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Technical Note

AGS/AD/Tech. Note No. 483

Beam Polarization and the Tuning of the Vertical Harmonics in the Booster

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April 20, 1999

AGS Tech note 20Apr99 Leif Ahrens

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Introduction:

One small but necessary step in the overall acceleration of polarized beam in the AGS complex for injection into RHIC is that piece of acceleration occurring in the Booster. This space was investigated experimentally rather well near the beginning of the first polarized run using the Booster in 1994 with no surprises. The beam can be measurably depolarized by adding vertical magnetic field components that enhance the imperfection resonances at $G\gamma=3$ and 4. At that time the "running values" for these magnetic harmonics, as they were left from high intensity proton acceleration, gave very nearly the best measured polarization. Since then we have made an "n=4th harmonic" polarization scan, some times fairly extensive and sometimes minimal, during three additional polarized proton runs. We should also note that "since then" namely since 1994, the ability to measure equilibrium orbits in the Booster has essentially disappeared as the electronics necessary for that measure has failed due almost certainly to the radiation dose the electronics has been subjected to. During the recent (March 99) run, the tuning of the fourth harmonic improved the measured polarization by a factor of two, which is to say the machine as found apparently had a rather significant fourth harmonic error present. This note collects the data from all of these scans; and notes the importance of doing such scans in the future if we wish to maintain as much of the input polarization as possible.

Some Details:

Measurements are available from every polarized proton run that has occurred except for October '97 – which was more an extension of the July '97 run - that is from April '94, July '96, July '97 and March '99. In all four cases the measurements were made in the AGS, using the "fishline" target in the C20 polarimeter, on a magnetic porch set at $G\gamma=7.5$. In all cases the AGS partial snake was powered, and so the polarization should have reversed three times in the AGS, at $G\gamma=5$, 6, and 7. Usually the condition of the C20 polarimeter had not yet "stabilized" as it does each run when these data were taken.

The vertical magnetic harmonic corrections in the Booster are generated by dipoles located just upstream of every vertically focussing quadrupole magnet – very near vertical beta max points. The amount of a particular harmonic reported by the application code as added to the fields that the particle otherwise sees is obtained from the readbacks (or commands) for the currents in the 24 correction

dipoles (measured at the specified time). The n = 4 sine and cosine Fourier components attributed to the magnets are calculated from the measured currents assuming the correctors are point dipoles, located azimuthially at the geometric angular position of the dipoles. (The arbitrary phase reference defining which is the sine piece is taken as the start of the C superperiod.) Current readbacks rather than setpoints are used in this analysis. That is a significant issue for only one year (1997) when the commands and readbacks disagreed for one set of magnets. In the present analysis of the corrections applied in the four years, the results from the orthogonal scans (sine and cosine) that were actually made are combined in the following sense. An ideal correction is assumed $\{Iso*\sin(4*\Theta)+Ico*\cos(4*\Theta)\}$ which we abbreviate as simply (Is0,Ic0). Were this amount of sine and cosine applied, the particle would see no fourth harmonic field on average. A particular asymmetry data point taken with currents (Isk, Ick) then is located a distance Ierrk $=\sqrt{[(Isk-Is0)^2+(Ick-Ic0)^2]}$ from the ideal setting. The magnitude of the orbit distortion at the 4th harmonic is proportional to this Ierrk. The beam is accelerating smoothly through the resonance, and as a result of this passage the magnitude of the polarization decreases. The effect is described by the Froissart - Stora equation, $P(final)=P(initial)*(2*e^{-X}-1)$, where X is a function of the strength of the resonance. In particular X varies as the square of the orbit (or magnetic) harmonic error, hence as Ierrk squared. This equation gives the familiar spin flipping result if X grows large compared to unity.

For the data taken in a given year, the measured polarizations, (really the asymmetries) are plotted against the currents applied to the dipoles expressed by the "Ierr" defined above. The Froissart-Stora evaluation, with the two defining parameters: the maximum asymmetry, and the current "Ierr" where the polarization would cross zero is also plotted. A fit of sorts is carried out between the points and the curve by varying the "best" value for the correcting harmonic currents, and the two Froissart-Stora parameters and minimizing the sum of the squares of the deviations. Asymmetry error bars are not included. The way the data is taken results in the asymmetries in a given run always having nearly the same statistical errors. The results for the four years are given in figures one through four.

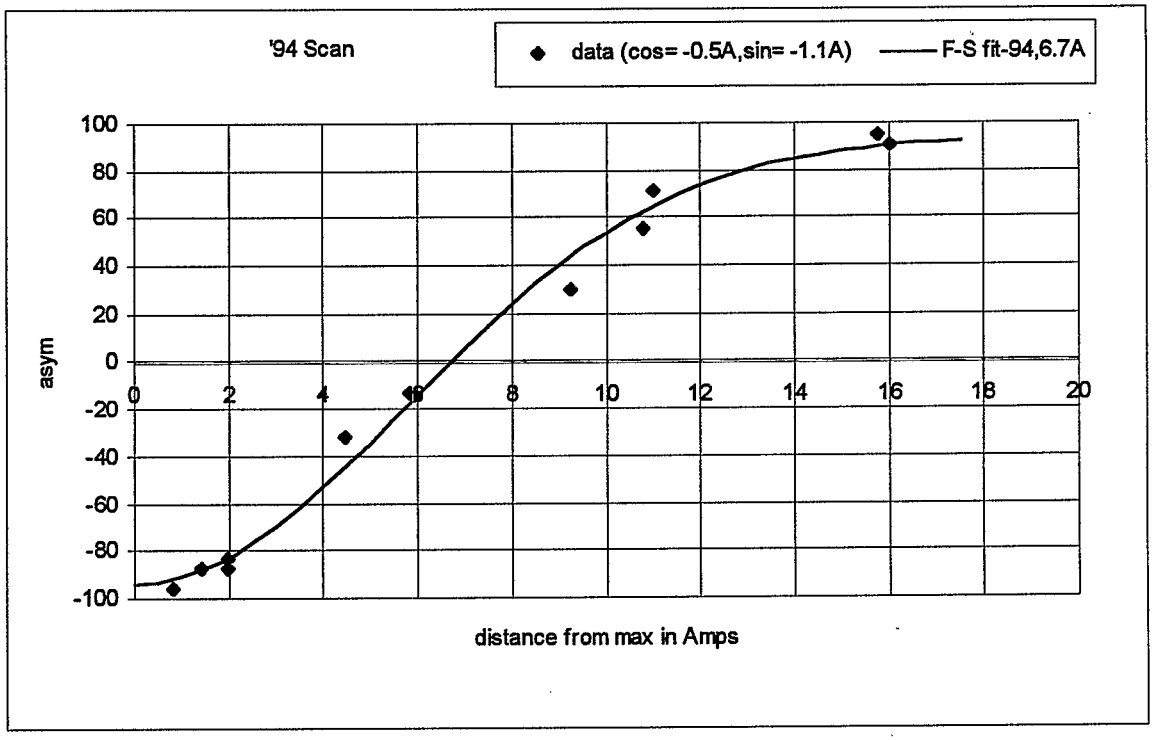

Figure 1 1994: Measured Asymmetry vs Relative Current in the 4th harmonic

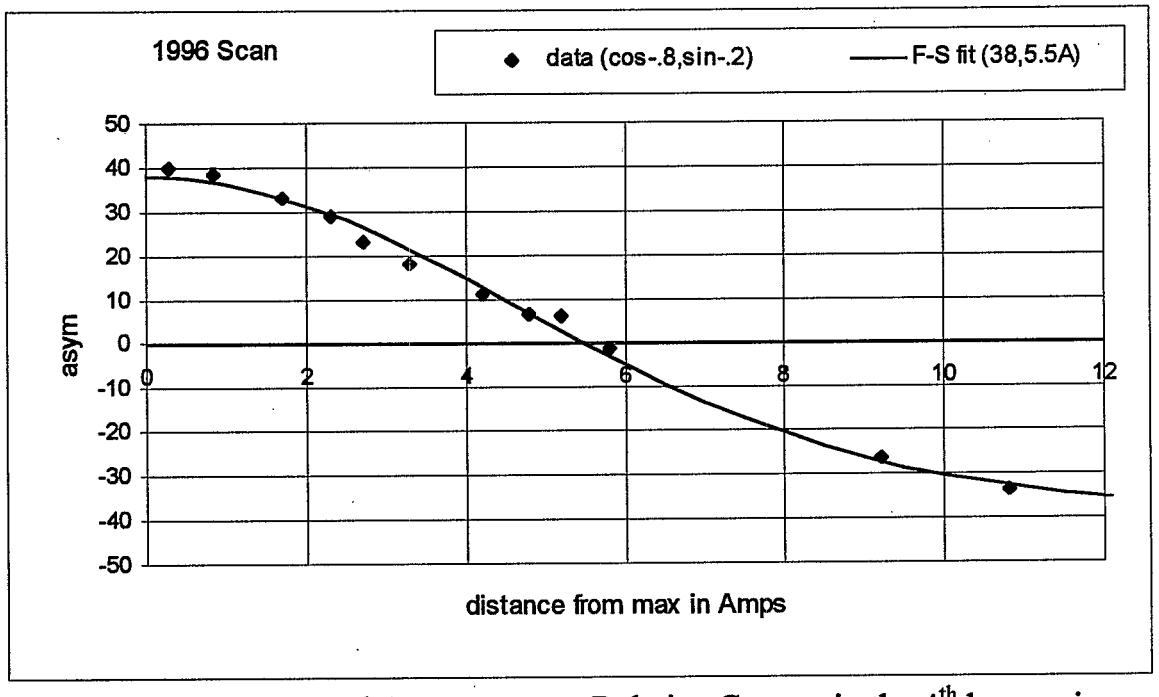

Figure 2 1996: Measured Asymmetry vs Relative Current in the 4th harmonic

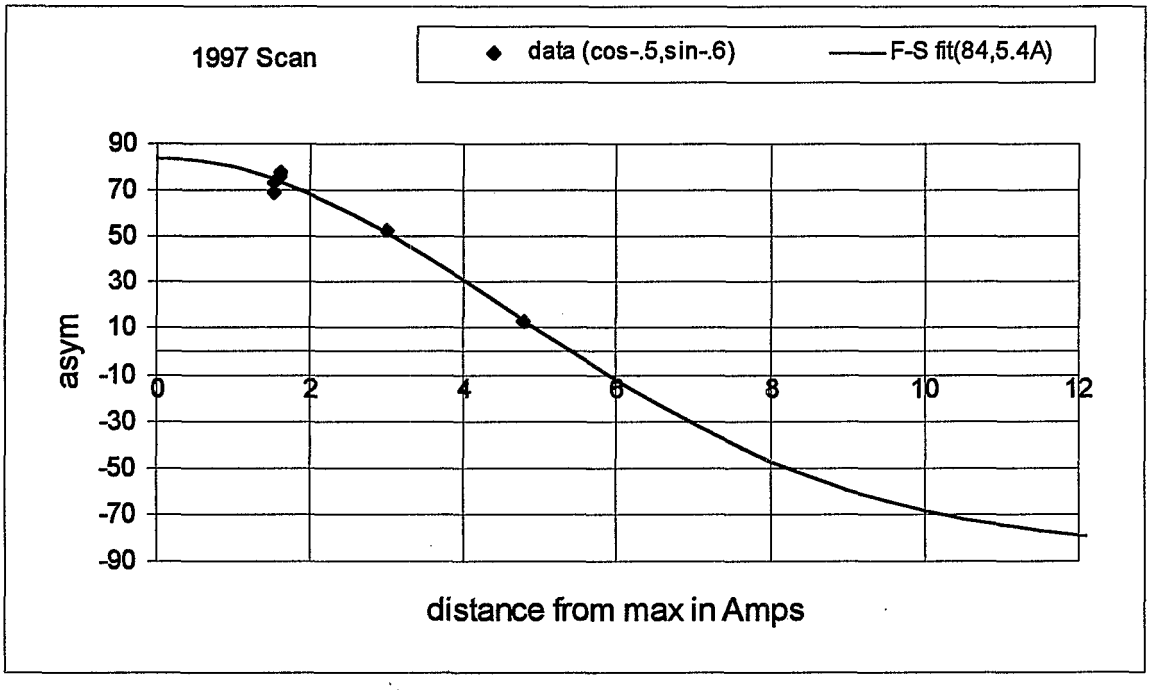

Figure 3 1997: Measured Asymmetry vs Relative Current in the 4th harmonic

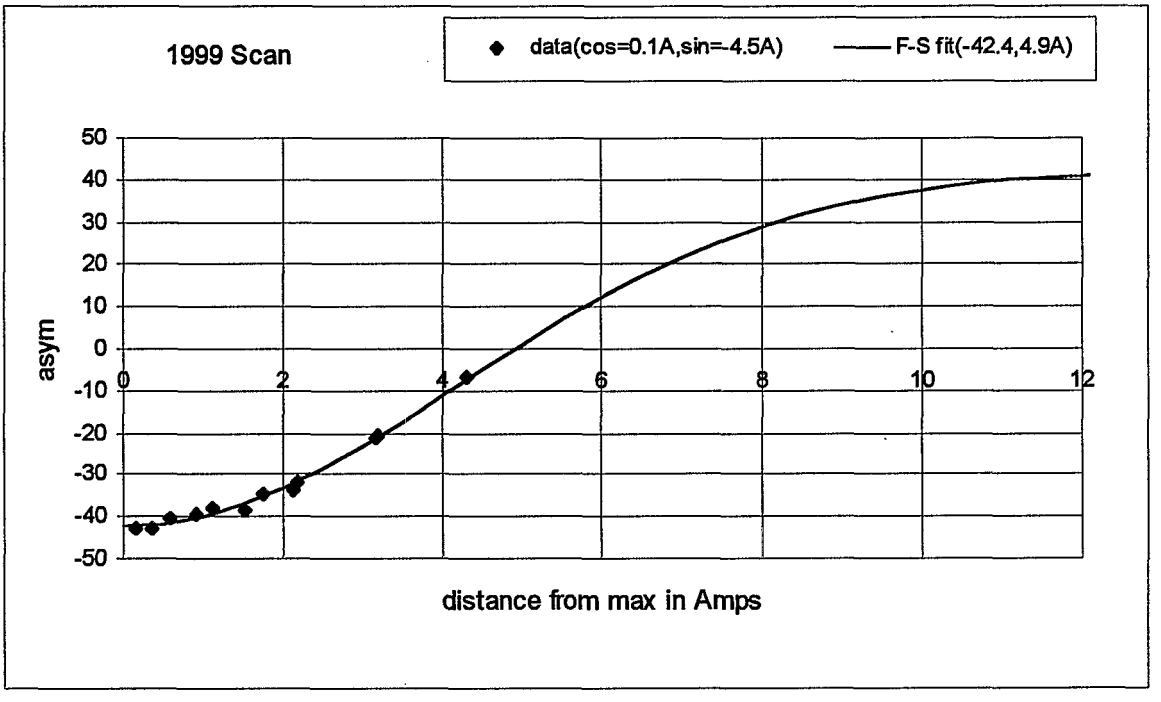

Figure 4 1999: Measured Asymmetry vs Relative Current in the 4th harmonic

That the sign of the asymmetry changes from year to year we do not really explain though this may be associated with the fact that the polarization measurement technique undergoes a relearning period each run. (In '96 the asymmetry sign switched and stayed negative shortly after this scan in association with some work at the polarimeter). That the magnitude also changes by a factor of two we also do not explain. The only other information, given that the F-S equation seems to apply, is the resonance strength. The amount of current required to reduce the polarization from its peak to zero varies somewhat, from 5 to 7 Amps over the years. This may just reflect a trivial point - the time at which the harmonic currents were measured relative to the time when the resonance is crossed. It may indicate slight changes in the vertical betatron tune at the time of crossing. Despite this variation, we can conclude that were we to run with the n=4 current wrong by 1.5 Amps, we would lose 25% of the polarization.

In the table below, the magnetic harmonics actually used in the four runs are recorded, (as well as the predicted best values from this analysis, and the parameters used in the Froissart-Stora fit).

4th Harmonic	Cosine used (Amps)	Cosine pred.	Sine used (Amps)	Sine pred.	F-S fit peak	F-S fit zero cross (Amp)
April 94	.19	-.7	-1.50	-1.0	-94	6.7
July 96	-.52	-.24	-1.62	-1.37	38	5.5
July 97	.65	-.5	-1.73	-.6	84	5.4
March 99	-.03	.1	-4.42	-4.5	-42.4	4.9

Following the same set of rules, we analyzed the only scan we have ever done at n or $G\gamma=3$, taken in 1994. The technique is the same, and the data given in figure 5. Even this scan only explored one of the dimensions – a sine scan – finding the expected very weak dependence. To get a 25% depolarization here would require error fields equivalent to about 5 Amps in n=3.

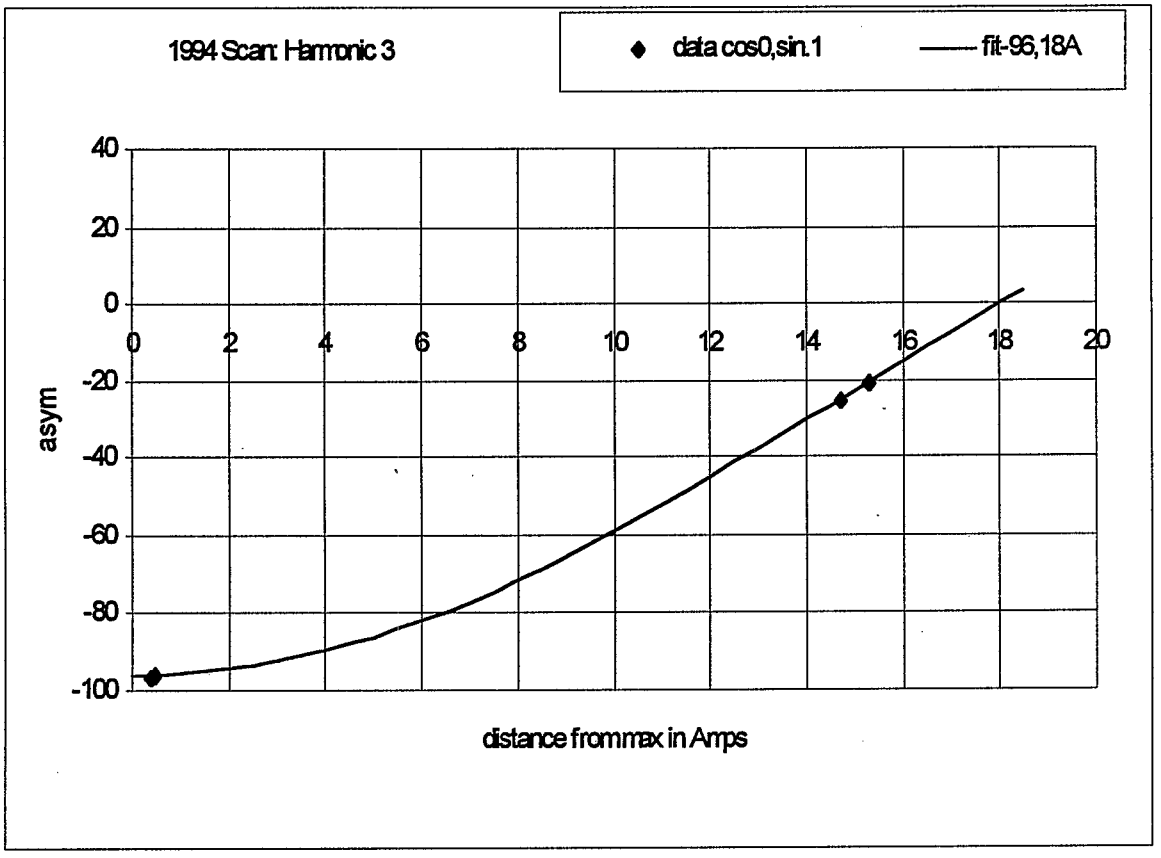

Figure 5 1994: Measured Asymmetry vs Relative Current in the 3th harmonic

Some Discussion:

At the fourth harmonic the required correction did not change much until this year. Why this has occurred remains unknown, and is worrisome. We apparently have a very much changed "sine 4 theta" in the Booster. We need an orbit system to get this back under control, even for nonpolarized running. Lacking that, but surely even with it, we should plan doing the h=4 (and h=3) scans again next time we polarize. The situation will be cleanest if we do these at $G\gamma = 7.5$ as in the past though that is certainly not required.