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AGS Extraction Radius Revisited -- Au77+

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AGS Complex Machine Studies **(AGS Studies Report No. 339)** **Title: AGS Extraction Radius Revisited - Au^{77+}, December 1995**
Study Period: December 18, 1995
Participants: L. Ahrens
Reported by: L. Ahrens
Machine: AGS
Beam: Au^{77+}
Tools: AGS Tune Meter, H.P. Frequency Analyzer, AGS Radial Loop, AGS High Field Sextupole System
Aim: Finding R_0

Introduction

To learn the momentum of the beam extracted from the AGS, one standard procedure involves measuring the revolution frequency of the beam as the beam is debunching. This frequency together with the circumference of the AGS orbit for this beam determines the momentum. The frequency can easily be measured to a much better accuracy than the spread in frequency of the particles in the debunched beam. The circumference (we will use "radius" from here on, where we simply mean the circumference divided by 2pi) is not so easy. The answer is always known at the +/-2 cm level just by the fact that the beam must lie in the machine acceptance. But that accuracy results in an uncertainty in the derived momentum (for full field Gold and for normal 24 GeV protons - not for 2 GeV Gold) which is large relative to the momentum spread in the extracted beam.

To do better, a standard trick which has been used in the past is to experimentally locate the radius (and associated radial loop command) satisfying the condition that changing current in the high field sextupole strings does not change the betatron tunes. This radius is then identified as R_0, the reference radius to which the sextupole centers are surveyed and whose length is known both from calculation and measurement to a millimeter. The beauty of this trick is that only tune measurements, rf frequency measurements, and a reproducible radial loop are required. An orbit measuring system is not needed. The difference between this radius and the radius to which the beam is held by the radial loop at debunching is again determined just from frequency measurements.

This method was used in December of 1995 to extract a value for the extraction momentum. The present note will document that measurement. But in addition this note will emphasize that more constraints can be applied to the (frequency, tune) data than has normally been assumed in the past by using the predicted changes in the chromaticity (from the "optics" application code). The data for this measurement was taken under conditions of high rigidity and of high horizontal chromaticity. The former fact reduces the changes in chromaticity available from the sextupole power supplies. The latter fact complicates (increases the error in) the determination of the central betatron tune. Due to the evolution in the plan of the study during the study the full set of data taken yielded many sparse (tune vs radius) sets.

All of the data was taken with the physics program running. The perturbations added to the machine were small and over (in time in the acceleration cycle) before extraction was reached. This constraint did not significantly affect the quality of the data.

Procedure

Radial scans of horizontal and vertical betatron tunes were taken, just before extraction, with the normal physics cycle sextupole currents. The range of the radial shifts applied was adjusted to give large (+/- .1 units) tune shifts. A quick plot of the data from this radial scan (tune vs frequency) suggested that it was adequate in quality for our purpose (i.e. close enough to linear), and a second scan with large but arbitrarily shifted sextupole currents was taken. Little change in tunes was measured, causing some confusion and motivating an exploration of tunes, at a fixed radius, for extreme changes in the sextupole string currents. The existence of this data, which do not constitute radial scans, motivated an addition to the normal analysis.

Data

Each data set (for each chromaticity setting) contains the scanned radial loop reference level - the "radial command", and the measured rf frequency and betatron tunes. The (radial command vs frequency) data shown in figure 1 calibrates the radial command sensitivity (i.e. 560Hz/Volt or using known machine parameters -3cm/Volt). The figure includes all the (frequency, radial command) data taken during the study and allows further evaluations to be done simply in terms of the radial command.

Table 1 gives the (tune vs radial command) data sets. Each set (each "square") corresponds to a different chromaticity. The "sparseness" is obvious.

Figure 2 plots most of these data sets. The lines are explained below. Figures 2a gives horizontal tune variation with radial command for various horizontal sextupole currents with the vertical string current fixed. Figure 2b is the same except the vertical tune is plotted. Figures 2c and 2d give the same sort of data presentation only now for variation in the vertical sextupole string current with the horizontal fixed.

Analysis

The extraction of R_0 from such data involves finding the radius (or frequency, or radial command) where the straight lines describing (tune vs radius) for two or more sextupole string currents intersect. In the present data set, along with two full (but initially unsatisfactory) scans (Sq1 and Sq2), there are several sextupole current settings with only one or two radial settings, not enough to allow extracting a (tune vs radius) line for that sextupole current set. The slope of this desired line is related in a simple way to the associated chromaticity. The Optics application code model includes a prediction for this chromaticity. Just taking this prediction doesn't work; the model doesn't have the right "bare" chromaticity for this high rigidity machine. However, the model is expected to do well in estimating chromaticity changes. Therefore the approach taken is to use the best full radial scan (Sq1) to fix the bare chromaticity, and then use the model to get the relative chromaticities, and hence the change in slopes expected as the sextupole currents are changed.

As has been said, the data are divided into two groups, one for changes in the vertical sextupole string and one for the horizontal sextupole string. This separation is motivated simply by the expectation, or at least the possibility, that the radius that centers the equilibrium orbit in the vertical sextupoles will be slightly different from that centering the orbit in the horizontal. Then for each set, the variation of horizontal and vertical tunes with radius is studied. The prediction from the application code model requires the center radius, the horizontal and vertical tune at this radius, and the bare chromaticities. These five quantities can be varied to optimize the fit to the data.

Results

The "fit" is strictly by eye in this analysis. Nevertheless, the results are strongly constrained, and data from sextupole currents with only one measured (tune, radius) point contribute. Somewhat surprisingly the data is consistent with the assumption that both strings are centered on the equilibrium orbit at the same radius, corresponding to a radial command of 5.15 "Volts". Taken separately, the two sets would like different values for the vertical tune at the center, (figure 2b perhaps .003 higher figure 2d .003 lower) which is not understood.

Conclusions and Discussion

The immediate point of the exercise was to extract the radial command corresponding to R_0 (the answer is 5.15 Volts), and the radial command calibration (-3V/cm), which leads to an estimate for the momentum of the extracted beam for the Dec '95 running conditions given that the radial command at debunching was 5.2 Volts of 11.69 GeV/c/nuc.

Including the predicted change in chromaticity to constrain the fits, and to allow single point data to be included was reasonably successful. This may remind one of silk purses and sow's ears, but a more defendable R_0 is obtained.

The initial study could have generated more statistically powerful data, if the chromaticity changes made had been better planned. In particular when studying the horizontal sextupole string, the vertical string should have been set to give as small a horizontal chromaticity as possible.

The tune measurements themselves were evaluated in too casual a fashion, given the width of the distributions (fft of the turn by turn position measurement), and given the small changes to be expected relative to that width. A more powerful, or simply a more friendly tune meter analysis program for extracting the center of the distribution would be very valuable. For example, when "zooming in" on the distribution to get a closer look, it is somewhat frustrating that the scales marked on the axes zoom away too and one is left with no fiducials against which to measure the results.

Hopefully during the 1996 proton run this subject can be confronted again, with information from the orbit acquisition system available to better define what the sextupoles do and where is R_0.

Fig 1

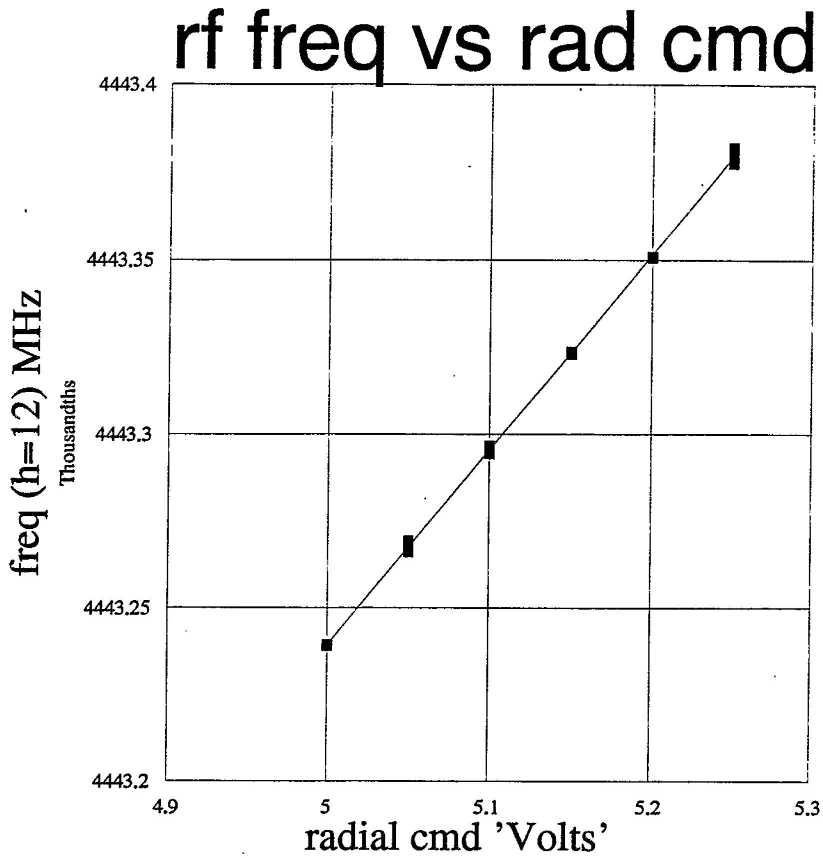

Figure 1 fitted slope (MHz/Volt)
5.61E-04

Rcmd		sq1	sq2	sq3	sq4	sq5	sq6	sq7	sq8
	Qh								
5						8.68	8.7	8.695	8.668
5.05			8.705	8.718					
5.1		8.74	8.73						
5.15		8.77	8.76						
5.2		8.79							
5.25		8.81	8.81	8.813	8.813			8.81	8.82
	Qv								
5						8.78	8.752	8.765	8.78
5.05			8.767	8.757					
5.1		8.749	8.746						
5.15		8.74	8.75						
5.2		8.73							
5.25		8.72	8.71	8.704	8.724			8.715	8.712

setups	Sext Ih	current Iv	Hchrom(prog)	Vchrom(prog)	Hchrom(pred) 0.6	Vchrom(pred) -0.51	Qh/Rcmd pred cm-1	Qv/Rcmd pred cm-1
sq1:	226	0	-2.3	0.8	-2.9	1.31	0.423574	-0.19152
sq2:	50	0	-3.55	1.38	-4.15	1.89	0.606149	-0.27632
sq3:	226	100	-2.54	1.31	-3.14	1.82	0.458629	-0.26609
sq4:	226	-100	-2.06	0.28	-2.66	0.79	0.38852	-0.1155
sq5:	226	150	-2.66	1.57	-3.26	2.08	0.476156	-0.3041
sq6:	226	-150	-1.93	0.02	-2.53	0.53	0.369532	-0.07749
sq7:	275	0	-1.955	0.64	-2.555	1.15	0.373184	-0.16813
sq8:	25	0	-3.73	1.46	-4.33	1.97	0.63244	-0.28802

Table 1

Fig 2a

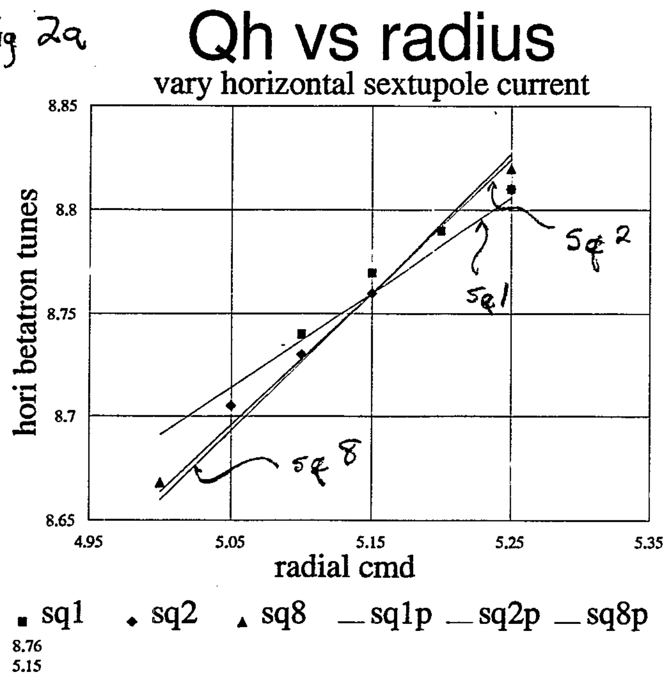

Fig 2c

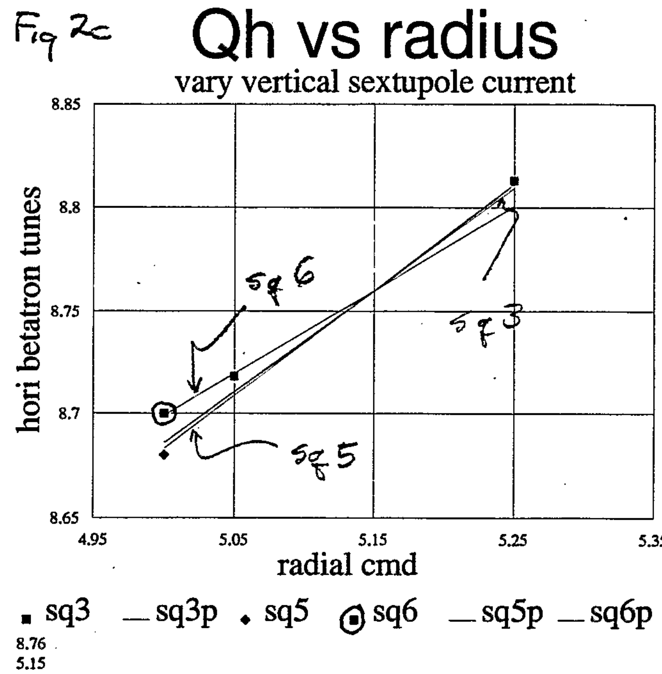

Fig 2b

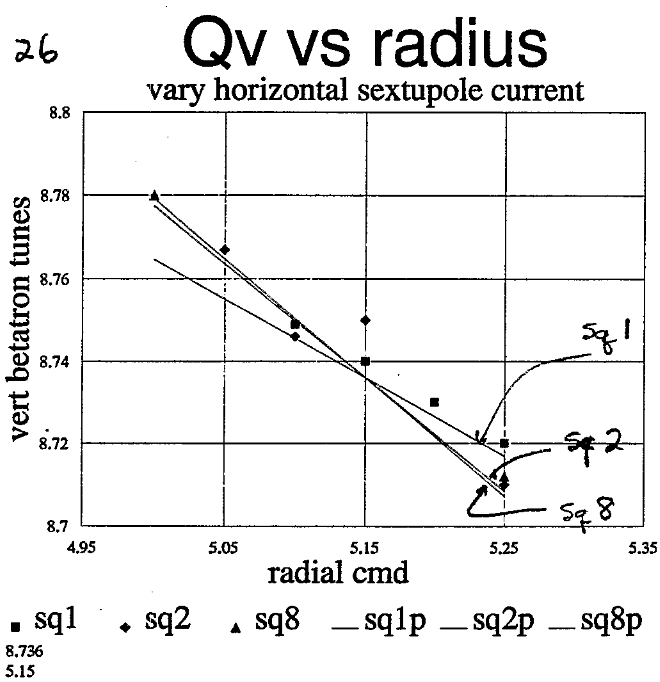

Fig 2d