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Stopband Correction of the AGS Booster C.O.D. Analysis

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AGS Complex Machine Studies **(AGS Studies Report No.** 307 **)** **Title: Stopband Correction of the AGS Booster C.O.D. analysis**	
Study Period:	April - July 1993
Participants:	C. Gardner and Y. Shoji
Reported by:	Y. Shoji
Machine:	AGS Booster
Beam:	
Tools:	
Aim:	We had already reported about our studies and data. But it will be good to report the progress of the analysis as a Studies Report.
Contents:	I Mistakes in SR-292 (Harmonic Component of C.O.D.) II Non-Linear Component of the dRest Dependence III A Model Which Explains the Tune Dependence IV C.O.D. from the Magnet Variation V Movement of the Booster Monuments VI C.O.D. at the Sextupole Magnets VII Harmonic Amplitudes VIII Rotation of Dipole Magnets IX Summary and Discussion

I <u>Mistakes in SR-292 (Harmonic Component of C.O.D.)</u>

- -

To make an order estimation of a half integer stop band, we assume that existing sextupole field are only the chromaticity control sextupoles, which just cancel the natural chromaticities. The combination of the dispersion function and the chromaticity control sextupoles changes the tune by 5 for dP/P=1. At that time the averaged displacement at the PUEs are 2.09m, which is identical to the average of the dispersion function. The stop band width of 9th half integer resonance is the same as the

<Wrong>   changed tune
<Correct>   twice of the changed tune

by the 9th error field. When the amplitude of 9th C.O.D. is 1mm the produced stop band width is;

<Wrong> $5 * (1mm/2.09m) = 0.0024.$
<Correct> $2 * 5 * (1mm/2.09m) = 0.005.$

This stop band corresponds to the quadrupole correction

<Wrong> $0.0024 * 10^5 * (0.7GeV/c) = 170 .$
<Correct> $0.0050 * 10^5 * (0.7GeV/c) = 350 .$

at the 1.7KG flat porch. This value is comparable or even larger than the long-term fluctuation of the correction currents of 2Qx=9. If the C.O.D. and the chromaticicities are constant throughout the cycle, the change of C.O.D. appears as a change of B terms of the correction currents. The change of B terms; Cb and Sb produced by the change of 1mm C.O.D. is

<Wrong>   170 / 1.7kG = 100 .
<Correct>   350 / 1.7kG = 200 .

That is comparable to the measured Cb and Sb.

- -

We will calculate how much Sr and Cr will change by this imperfection. The relation between dRset and dP/P is

<Wrong> $\delta(dP/P)/\delta(dRset) = 0.000314$ (/cm)
<Correct> $\delta(dP/P)/\delta(dRset) = 0.00314$ (/cm)

Then the change of correction current by the change of dRset by 1cm is

<Wrong> $0.000314 * 5 * (1/100) * 10^5 * (0.7GeV/c) = 1.1 .$
<Correct> $0.00314 * 5 * (1/100) * 10^5 * (0.7GeV/c) = 11 .$

This is the Cr and Sr produced by the imperfection of the dispersion. But the measured Cr and Sr at the same flat porch was -96 and -47 for 2Qx=9. The imperfection of dispersion function less contributed to the residual loss of the half integer resonance. This result is consistent with the experimental result; the residual loss did not depend on the chromaticities.

<Wrong>
The other possible origin of the Cr and Sr is 6*n+3 harmonic sextupole error, which does not come from the

chromaticity control sextupoles. To produce as large Cr and Sr as 100, the amplitude of error sextupoles should be comparable to the amplitude of the chromaticity control sextupoles. Then the bare chromaticities should have changed significantly. We must remember that the measured bare chromaticities are $\xi x=-1.568$ and $\xi y=-0.623$ [W. Van Asselt]. They are much different from the expected chromaticities.

<Correct>

The other possible origin of the Cr and Sr is 6*n+3 harmonic sextupole error, which does not come from the chromaticity control sextupoles. Much weaker sextupole than the chromaticity control sextupoles could produce Cr and Sr as large as 100. The unexpected bare chromaticities; $\xi x=-1.568$ and $\xi y=-0.623$ was explained with the sextupole component at the edge of dipole magnets [W. Van Asselt]. The order of sextupole component was misprinted in Booster TN-190 [R.Thern, 'Booster Dipole Production Measurement'].

II Non-Liner Component of the dRset Dependence

The dependence of harmonic C.O.D. components on dRset was analyzed. The data had been taken in April 30, 1993 [1]. FFT components analyzed by the default analysis program are listed in Table I. The amplitudes was fitted with linear function;

$$\text{Amplitude} = Ao + Ar\ dRset \quad \text{(II-1)}$$

where Ao and Ar are fitting parameters. The results are listed in Table II. In this table reduced kai-square; $\underline{X^2/f}$ were calculated under the assumption that the amplitude error were 0.001mm for each data points. Some non-systematic harmonic (not 6n-th harmonic) components has large linear dependence on dRset. Maybe the default FFT program did not work properly because of a fault PUE. The position data itself before the FFT analysis showed little dependence of non-systematic harmonics [1]. The more strange thing was that the vertical C.O.D. looked to have a dependence on dR.

In many cases the fit was bad, because of the existence of $(dRset)^2$ term. When the Arr was larger the $\underline{X^2/f}$ was worse. The data of several harmonics, which had large $\underline{X^2/f}$, was fitted with parabolic function;

$$\text{Amplitudes} = Ao + Ar\ dRset + Arr\ (dRset)^2 \quad \text{(II-3)}$$

Here the units of amplitudes and dRset were mm. The results were listed in Table III. The $\underline{X^2/f}$ were improved. The ratio of the second order term; Arr to the first order term; Ar was almost the same for every component. That suggested the non-linearity of the dRset. Non-linearity of the dispersion function was thought to be very small;

$$|Arr/Ar| << 0.007 \text{ /mm} \qquad \text{(II-4)}$$

because the Arr/Ar of the systematic and that of the non-systematic harmonic components were the same.

The $\underline{X^2/f}$ of components which had small Ar were very small. Which meant that the stability of the position monitor in a short period was as good as 0.001mm. That was very much smaller than the accuracy of the position monitors reported by E.Blesser [2]. A number of averaged cycle to produce the data might be different. But it was not an enough reason to explain the difference of accuracy between the orbit and the harmonic amplitudes.

Table I

FFT data of C.O.D. Measured on April 30, 1993.

dRset	-6.0	-1.0	4.0	9.0	14.0	19.0 (mm)
cos0X	-5.787	-1.531	1.825	4.527	7.511	10.610
sin1X	0.002	-0.430	-0.780	-1.069	-1.394	-1.719
cos1X	-1.140	-0.564	-0.094	0.282	0.700	1.092
sin2X	1.332	1.237	1.157	1.096	1.020	0.922
cos2X	-0.205	0.407	0.900	1.295	1.723	2.204
sin3X	-2.223	-1.156	-0.326	0.322	1.079	1.836
cos3X	2.488	1.643	0.971	0.424	-0.157	-0.814
sin4X	-0.041	-0.883	-1.560	-2.079	-2.678	-3.290
cos4X	1.117	1.308	1.435	1.529	1.631	1.754
sin5X	0.718	0.253	-0.055	-0.337	-0.644	-0.941
cos5X	-0.048	0.123	0.256	0.326	0.427	0.494
sin6X	-0.418	-0.349	-0.270	-0.199	-0.150	-0.083
cos6X	4.608	2.638	1.128	-0.121	-1.499	-2.900
sin7X	0.785	0.061	-0.485	-0.938	-1.435	-1.931
cos7X	0.987	0.521	0.192	-0.104	-0.417	-0.762
sin8X	1.090	1.001	0.946	0.893	0.839	0.750
cos8X	0.926	0.614	0.379	0.209	-0.007	-0.197
sin9X	-0.681	-0.495	-0.379	-0.272	-0.166	-0.035
cos9X	-0.449	0.681	1.601	2.316	3.108	3.915
sin10X	0.308	0.174	0.051	-0.058	-0.168	-0.298
cos10X	0.788	0.212	-0.242	-0.624	-1.056	-1.478

cos0Y	-1.098	-1.006	-1.002		-1.120
sin1Y	-0.825	-0.795	-0.763		-0.761
cos1Y	0.692	0.584	0.541		0.645
sin2Y	0.660	0.708	0.676		0.752
cos2Y	-0.984	-0.860	-0.837		-0.975
sin3Y	0.298	0.278	0.308		0.282
cos3Y	0.989	0.847	0.865		1.131
sin4Y	-0.167	-0.197	-0.185		-0.194
cos4Y	0.765	0.671	0.651		0.626
sin5Y	-1.166	-1.132	-1.085		-1.015
cos5Y	-1.199	-1.098	-1.126		-1.209
sin6Y	0.693	0.719	0.721		0.781
cos6Y	0.830	0.894	0.939		1.113
sin7Y	-0.715	-0.671	-0.614		-0.638
cos7Y	0.542	0.443	0.434		0.523
sin8Y	0.241	0.323	0.277		0.347
cos8Y	0.059	0.069	0.043		-0.004
sin9Y	-0.302	-0.354	-0.328		-0.368
cos9Y	-0.510	-0.553	-0.501		-0.562
sin10Y	0.544	0.523	0.520		
cos10Y	-0.119	0.533	-0.156		

Table II
Linear fit to the FFT amplitudes.

	Ao(mm)	$Ar(10^{-3})$	X^2/f
cos0X	-1.294±0.0051	638.9±0.47	248.5
sin1X	-0.461	-67.4	2.0
cos1X	-0.523	47.8	4.9
sin2X	1.230	-15.8	0.12
cos2X	0.445	93.6	4.7
sin3X	-1.105	158.0	16.6
cos3X	1.579	-127.2	6.9
sin4X	-0.933	-126.6	10.3
cos4X	1.305	24.3	1.0
sin5X	0.251	-64.4	3.5
cos5X	0.126	21.1	1.5
sin6X	-0.332	13.4	0.08
cos6X	2.544	-292.6	53.0
sin7X	3.076	-105.8	7.9
cos7X	0.510	-67.7	2.8
sin8X	1.003	-12.8	0.18
cos8X	0.605	-43.7	2.0
sin9X	-0.499	24.7	0.66
cos9X	0.755	170.4	19.3
sin10X	0.156	-23.8	0.08
cos10X	0.176	-88.7	3.6

cos0Y	-1.048+0.0054	-2.3+0.53	0.48
sin1Y	-0.795	2.3	0.41
cos1Y	0.617	-0.5	6.6
sin2Y	0.686	3.3	0.61
cos2Y	-0.909	-1.4	8.4
sin3Y	0.293	-0.4	0.27
cos3Y	0.926	8.1	14.4
sin4Y	-0.183	0.7	0.19
cos4Y	0.697	-4.6	1.8
sin5Y	-1.123	6.0	0.14
cos5Y	-1.151	-1.9	3.8
sin6Y	0.715	3.4	0.06
cos6Y	0.899	11.2	0.03
sin7Y	-0.670	2.7	1.6
cos7Y	0.483	0.6	4.5
sin8Y	0.284	3.4	1.4
cos8Y	0.053	-2.8	0.15
sin9Y	-0.330	-2.1	0.52
cos9Y	-0.525	-16.1	0.94
sin10Y	0.526+0.0059	-2.4+1.41	0.05
cos10Y	-0.129	-3.7	0.42

Table III
Parabolic fit to the FFT amplitudes.

harmonics	Ao	Ar	Arr	X^2/f	Arr/Ar
cos0X	-1.13±0.55	0.710±0.10	-0.0052±0.0066	121	-0.0074
sin3X	-1.07	0.175	-0.00132	9	-0.0075
cos6X	2.47	-0.324	0.00241	26	-0.0074
cos9X	0.81	0.190	-0.00152	8	-0.0080

III A Model Which Explains the Tune Dependence

The tune dependence of harmonic amplitudes of C.O.D. was measured by K. Brown et al [3]. According to them harmonic amplitudes of C.O.D. could be fit with function;

$$An+iBn = (Ano+jBno) + (Q^2/Q^2-n^2)(an+jbn) \ . \qquad \text{(III-1)}$$

Result was reprinted in Table IV. The correlation between the off-set (Ano or Bno) and the tune dependent term (an or bn) is shown in the Figure 1. If Ano and Bno came from the random off-set of each PUE (for example an off-set of electric circuit) there should not be any correlation. But if Ano and Bno came from a displacement of PUE which was close to the displacement of a quadrupole magnet, there should be a correlation. In this section we will calculate the correlation constant and see if it explains the data.

We assume that the displacements of a position monitors (PUE) and a quadrupole magnets are the same because they were tightly packed. When their displacements have n-th harmonic component;

$$\delta Xn = Xno \cos n\theta \qquad \text{(III-2)}$$

expected off-set amplitude by the displacements of the PUEs is

$$Ano = -Xno \; . \qquad \text{(III-3)}$$

On the other hand the displacements of the quadrupole magnets produce dipole kicks

$$D = K\, \delta Xn \; . \qquad \text{(III-4)}$$

Here K is the defocusing strength of quadrupole magnets. The harmonic C.O.D. amplitude produced by the harmonic dipole kick is

$$Q^2/(Q^2-n^2)\ an = Q^2/(Q^2-n^2)\ (1/2\pi Q)\ \sqrt{\beta_{PUE}}\ \sqrt{\beta_{QF}}\ \Sigma\ D\cos n\theta \qquad \text{(III-5)}$$

here β_{PUE} and $X\beta_{QF}$ are beta function at the PUE and the quadrupole magnet. Q is a tune. The ratio of an to the Ano is

$$\begin{aligned} an/Ano &= (1/2\pi Q)\ \sqrt{\beta_{PUE}}\ \sqrt{\beta_{QF}}\ \Sigma\ K_{QF}\ \cos^2 n\theta \\ &= (1/2\pi Q)\ \sqrt{\beta_{PUE}}\ \sqrt{\beta_{QF}}\ K_{QF}\ (N/2) \qquad \text{(III-6)} \end{aligned}$$

When we use parameter values calculated by A.Luccio and M. Blaskiewicz [4];

$Qx = 4.633$
$X\beta x_{QF} = 13.4$ m
$X\beta x_{QD} = 4.0$ m
$X\beta x_{PUE} = 12.7$ m
$N = 24$ (number of focusing quadrupole magnet)
$K_{QF} = -0.2706$ /m
$K_{QD} = 0.2766$ /m

the ratio is

$$an/Ano = -1.46 \; . \qquad \text{(III-7)}$$

This correlation coefficient is bigger than the observed. The same amount of displacement at the defocusing quadrupoles will add the random disturbance. Which would be $[K_{QD}\sqrt{\beta x_{QD}}]/[-K_{QF}\sqrt{\beta x_{QF}}] = 0.56$. Then

$$an/Ano = -1.46\ (\ 1 \pm 0.56\ )\ . \qquad \text{(III-8)}$$

But when the displacement was not random but was systematic the an/Ano becomes different.

$$an/Ano = (1/2\pi Q)\ \sqrt{\beta_{PUE}}\ (\sqrt{\beta_{QF}}K_{QF} + \sqrt{\beta_{QD}}K_{QD})\ \ (N/2)\ . \qquad \text{(III-9)}$$

In this case the ratio is

$$an/Ano = -0.64\ . \qquad \text{(III-10)}$$

The observed ratio was about -0.86 which was between -0.64 and -1.46. That was consistent with (III-8). Our model explains the correlation between the tune dependent term (ano and bno) and the off-set (Ano and Bno).

The harmonic amplitude of the horizontal displacements were about 1mm. The vertical displacement was much smaller than that of horizontal. The harmonic amplitude of the vertical displacements were about 0.3mm or less.

The measurement took place before the eddy current correction winding at C5 was fixed. But the main result did not change after that [5]. The experimental result that C.O.D. did not depend on dB/dt and less on B [5] was consistent with the above results.

Table VI
Tune dependence of the C.O.D. measured and analyzed by K.Brown et al [3].

	Ano(mm)	Bno(mm)	ano(mm)	bno(mm)
horizontal				
4th	0.85±0.15	0.05±0.03	-0.75±0.02	0.01±0.003
5th	-0.02±0.09	-1.35±0.07	0.41±0.01	1.14±0.01
vertical				
4th	-0.27±0.03	-0.14±0.05	0.21±0.001	-0.18±0.001
5th	-0.14±0.03	-0.26±0.03	0.34±0.002	0.31±0.003

IV **C.O.D. From the Magnet Variation**

The production errors of magnets would contribute to an and bn. We calculated the amplitude $\sqrt{an^2+bn^2}$ from the data of magnetic field measurement [6]. The last equation of (IV-1) was used to calculate the amplitudes.

$$an = \sqrt{\beta}\sqrt{\beta err}/2\pi Q\ \Sigma\ (\delta Kods)\cos n\theta$$

$$an^2 = \beta\ \beta err/(2\pi Q)^2\ \Sigma\ (\delta Kods)^2\cos^2 n\theta$$

$$<an^2> = \beta\ \beta err/(2\pi Q)^2\ N <(\delta Kods)^2><\cos^2 n\theta>$$

$$<an^2+bn^2> = \beta\ \beta err/(2\pi Q)^2\ N <(\delta Kods)^2>$$

$$\sqrt{<an^2+bn^2>} = \sqrt{\beta}\sqrt{\beta err}/2\pi Q\ \sqrt{N}\ (\delta Kods)rms \quad (IV-1)$$

Here the bracket means the average or expected value. The results were listed in Table V. The expected C.O.D. amplitude from the variation of magnets were much smaller than the observed C.O.D. Then the C.O.D. were mainly produced by the misalignment of magnets.

Table V

C.O.D. harmonic component produced by the random variation of magnets.

The dipole error of quadrupole magnets listed here has no correlation to the displacement of PUEs. The βx=12.7m at the horizontal PUEs and βy=12.9m at the vertical PUEs.

magnet	βerr(m)	$\sqrt{<\delta Kods^2>}$	N	$\sqrt{an^2+bn^2}$ (mm)
horizontal				
B(2,4,8)	8.9	$\pi/18$ X1.5E-4	18	0.055
B(1,5,7)	7.2			
QF	13.4	0.2706 X0.8E-5	24	0.005
QD	4.1	0.2766		
horizontal total				0.06
vertical				
B(2,4,8)	9.0	$\pi/18$ X4.9E-5	18	0.018
B(1,5,7)	7.3			
QF	4.0	0.2706 X1.1E-5	24	0.008
QD	13.6	0.2766		
vertical total				0.020

V Movement of the Booster Monuments

The horizontal displacements of the Booster monuments were surveyed in 1989 and 1992 [7]. The Fourier amplitudes of the shifts were calculated and listed in Table VI. Here the 0th harmonic movements were ignored. And the longitudinal movements were also ignored because they would have less effect than that of the radial movement.

The 4-5th harmonic amplitude of the movement was about 0.2mm, which was also much less than the observed misalignment. Then the systematic horizontal displacement was small.

Table VI
Harmonic component of the radial movement of the Booster monuments. Calculated from the data reported by F. X. Karl and M. A. Goldman [7].

harmonic number	movement (mm)
1	0.19
2	0.26
3	0.21
4	0.12
5	0.20
6	0.08
7	0.12
8	0.12
9	0.03
10	0.02
11	0.07
12	0.05
13	0.03
14	0.02
15	0.02

VI C.O.D. at the Sextupole Magnets

By turning ON and OFF the chromaticity sextupoles, the correction current of half integer stopband N(9X) changed by

$\delta N(9X) \approx 70\ \delta\xi x$ at B=1.65 kG [8] . (VI-1)

The 9th harmonic amplitude of horizontal C.O.D. can be estimated from this strength as;

$$\delta(dQx)/\delta\xi x = 70*1.65/2.40 = 100\ E\text{-}5 . \quad \text{(VI-2)}$$

$$\delta N(9X) = (10^5/2\pi)\ N\ (e/cp)\ \beta x\ 2B2\ \delta Xo\ (2/\pi) \quad \text{(VI-3)}$$
$$Qx\ \delta\xi x = (1/4\pi)\ N\ \beta x\ 2B2/B\rho r\ \langle \underline{h} \rangle \quad \text{(VI-4)}$$

$$\delta X = 10^{-5}\ (\pi/4)\ (cp/e)/B\rho\ \langle \underline{h} \rangle/Qx\ [\delta N(9X)/\delta\ \xi x]$$
$$= 1.1\ mm \quad \text{(VI-5)}$$

On the other hand the estimated amplitude from the equation (III-8) is

$$\delta X = 1mm*\sqrt{[(1+1.46Qx^2/(Qx^2-9^2))^2+(0.56*1.46Qx^2/(Qx^2-9^2))^2]}$$
$$= 0.53\ mm \quad \text{(VI-6)}$$

Here the displacements were assumed to be random. Then the 9th harmonic amplitude of C.O.D. may be similar to those of 4th and 5th harmonic amplitude; 1mm. The agreement was not bad. The 4th, 5th and 6th (vertical only) harmonic components were reduced by dipole corrections (with steering dipole magnets) but the 9th harmonics was not. The 1mm displacement really existed.

VII Harmonic Amplitudes

If the conclusion of the above sections is correct, harmonic amplitudes of C.O.D. should not be proportional to $Q^2/(Q^2-n^2)$. We saw the Q dependence in section III. In this section we will see n dependence of amplitudes. The FFT amplitudes of C.O.D. measured on April 30 are listed in Table VII. The values were average of two measurement at dRset=-0.1 and 0.4. As described in section II the Fourier analysis at that time was not reliable. But hopefully we can see the rough dependence on the harmonic number;n. The 0th and 6th harmonic components of the horizontal C.O.D. contained the dispersion and were not the bare C.O.D. The 4th and 5th and 6th (vertical only) components were adjusted by the correction dipoles then they were not bare C.O.D.

The two types of amplitude factors were calculated to compare with the measured amplitudes. One was

$$\text{(a)}\quad Q^2/(Q^2-n^2) \quad \text{(VII-1)}$$

and the other was

$$\text{(b)}\quad \sqrt{[(1+1.46(a))^2+(0.56*1.46(a))^2]} \quad \text{(VII-2)}$$

which followed the equation (VI-6). The tune Q was set to 4.8. The results are listed in the same table; Table VII and shown in Figure 2.

The results were confusing. The measured amplitudes were closer to the (a) than (b). The case (b) predicted the 2-4 mm amplitude of 1st, 2nd and 3rd harmonic components of the horizontal C.O.D. But we could not see such a large amplitude. It was also curious that the amplitudes of the horizontal and the vertical C.O.D. were roughly the same.

Table VII
Harmonic amplitude of C.O.D. [1].

harmonics	measured amplitude(mm)		calculated factor	
n	hori	vert	(a)	(b)
0	(0.147)	1.004	1	2.59
1	0.689	0.826	1.05	2.67
2	1.364	0.961	1.21	2.94
3	1.502	1.095	1.64	3.65
4	(1.837)	(0.905)	3.27	6.37
5	(0.214)	(1.570)	11.76	18.80
6	(1.908)	(1.165)	2.60	2.16
7	0.415	0.778	0.89	0.78
8	1.093	0.305	0.56	0.49
9	1.222	0.628	0.40	0.53
10	0.113	0.537	0.30	0.61

VIII Rotation of Dipole Magnets

A random rotation of dipole magnet might have produced the random component of the vertical C.O.D.

The correlation between Ano and an and between Bno and bn of the vertical C.O.D. was weak. Which meant that the random dipole error, which was independent with the displacement, was comparable or larger than the displacement. The possible sources of the random dipole errors were;

(1) random displacement between quadrupole magnet and PUE
(2) random variation of magnets
(3) random rotation of dipole magnets .

From the measured vertical C.O.D. we can estimate the largest possible error of (3) magnet rotations. We used the equation (IV-1);

$$\sqrt{\langle an^2 + bn^2 \rangle} = \sqrt{\beta}\sqrt{\beta err}/2\pi Q \sqrt{N}\ (\delta Kods)rms \qquad \text{(VIII-1)}$$

and

$$(\delta Kods)rms = (\pi/18)\ \delta\phi rms\ . \qquad (VIII\text{-}2)$$

And we assumed that

$$\sqrt{<an^2+bn^2>} < 0.2E\text{-}3\ m\ . \qquad (VIII\text{-}3)$$

We obtain the rms of the random rotation error as

$$\delta\phi rms < 0.5\ mrad. \qquad (VIII\text{-}4)$$

That was about a twice of the designed error. The rotation error was not bad.

IX Summary and Discussion

The main error source of the C.O.D. might be the random displacement of quadrupole magnets. The horizontal displacement was about 1mm and the vertical displacement was about 0.3mm. These values were not the rms displacement but were 4th or 5th harmonic amplitude of the displacement. The displacement was much larger than the designed misalignment [9]. And this displacement produced the dominant dipole error and a dominant quadrupole error [10].

E.Blesser reported the very good agreement [2] between the measured C.O.D. and one of the simulations done before the construction. But the agreement was accidental. In the simulation by J.Milutinovic et al. [9] the magnet imperfections were over estimated, the misalignments (= displacement) were underestimated and the displacements of PUE were not took into consideration. The desired orbit center is the center of PUE. Because a quadrupole magnet and a sextupole magnet are thought to be displaced with PUE.

The displacements of quadrupole magnet have produced the complicated tune dependence of dipole correction. The tune dependence of the change of C.O.D. by the harmonic dipoles is

$$an = \sqrt{\beta}\sqrt{\beta err}/2\pi Q\ \Sigma\ (\delta Kods)\ \cos n\theta\ . \qquad (IX\text{-}1)$$

This an does not depend on tune. The dipole correction to correct the dipole imperfection of bending dipoles does not depend on tune. But when dipole errors were produced by the displacement of quadrupoles the tune dependence is

$$\begin{aligned} an &= \sqrt{\beta}\sqrt{\beta err}/2\pi Q\ \Sigma\ (K_1 ds)\,\delta X\ \cos n\theta\ . \\ &\propto K_1 \\ &\propto Q\ . \end{aligned} \qquad (IX\text{-}2)$$

$$\delta Ko \propto Q\ . \qquad (IX\text{-}3)$$

The dipole correction field is proportional to the tune. And the dipole correction to cancel the off-set of PUE depends on tune as

$$\delta Ko \propto (Q^2 - n^2)/Q^2 . \qquad \text{(IX-4)}$$

In our case this dependence is serious because the tune is close to integer at the proton injection.

A main purpose of this report is to prepare for the estimation of down feed effect which produce the stop bands. So more discussions about the dipole errors in the AGS Booster is desired with new data. After all we do not have any solution which explains everything. Especially the result discussed in section VII is confusing.

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FIGURE CAPTION

Figure 1 The correlation between the off-set term (Ano or Bno) and the tune dependent term (ano or bno). The data were taken by K. Brown et al. [2].

Figure 2 The dependence of harmonic amplitudes of C.O.D. on harmonic number;n. Two lines showed the expected amplitude factor from the differnt model.
O ; horizontal amplitude (mm)
Δ ; vertical amplitude (mm)
broken line ; model (a)
solid line ; model (b) assuming 1mm displacement

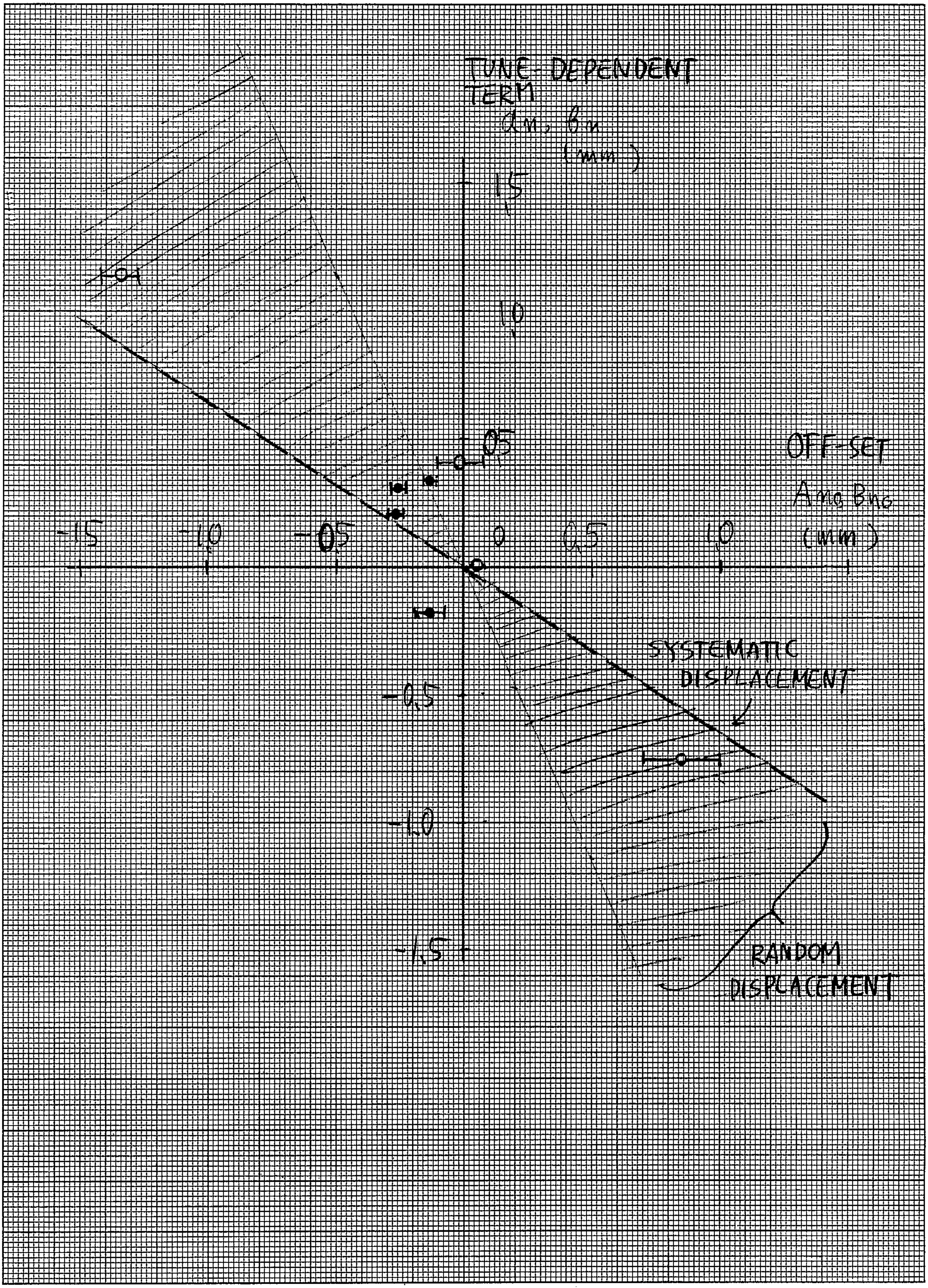
TUNE-DEPENDENT TERM
a_n, b_n (mm)
1.5
1.0
0.5
OFF-SET
A_{n0}, B_{n0} (mm)
-1.5
-1.0
-0.5
0
0.5
1.0
-0.5
-1.0
-1.5
SYSTEMATIC DISPLACEMENT
RANDOM DISPLACEMENT

Figure 1

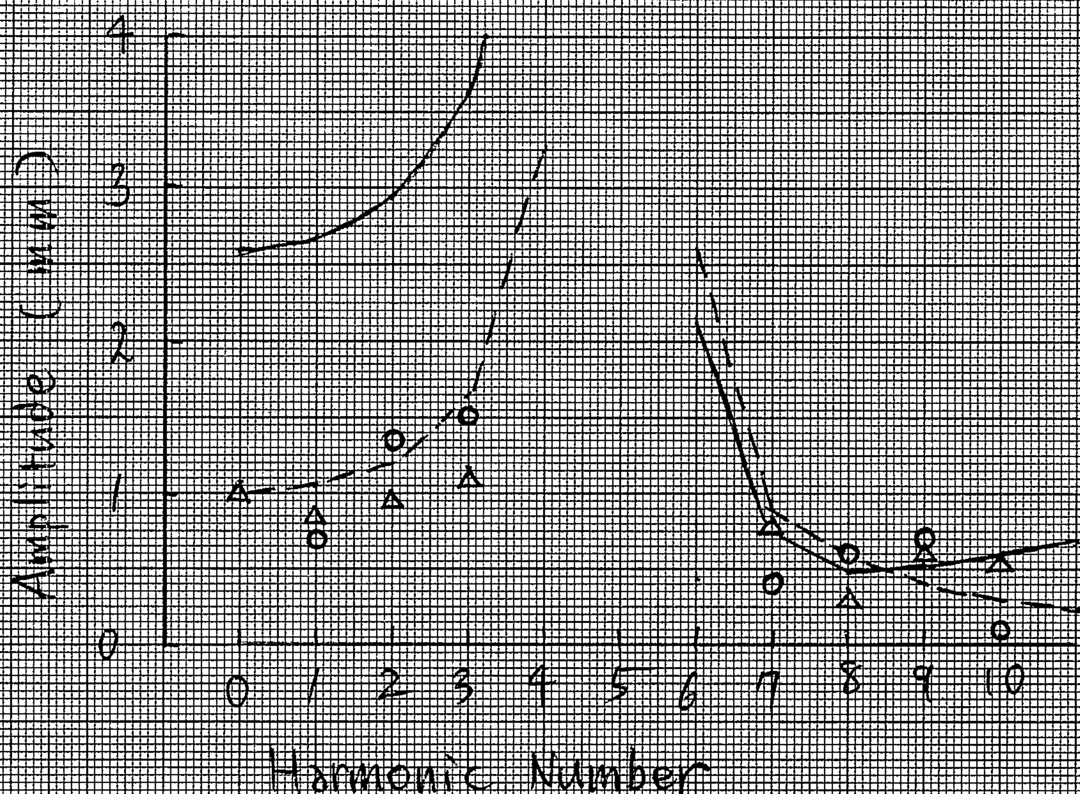

Figure 2