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Stopband Correction of the AGS Booster 2Qx=9 Correction Data Before May 7

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Study Period:	March 28-May 7, 1993
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Reported by:	Y. Shoji

All data points before the installation of 9th harmonic sextupole are listed in Table I. The correction currents of 2Qx=9; N(cos9X) and N(sin9X), depend on many parameters; B, dB/dt, dR(= dP/P), C.O.D. and chromaticities.

We measured B and dB/dt dependence a few times. The data points were fitted with functions;

$$N(\cos 9X) = Co + Cb\ B + Cbt\ (dB/dt)$$
$$N(\sin 9X) = So + Sb\ B + Sbt\ (dB/dt). \qquad (1)$$

Here Co, Cb, Cbt, So, Sb and Sbt are fitted parameters. The unit of N is program digit, which is proportional to the correction winding current and corresponds to the stop-band width 10^{-5} at 1GeV/c. The unit of B and dB/dt are kG and G/ms=kG/s. The results are listed in Table II.

The data of radial dependence of correction currents were fitted with functions

$$N(\cos 9X) = Co + Cr\ dRset$$
$$N(\sin 9X) = So + Sr\ dRset. \qquad (2)$$

Here Co, Cr, So and Sr are fitted parameters, and dRset is the set value of RF steering program (cm unit). The results are listed in Table III.

Table I   List of 2Qx=9 correction data

date & other information T (ms)	B (kG)	dB/dt (G/ms)	dRset (cm)	N(cos9X)	N(sin9X)	crossing speed (dQ/ms)	residual loss(%) /cross times
last year [C.Gardner, AGS SR-273]							
	3.6	0	?	350	300	0.012	< 1/1
	1.7	0	?	50	50	0.007?	10?/1
Mar.28 Qy=4.76							
40	1.622	22	0.4	200 ±10	120 ±10	?	17/1
60	2.889	70	0.4	430 ±30	180 ±20	0.016	24/1
75	3.964	70	0.4	570 ±30	330 ±20	0.021	12/1
90	5.033	70	0.4	660 ±20	490 ±20	?	1.1/1
100	5.433	23	0.4	630 ±20	730 ±30	?	3/1
Mar.30 u1 10t Qy=4.6							
40	1.622	22	?	260 ±10	150 ±20	0.010	33/?
Apr.08 u1 Qy=4.62 *1) chrom=-0.5 -0.25 *2) crom. sext. OFF							
30?	1.62?	70?	?	370 ±20	-10 ±10	?	39/2 *1)
				430 ±20	-20 ±20	?	38/2 *2)
Apr.11 u1 5t							
35	1.97	70	?	520 ±20	-20 ±20	?	28/?
55	3.34	70	?	580 ±20	160 ±20	?	3/?
Apr.12 u1 5t 80deg. chrom =-0.5,-0.25 Qy=4.6							
35	1.97	70	(0.6)	600 ±40	70 ±40	0.05	18 /2
55	3.34	70	(1.2)	700 ±50	250 ±50	?	4.6/2
75	4.74	70	(1.3)	700 ±50	400 ±50	?	1.6/2
101	4.95	-70	(1.5)	-300 ±50	700 ±50	?	6.2/2

Apr.15

- - - -

30	1.59	31	?	420 ±20	100 ±20	0.025	13/2

Apr.19 u1 10t *3) C5 closed *4) C5 open

- -

35		?	?	? 550	0	?	40/1 *3)
				350	100	?	44/1 *4)

Apr.20 u3 10t 70deg Qy=4.8

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31.5	1.595	36	(.075)	480 ±10	105 ±10	0.014	24 /1
31	1.59	34	(.075)	530 ±10	110 ±20	0.04	7.0/1
33	1.615	43	(.075)	565 ±10	110 ±10		5.5/1
35	1.657	52	(.075)	610 ±10	90 ±20		5.1/1
37	1.857	61	(.085)	670 ±10	60 ±10		4.7/1
39	1.99	69	(.095)	720 ±10	65 ±10		4.0/1
41	2.13	70	(1.)	755 ±10	55 ±10		2.5/1
43	2.27	70	(1.)	775 ±15	75 ±15		1.8/1
45	2.41	70	(1.)	775 ±10	90 ±20		1.1/1
						0.027	4.0/1

Apr.21

- - - -

55	3.35	70	-2.0	1050(±30)	450(±30)	0.006	19/1
			-1.2	900	300		16/1
			-0.8	850	325		11/1
			-0.4	800	300		11/1
			0.0	700	250		12/1
			0.4	600	250		12/1
			0.8	525	225		10/1
			1.2	450	200		9/1
			2.0	300	100		19/1

Apr.23 u3 100ms flat porch all sext=0 *5) DumpBump ON

- -

100	1.70	0	-0.8	330 ±10	195 ±10	0.016	12/?
			-0.4	280 ±10	170 ±10		11 /?
			0.4	225 ±10	120 ±20		5.7/?
			1.2	130 ±10	100 ±10		6.5/?
			0.4	215 ±10	165 ±10		10/? *5)

Apr.24 u3 5t Qy=4.6 1.4GeV/c Chromaticity = 0A
Sextupole correction = 0A DumpBump=OFF

135	3.60	0	-1.2	500	350	0.012	0 /?
			-0.4	350 ±50	275 ±50		0 /?
			0.4	350 ±10	275 ±10		0.5/?
			2.0	100	200		2.8/?

Apr.25 u1 chr=-0.5,-0.25 Qy=4.8

28.2	1.53	30	0.35	430 ±20	135 ±20	0.05	20/1
30.3	1.60	31	0.35	410 ±10	160 ±20		19/1
40.5	2.09	70	0.35	680 ±10	110 ±10	0.027	15/1
44.5	2.37	70	0.35	710 ±20	120 ±15		8/1

Apr.27 u3 low porch 5t 60deg. Qy=4.6
stop band corrections and chromaticity control = OFF

80	1.7	0	-0.8	300 ±15	180 ±10	0.02	9/1
			0.4	195 ±15	110 ±15		7/1
			1.2	110 ±10	105 ±10		13/1

Apr.30 u3 5t 60deg.
stopband sext = 0, skew quad.= OFF Dipole = OFF
chrom.sext = ON *6) =OFF *7)

80	1.7	0	0.4	125 ±20	255 ±10	?	45/? *6)
			1.4	-30 ±10	200 ±10	?	28/? *6)
			-0.6	200 ±25	270 ±20	?	32/? *6)
			-0.6	280 ±10	180 ±20	?	27/? *7)
			1.4	30 ±25	115 ±10	?	53/? *7)

May 7 u3 Qy=4.6
chrom sext=0A,DumpBump=0 norm sext stopband=OFF

80	1.7	0	0.4	190 ±15	100 ±15	0.01	19/?
			1.4	65 ±15	70 ±10		26/?
			-0.6	276 ±10	150 ±20		24/?

Table II Correction coefficients of 2Qx=9

date	Co	Cb	Cbt	X^2/f
cos9X				
Mar.28	-21±17	112± 6	1.8±0.4	0.34
Apr.11		44±21		
Apr.12	23±97	38±23	7.3±0.5	0.73
Apr.20	160±27	107±26	5.2±0.5	3.74
Apr.25	104±92	85±78	5.7±1.2	2.09
Apr.21-24 (dRset=.4cm)	93±13	134± 7	4.0±0.2	

date	So	Sb	Sbt	X^2/f
sin9X				
Mar.28	-61±17	156± 7	-3.2±0.4	0.57
Apr.11		131±21		
Apr.12	-28±98	120±23	-1.9±0.5	0.08
Apr.20	96±43	57±39	-2.2±0.7	3.52
Apr.25	127±75	42±64	-1.5±1.1	0.70
Apr.21-24 (dRset=.4cm)	10±14	74± 6	-0.3±0.2	

Table III Fitted results of dR dependence

date	B	dB/dt	cos9X Co	Cr	X^2/f	sin9X So	Sr	X^2/f
Apr.21	3.35	70	686±10	-191± 9	0.40	267±10	-74± 9	0.94
Apr.24	3.6	0	330±29	-120±21	0.75	291±12	-42+21	0.24
Apr.23	1.7	0	250± 6	-96± 7	1.4	154± 6	-47± 7	0.41
Apr.27	1.7	0	226± 9	-96± 9	0.27	146± 7	-38± 7	2.25
Apr.30	1.7	0	147±15	-124±12	2.75	265±10	-42±10	1.78
Apr.30	1.7	0	205±10	-125±14		160±14	-33±11	
May 07	1.7	0	217± 7	-104± 9	1.24	122±12	-38±11	0.29
Apr.21 dR=0.4			610±11			237±11		
Apr.24 dR=0.4			346±10			275±10		
Apr.23 dR=0.4			212± 6			135± 6		

I Dependence on the Chromaticity

On April 30 radial dependence of the correction currents were measured for the different chromaticities at the flat porch. By turning on the chromaticity sextupoles, Co Cr, So and Sr changed by

$$\delta\ \mathrm{Co} = -58 \pm 18 \qquad \delta\ \mathrm{Cr} = 1 \pm 19/\mathrm{cm}$$
$$\delta\ \mathrm{So} = 105 \pm 17 \qquad \delta\ \mathrm{Sr} = 9 \pm 15/\mathrm{cm}. \qquad (3)$$

The off-set values changed significantly. But the change of the radial coefficients were negligibly small.

On April 8 we measured the same effect but under the different situation. By turning on the chromaticity sextupoles we observed the change of the correction currents by

$$\delta\ N(\cos 9X) = -60 \pm 30$$
$$\delta\ N(\sin 9X) = 10 \pm 20 \qquad (4)$$

and the residual loss did not change. The situation were different on April 8 and 30. The set values of chromaticities were ξx=-0.5, ξy=-0.25 (bare chromaticities were ξx=-1.568, ξy=-0.623) on April 8 but they were ξx=0, ξy=0 (bare chromaticities were ξx=-1.568, ξy=-0.623) on April 30.

The change of N(9X) means the existence of 9th harmonic component in the combination of chromaticity strings and C.O.D.

II Change of C5 Back-Leg Winding

On April 19 we observed the change of correction currents came from the C5 back-leg winding. By turning off (opening) the C5 back-leg winding, the correction currents changed by

$$\delta\, N(\cos 9X) = -200$$
$$\delta\, N(\sin 9X) = 100 \qquad (5)$$

At this time dB/dt=70G/ms. Then Cbt and Sbt would have changed on April 7 when we changed the polarity of the C5 back-leg winding.

$$\delta\, Cbt = -200 * (-2) / 70 = 5.7$$
$$\delta\, Sbt = 100 * (-2) / 70 = -2.9 \quad . \qquad (6)$$

On Table II we can see the change of Cbt and Sbt since then. In this table the changes look like

$$\delta\, Cbt = 4$$
$$\delta\, Sbt = 1 \, . \qquad (7)$$

This δ Cbt is consistent with (5). But the polarity of δSbt is opposite.

The phase of up-stream correction winding of C5 is calculated to be [C.Gardner, Booster TN-217, A. Luccio & M. Blaskiewicz, Booster TN-196]

$$N(\sin 9X) / N(\cos 9X) = -0.0 \, . \qquad (8)$$

That predicted the very small change of sin9X string. Then the above inconsistency of δSbt came from error or other kind of change.

III Dump Bump

According to the data taken on April 23, by turning on the dump bump correction currents changed by

$$\delta\, N(\cos 9X) = 85 + 15$$
$$\delta\, N(\sin 9X) = 65 + 15 \, . \qquad (9)$$

This change was considerably large.

IV Radius Dependence

Radius dependence of correction currents are listed in Table III. The slope; Cr and Sr came from the 9th harmonic component in the combination of normal sextupole field and dispersion function. The linear fit with equations (2) were very good as shown in Fig.1. Then the contribution from higher field components than octupole was very small.

Among 5 sets of measurement at B=1.7kG and dB/dt=0, the first set of April 30 was different because the chromaticity sextupoles were excited here. And the second set was measured with the correction dipoles OFF. It looked a little bit different but the different was not larger than the error. The other 3 sets, measured on April 23, April 27 and May 7 were taken under the same condition. The Cr and Sr of these data were the same. But Co and So fluctuated more than Cr and Sr.

The dependence of Co, So, Cr and Sr on B and dB/dt were calculated from three sets of radial dependence data, taken on April 21, 23 and 24.

Co[B=dB/dt=0]	=	92 ±15
So[B=dB/dt=0]	=	10 ±15
dCo/dB	=	71 ± 7
dSo/dB	=	74 ± 7
dCo/d(dB/dt)	=	4.02 ±0.20
dSo/d(dB/dt)	=	-0.28 ±0.20
Cr[B=dB/dt=0]	=	-75 ±40
Sr[B=dB/dt=0]	=	-52 ±40
dCr/dB	=	3 ±12
dSr/dB	=	-13 ±12
Dcr/d(dB/dt)	=	-1.06 ±0.29
dSr/d(dB/dt)	=	-0.45 ±0.29 (10)

The dependence of Cr and Sr on B were smaller than measurement errors. But Cr and Sr depended on dB/dt. That meant 9th sextupole component had off-set (remanent field) and dB/dt term and less B term. The polarities of most of the dB/dt coefficients were the same as that of off-set. It means that the residual loss may be smaller at negative dB/dt than at positive dB/dt. But the residual loss observed on April 12 did not agree with this. We will have clear result from the measurement with 9th sextupole correction.

V B and dB/dt Dependence

Data of B and dB/dt dependence are listed on Table II. These coefficients are plotted by date in Fig.2. We also calculated the B and dB/dt dependence from three radial dependence data on April 21, 23 and 24 (dRset=0.4cm). The fluctuation of data points were larger than errors. As mentioned before dB/dt coefficient, Cbt had changed on April 7. Except this, data points looked changing slowly in time. When dates were closer, the results were closer. We cannot identify the source of fluctuations because we didn't have fixed some of important parameters, dR, chromaticities and bump orbits.

It may be useful to make an average of coefficients from these we can roughly estimate the correction current. We averaged the data on Table II with the weight function $1/\text{error}\sqrt{(X^2/f)}$. Here X^2/f of data on April 11 and April 21-24 were assumed to be 1 and 3, respectively. The Cbt and Sbt on March 28 were not taken into the average. The results were

Co	= 33 ±40	X^2/f	= 11
So	= -12 ±30		= 5.5
Cb	= 101 ±13		= 7.0
Sb	= 122 ±18		= 13
Cbt	= 5.5 ±1.1		= 12
Sdt	= -1.5 ±0.5		= 6.8

Errors were normalized with $1/\sqrt{(X^2/f)}$.

All data points (after April 7) at dB/dt=70 G/ms were plotted against B on Fig.3. The fluctuation of N(cos9X) was much larger than the fluctuation of N(sin9X). Fig.4 shows the N(cos9X) and N(sin9X) at B=2.5kG and dB/dt=70G/ms. The dR dependence can not explain this fluctuation.

VI Beam Loss Pattern

The time structure of beam loss when the tune crossed a resonance depended on correction currents. Fig.5 is the typical example recorded on April 12. That change can be explained with the radial dependence of correction currents.

When N(cos9X) is higher by	δN(cos9X)=200
2Qx=9 is corrected at lower dRset	dRset=-1 cm
because δN(cos9X)/δ(dRset)=-190	
(April 21 on Table III)	
2Qx=9 is corrected at low dP/P	dP/P=-0.3%
because δ(dP/P)/δ(dRset)=0.314 %/cm	
[Shoji and Gardner, Booster SR-286]	
lower momentum has higher tune	dQx=0.007
because chromaticity=-0.5	
lower momentum reached to the resonance later	dt=0.14 ms
because crossing speed dQx/dt=-0.05/ms	
higher momentum reached to the resonance earlier	
beam loss occurs early	

The calculated change of loss start time was roughly the same as that of Fig. 5. And the calculated momentum spread was reasonable.

The other strange thing of the time structure of the beam loss was a multi-step loss at one resonance. Fig. 6 shows the example of that kind of loss. There are two possible reasons.

i) Tune ripple

The fluctuation of tune is considerable when it crosses the resonance very slowly. The typical tune fluctuation was dQ = 0.006 p-p, 2.5kHz at 2kG [Shoji and Gardner, Booster SR-282]. Then the crossing speed was fluctuated by 0.05/ms. When the controlled resonance crossing speed was comparable to this fluctuation, beam would not be lost uniformly.

ii) Density distribution in the tune space

Many times we observed the double-peak structure in the FFT spectrum of the tune meter. As shown in Fig.7 the beat of betatron amplitude meant the two separated component. It would produce two-step beam loss at one resonance crossing. But we don't know why the tune space distribution has such a structure.

FIGURE CAPTIONS

Fig. 1 Radial dependence of correction current for 2Qx=9.

Fig. 2 Coefficients of B and dB/dt dependence and off-set.

Fig. 3 Correction currents at dB/dt=70G/ms.

Fig. 4 N(cos9X) and N(sin9X).

Fig. 5 Example of the change of beam loss pattern to the correction current.

Fig. 6 Example of the multi-step beam loss.

Fig. 7 Example of the tune meter output.

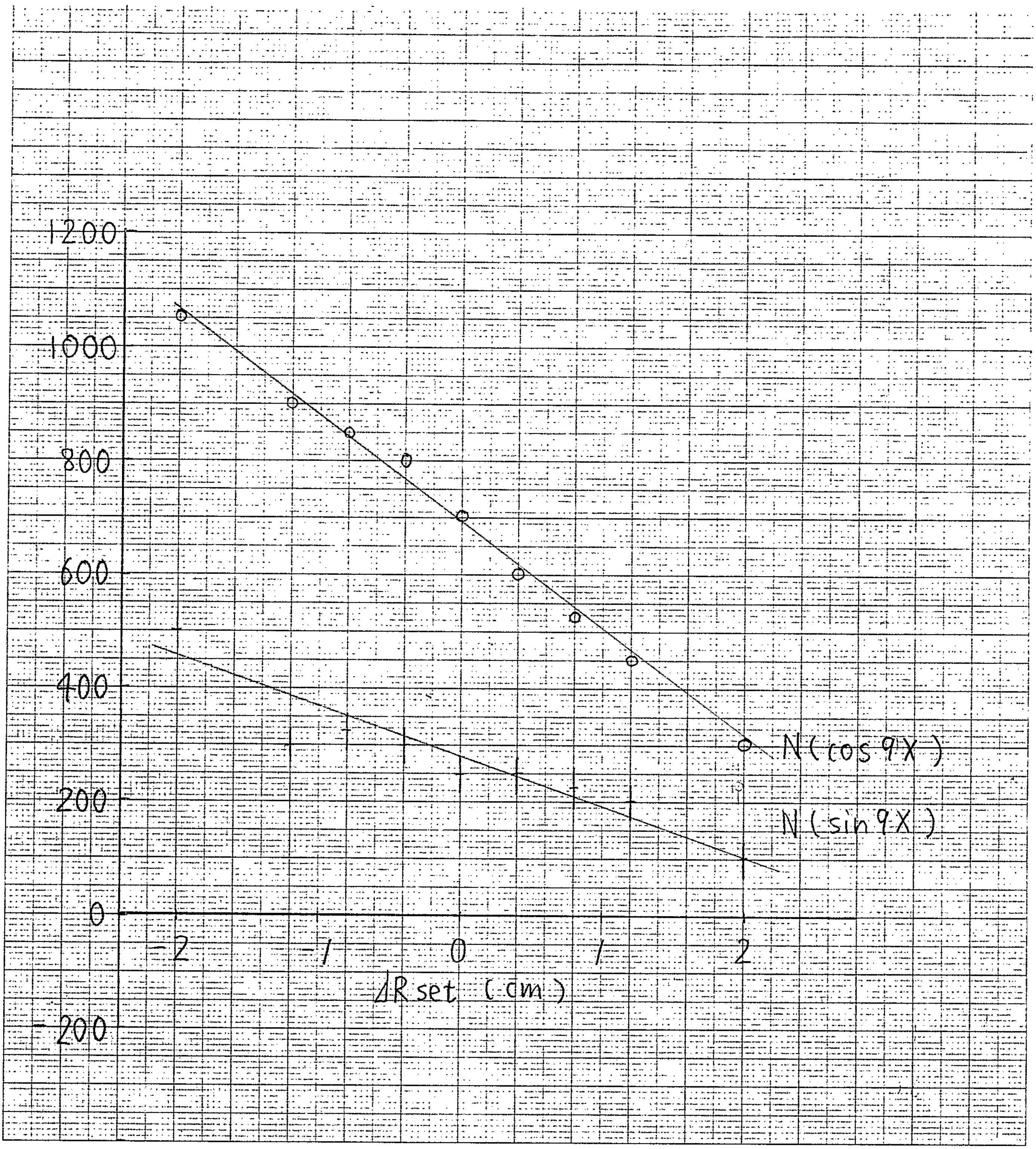
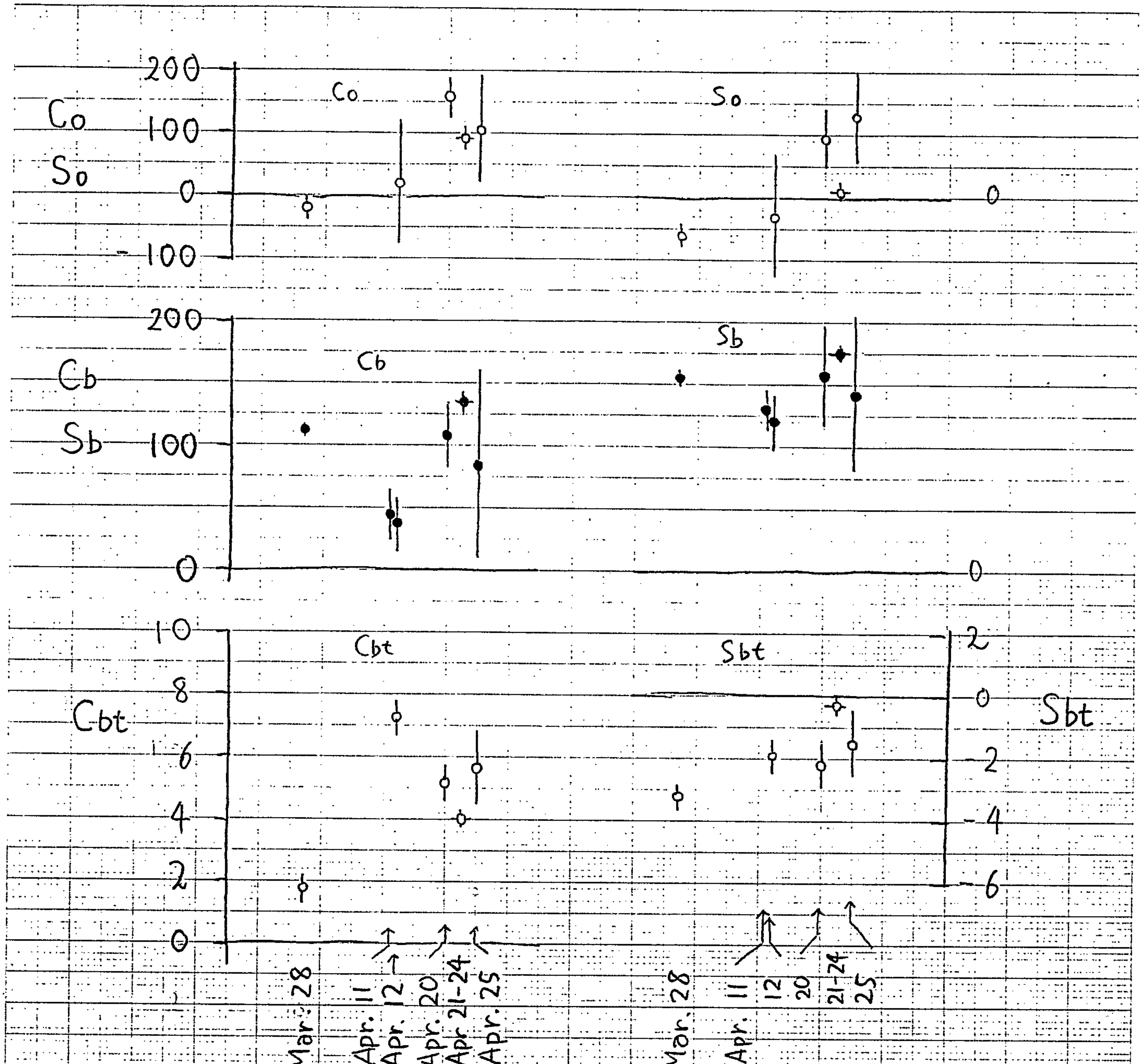
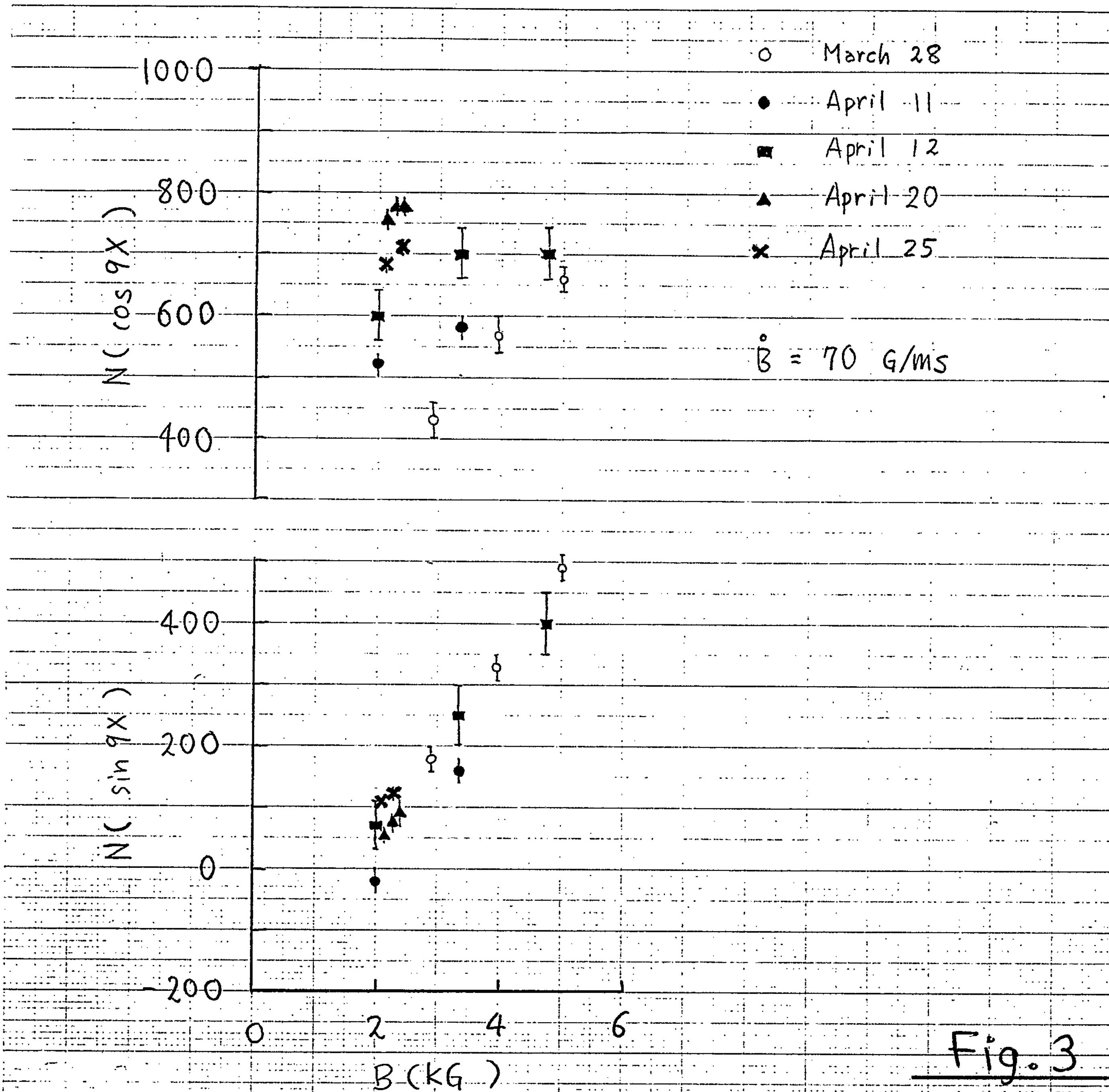


Fig. 1



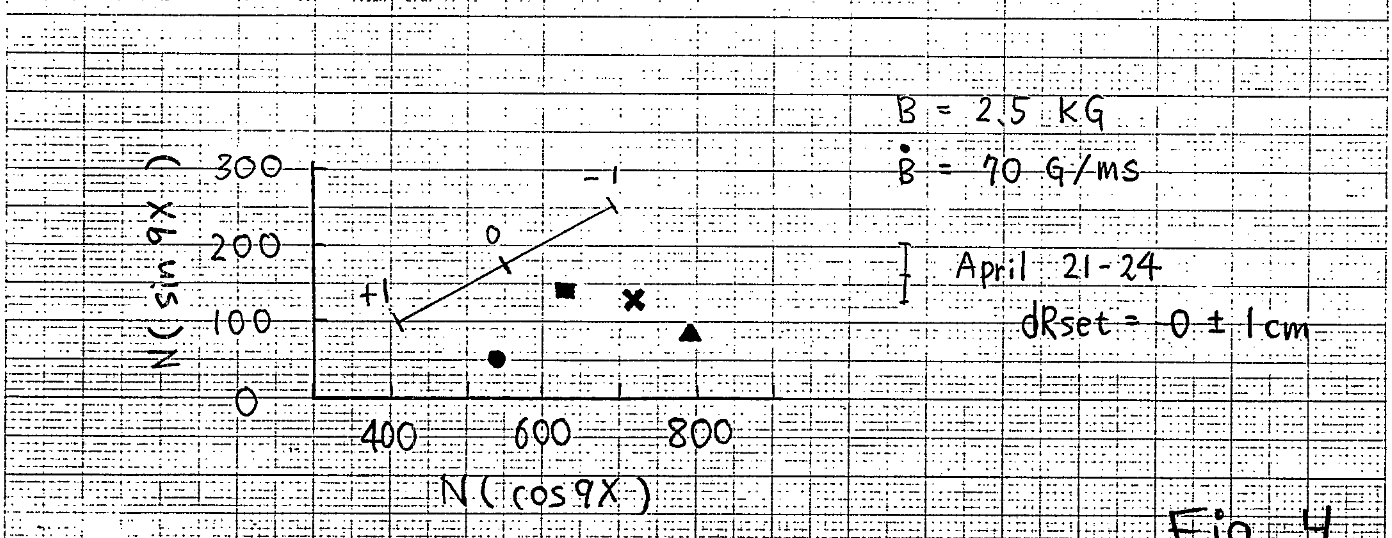
Co
So
200
100
0
-100
Co
So
0
Cb
Sb
200
100
0
Cb
Sb
0
Cbt
10
8
6
4
2
0
Cbt
Sbt
2
0
-2
-4
-6
Sbt
Mar. 28
Apr. 11
Apr. 12
Apr. 20
Apr. 21-24
Apr. 25
Mar. 28
Apr. 11
12
20
21-24
25

Fig. 2



March 28
April 11
April 12
April 20
April 25
Ḃ = 70 G/ms
N (cos 9X)
1000
800
600
400
N (sin 9X)
400
200
0
-200
0
2
4
6
B (KG)

Fig. 3



B = 2.5 KG
Ḃ = 70 G/ms
April 21-24
dRset = 0 ± 1cm
-1
0
+1
N (sin 9X)
300
200
100
0
400
600
800
N (cos 9X)

Fig. 4

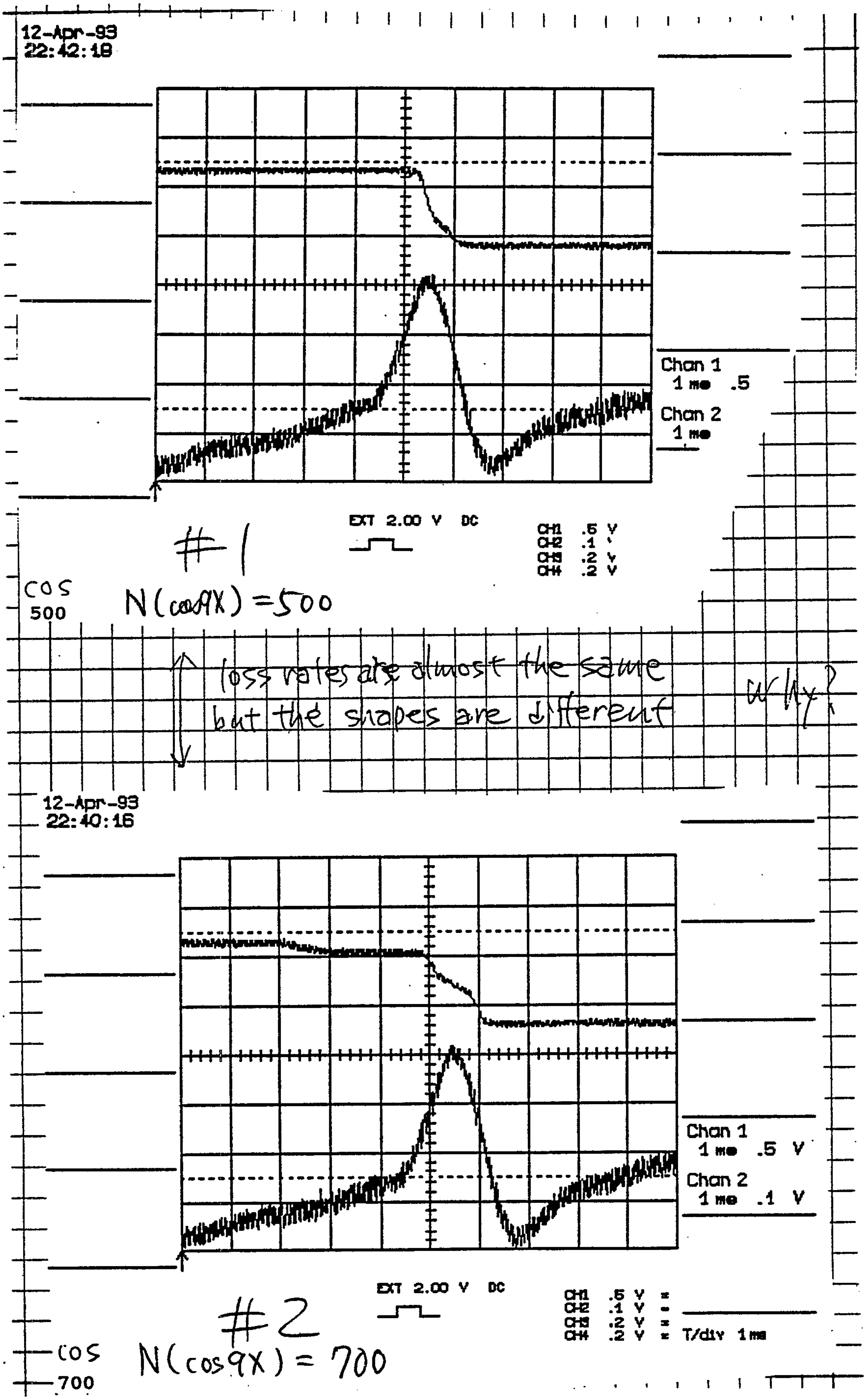

12-Apr-93
22:42:18
Chan 1
1 ms .5
Chan 2
1 ms
EXT 2.00 V DC
CH1 .5 V
CH2 .1 V
CH3 .2 V
CH4 .2 V
#1
cos
500
N(cos9X) =500
loss rates are almost the same
but the shapes are different
why?
12-Apr-93
22:40:16
Chan 1
1 ms .5 V
Chan 2
1 ms .1 V
EXT 2.00 V DC
CH1 .5 V
CH2 .1 V
CH3 .2 V
CH4 .2 V
T/div 1 ms
#2
cos
700
N(cos9X) = 700

Fig. 5

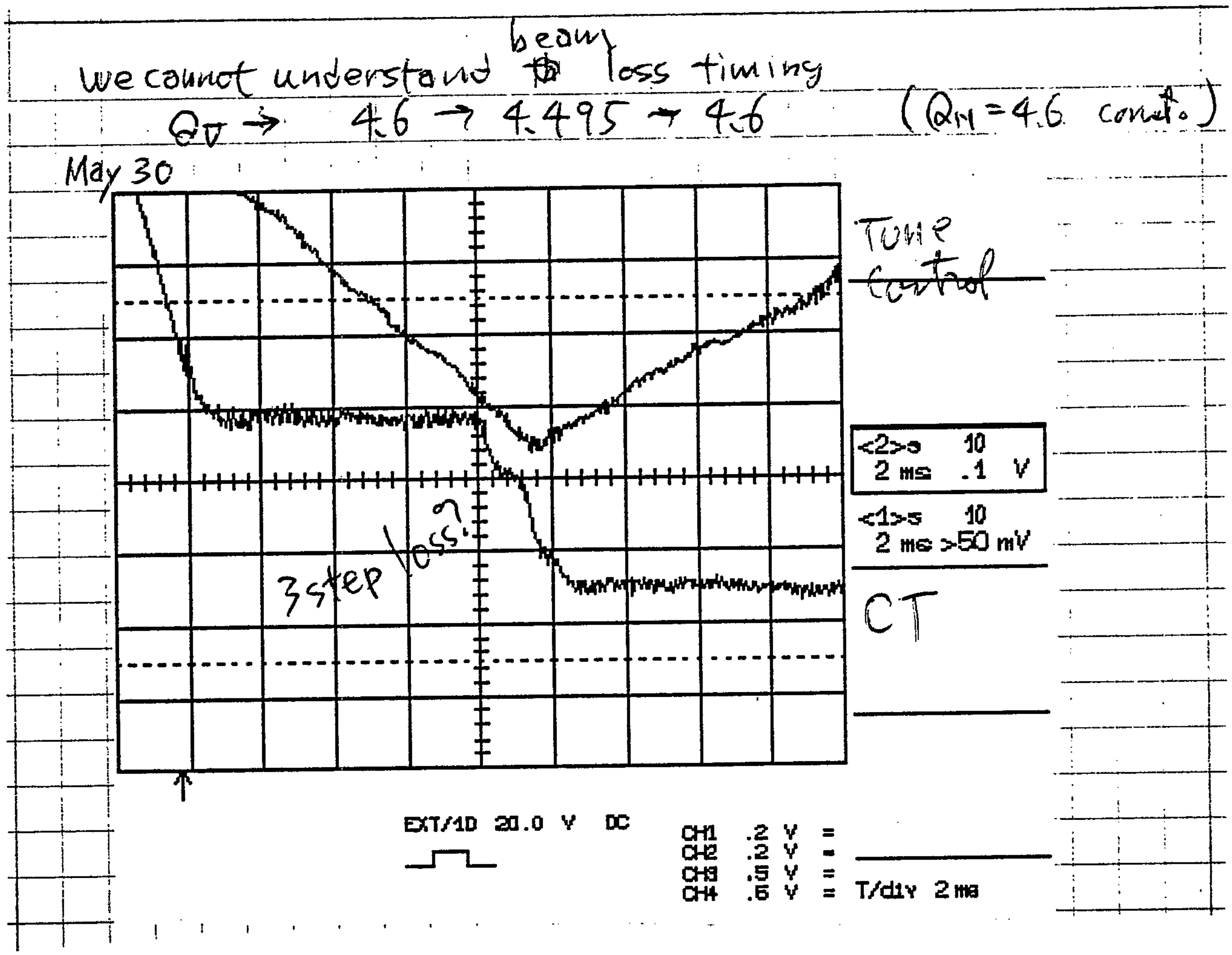

we cannot understand beam loss timing
Q_V → 4.6 → 4.495 → 4.6
(Q_H=4.6 const.)
May 30
Tune control
3 step loss?
<2>s 10
2 ms .1 V
<1>s 10
2 ms >50 mV
CT
EXT/10 20.0 V DC
CH1 .2 V =
CH2 .2 V =
CH3 .5 V =
CH4 .5 V =
T/div 2 ms

Fig. 6

Tune Meter Data Record - Default

Tune Acquired - Thu May 20 15:19:03 1993

	Parameter	Readback		Parameter	Readback		Parameter
BMD.KH_TUN.V	5.000	0.000	BMD.KV_TUN.V	5.000	0.000	Num Aver:	5
	SHORT	SHORT		SHORT	SHORT	Which Cycle:	1
BMD.KH_TUN.CMD		ON	BMD.KV_TUN.CMD		ON	Kick Plane:	BOTH
BMD.KH_TUNE_TRIG.RT	37.000	37.000				Dig Plane:	BOTH

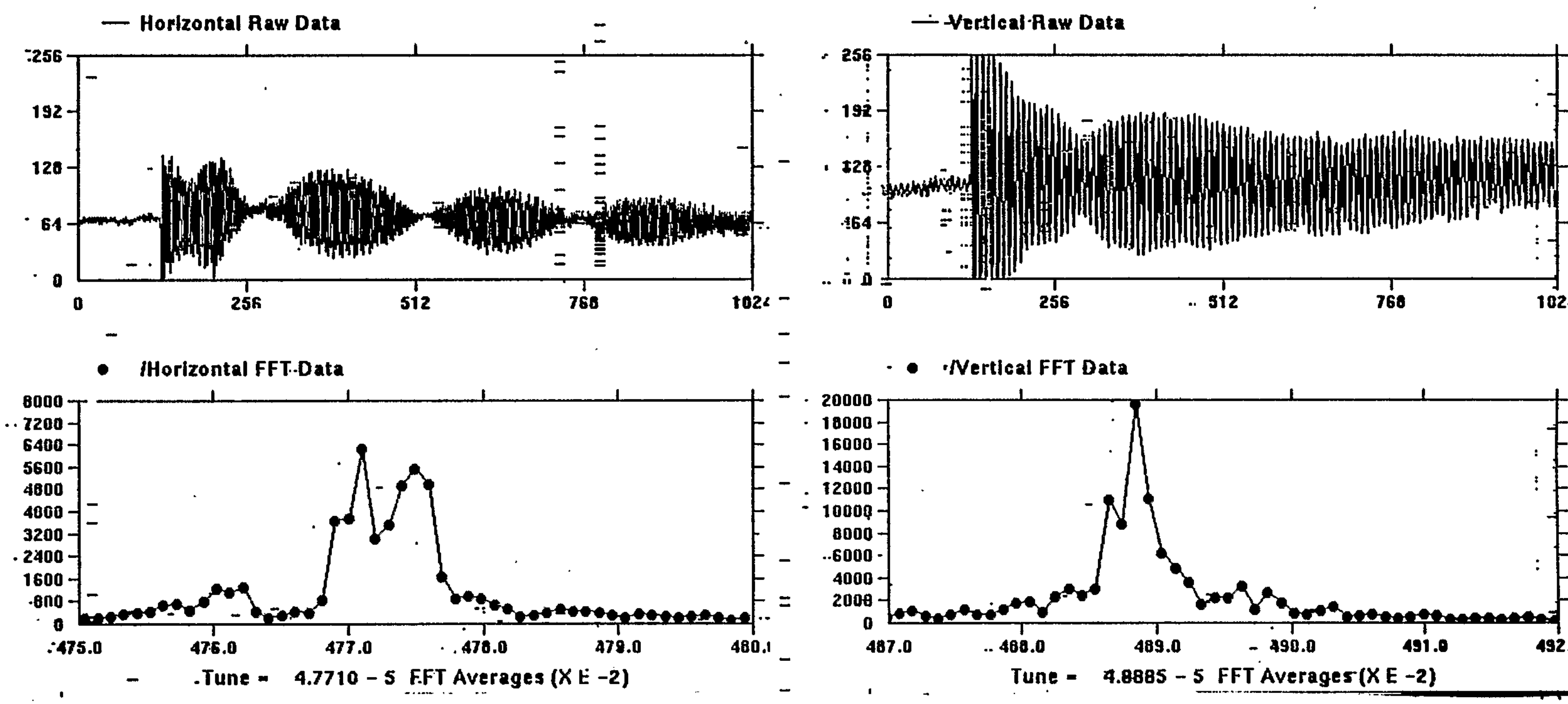


Fig. 7