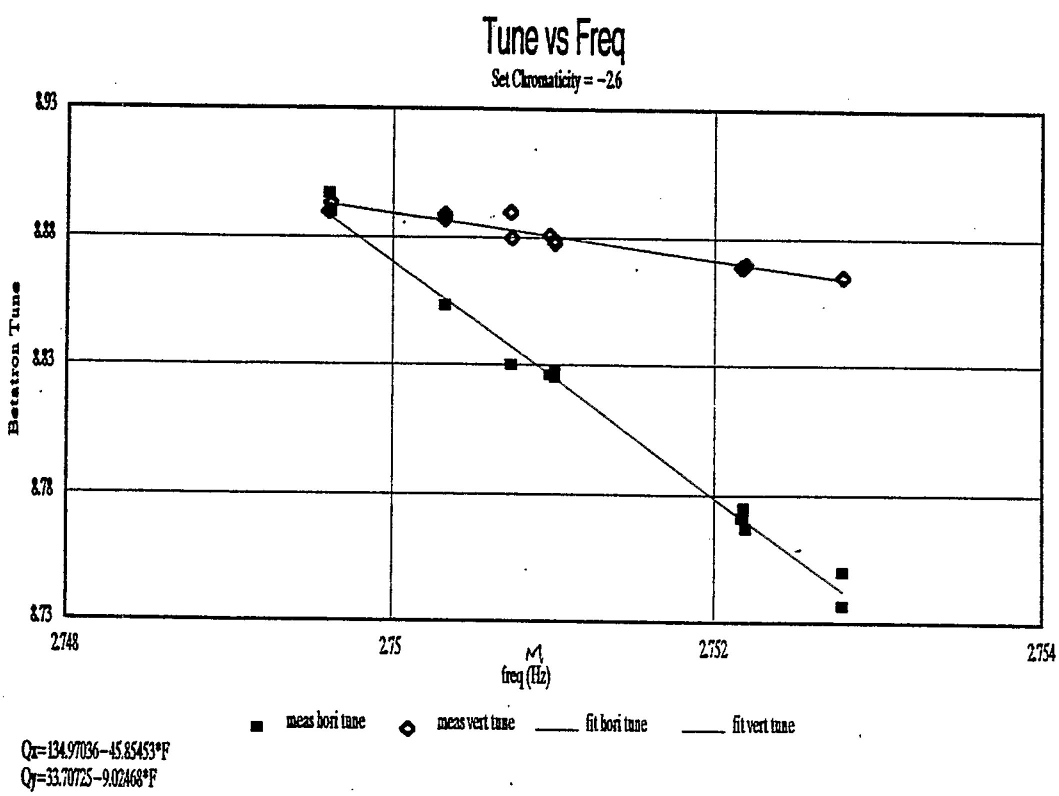

Figure 3d: Horizontal chromaticity set to -2.6. Measured chromaticity (H,V) = (-1.62, -.30)

The numbers extracted from this data are summarized in Tables I. and II. below.

Set ξ hori	I_{hori} Amps	I_{vert} Amps	dQ_h/dR_{cmd} $Volts^{-1}$	meas ξ hori	pred ξ hori
+1	94	28.5	.025	+.75	+1.0
-.5	53.2	15.5	-.019	-.57	-.5
-4.	0	-14.9	-.047	-1.41	-2.02
-2.6	0	-2.7	-.054	-1.62	-2.41

Table I. Horizontal Chromaticity Measurements

Set ξ hori	I_{hori} Amps	I_{vert} Amps	dQ_v/dR_{cmd} $Volts^{-1}$	meas ξ vert	pred ξ vert
+1	94	28.5	-.046	-1.38	-.3
-.5	53.2	15.5	-.034	-1.02	-.3
-4.	0	-14.9	-.028	-.84	-1.22
-2.6	0	-2.7	-.01	-.30	-.39

Table II. Vertical Chromaticity Measurements

The "set" chromaticity was the horizontal value casually sent to the program. One "gotcha" in the Chromaticity program is associated with the fact that one of the power supplies is monopolar while the other is bipolar. The program apparently knows about this limitation of the supply and adjusts the functions it calculates given a chromaticity request, for this limitation, and even warns the user. What it does not do is to modify the stored "live" function as a result. The stored function apparently keeps the impossible (in this case negative) current requests even though they cannot be sent to the hardware. Subsequent loading of the active "live" function results in the same warning message as before - with the result that this message seems always to be coming and hence is totally ignored. We did! The chromaticities reported are in this case wrong though the program can be "tricked" into giving the answer corresponding to the currents actually sent simply by loading a zero current into the string trying to go negative. This is why in this note the runs are identified by the "set" horizontal chromaticity which differed considerably from the chromaticity predicted by the program for the currents actually sent.

Consideration of the above tables and plots shows that the horizontal chromaticities measured are qualitatively in agreement with prediction. A dependence of chromaticity on the currents in the high field quads which is not taken into account in the program may explain some of this. (Blaskiewicz knows more.) The vertical measurements are less understandable. The +1 setting data gives a clean line, but much too steep for the prediction. We did not ever try to actually look at what current was flowing in any string during the study. Nevertheless we press forward.

The objective is to find the radius or frequency at which the tunes do not change with sextupole string current. Figure 4a and 4b (just a zoom of 4a) give just the fitted lines as drawn in figures 3(a-d) for the horizontal tune vs frequency. Translating to average radius, the precision of the crossings radius (assuming there is a single answer for this ... see below) is defined to about a mm, and to the frequency 2750.1 +/- .1 KHz.

Unfortunately there is the vertical tune data to deal with as well. Here (Figure 5a and 5b) the crossing point is far less well defined. The frequency extracted from the horizontal tune (marked on 5b) does not help clarify the issue. This data and the vertical chromaticity measurements remain unresolved.

One relavant complication: We have two strings of sextupoles, the Horizontal string - which is reduced to 6 magnets at this point, at the #13 straight sections of superperiods ...and the vertical string with 12 magnets at the #7 straight sections. . One could imagine that the two strings have different centers. For the purpose of this study that possibility is not helpful - we are trying to tie the Orbit to the sextupoles. But the study should have been designed to work with the strings independently. The study as run did not intentionally power these strings independently though two runs with 0 Amps in the horizontal string inadvertantly occurred. The other two runs have large currents in the horizontal relative to the vertical. A first pass at unraveling the data using the strings independently did not yield instant clarification.

Another complication to keep in mind: The equilibrium orbit does not have the same radial offset at each sextupole. The measured orbit has deviations of +/- 5 mm from its average, largest at the intentional inward bump at E20. From an orbit taken at the start of the study the positions at the #8 straight section pue's (nearest the #7 sextupoles) had a standard deviation of 1.6mm, similar numbers from a #12 (closest to a #13) gave 2.3mm.

Back to the conclusions. We take the center frequency from the horizontal data. We assume this is R_0. Then the zero of the Orbit report is 9.6 mm further to the outside (not the 4 mm expected). Can this be? Well there is a possibility it could be. If the offsets in the Orbit program have not been adjusted to follow the centering of the pue plates in the vacuum chambers the Orbit program would have just such an error. We are checking.

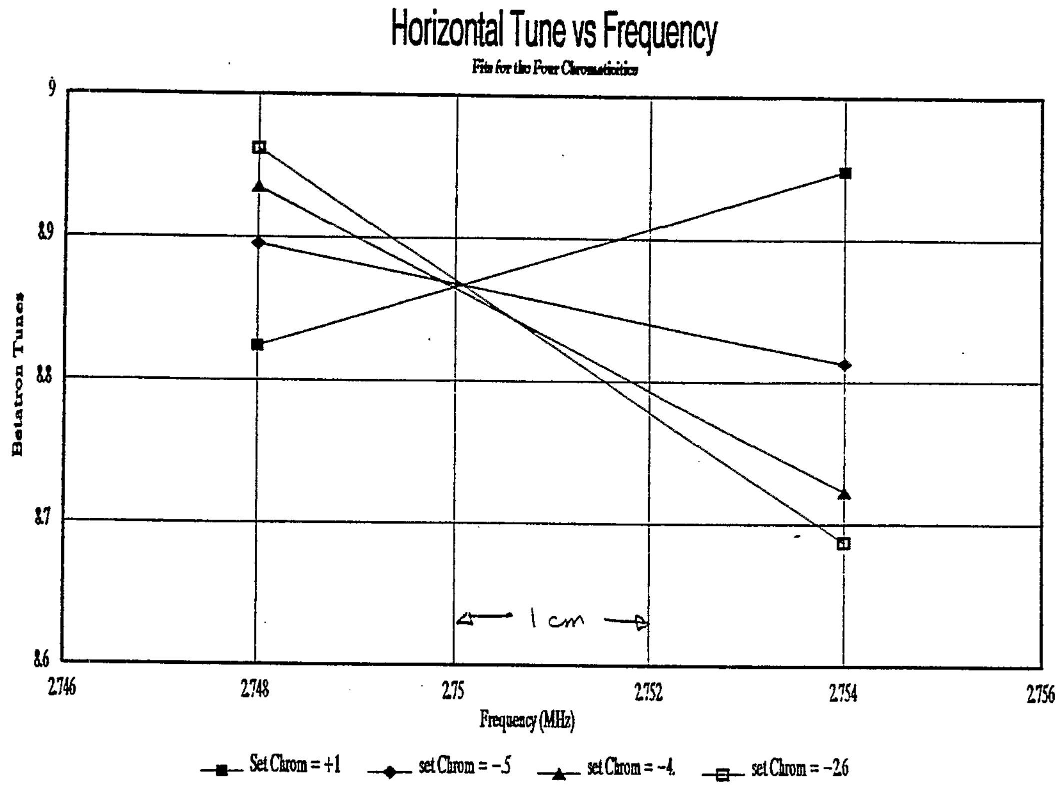

Figure 4a Horizontal Tune vs RF Frequency

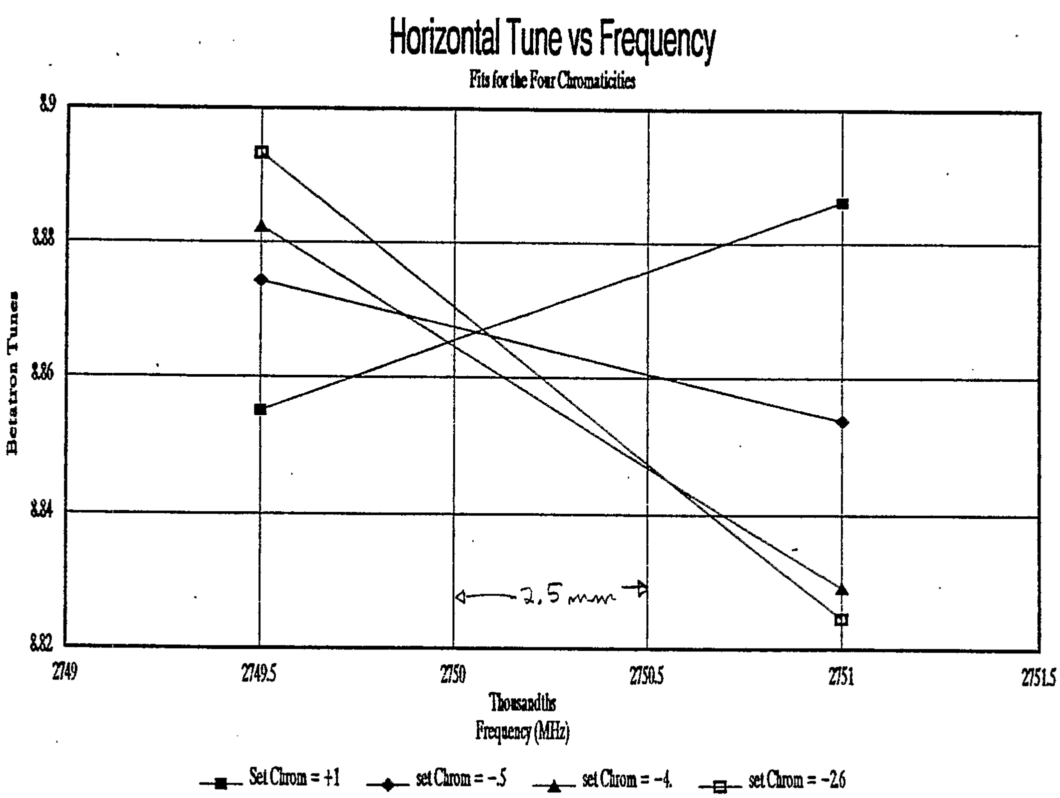

Figure 4b A Blowup of Figure 4a

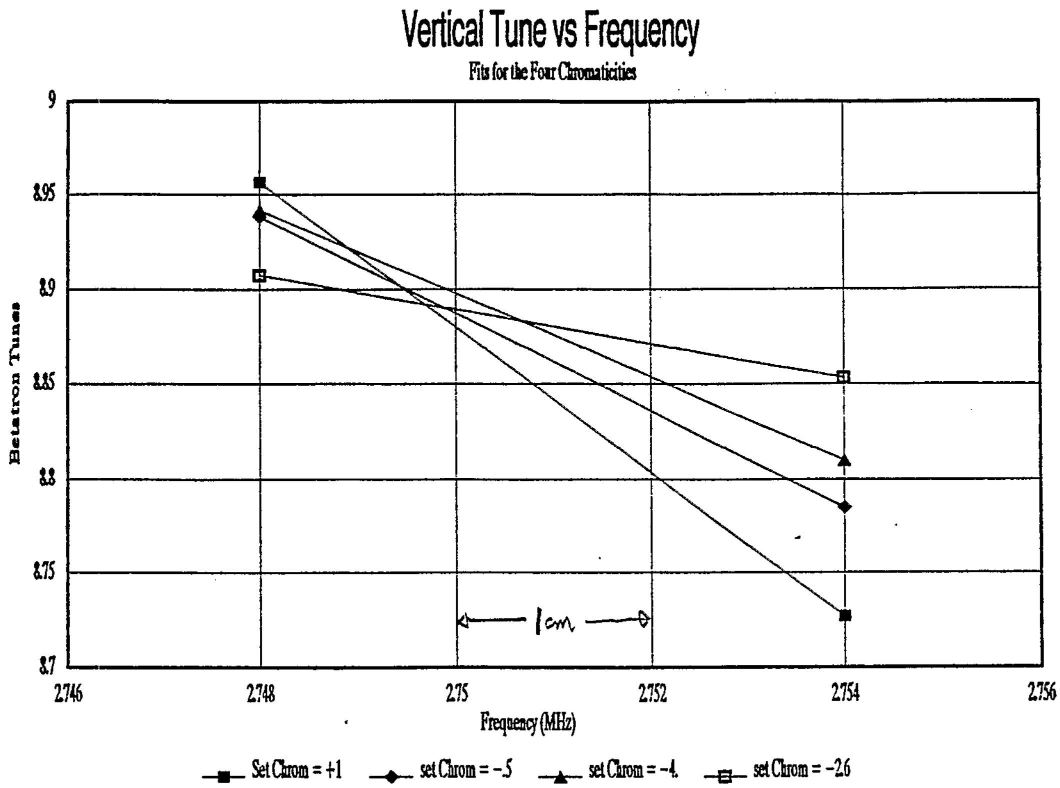

Figure 5a Vertical Tune vs RF Frequency

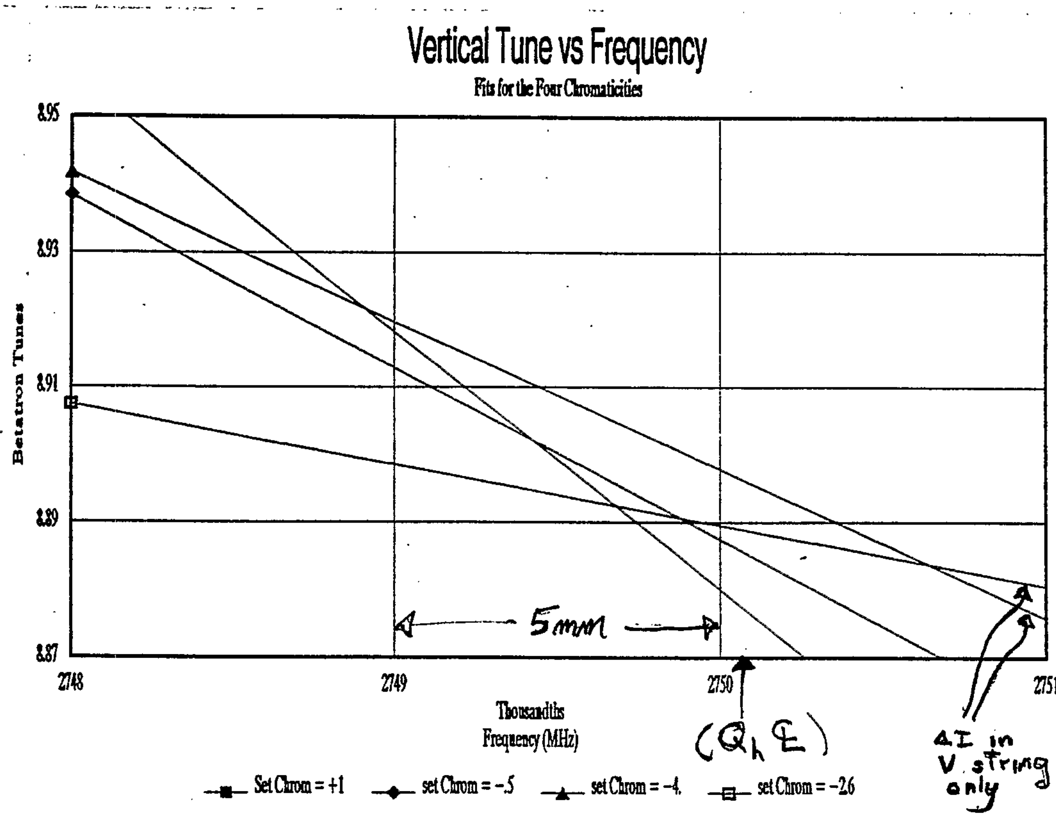

Figure 5b A Blowup of Figure 5a