p̄ Note # 501

BPM System Improvements

M. Church

24 April 1991

I. Motivation

During the accelerator studies period of 12/90 through 1/91 the Accumulator BPM system was investigated in some detail in an effort to improve its reliability and accuracy in making closed orbit measurements. The motivation for this is to try and improve the beam energy resolution for E760. The relativistic β of the $\bar{p}$ is given by

$$\beta = f_R L/c \tag{1}$$

where f_R is the revolution frequency, L is the orbit length ($\sim 474050mm$), and c is the speed of light. Hence, the error in β is given by

$$d\beta/\beta = df_R/f_R + dL/L. \tag{2}$$

Since df_R/f_R is $\sim 2\times10^{-7}$, the main contribution to the error comes from dL. During the E760 run of 5/90 to 9/90 dL was estimated to be $\sim 1mm$. It is thought that this can be reduced to $\sim .25mm$ with proper use of the present BPM system.

L is given by

$$L = L_0 + \delta L \tag{3}$$

where L_0 is the accurately known orbit length of a reference orbit (extracted from an energy scan of the J/Ψ or Ψ'), and δL is the difference orbit between the current orbit and the reference orbit. δL is calculated in the 1st approximation by

$$\delta L = \sum_i C_i \sum_j \Delta BPM_{ij} \tag{4}$$

where ΔBPM_{ij} is the horizontal difference orbit at the ith BPM in the jth sector and C_i are constants depending upon the location of the BPM pickup and the strength of the quadrupoles.[1] Table I lists the constants C_i, and Fig. 1 shows a typical difference orbit, ΔBPM_{ij}.

These studies were all done with "reverse protons" and concentrated on closed orbit measurements with the Accumulator horizontal BPMs. The low frequency (H=2) mode of the BPM system is used in all cases, therefore it is required that the beam be bunched with ARF3 at some level.[2] The low frequency RF module in the BPM

[1] For a more accurate calculation of the orbit length difference, see S Werkema, future Pbar Note.

[2] See FNAL TM-1254, Bagwell, et al, 1984, for a fairly complete, although slightly out-of-date description of the Antiproton Source Beam Position System.

system had previously been modified to track the H=2 frequency

II. Sources of BPM Error

There are 4 potential sources of errors in the BPM system that have been identified and corrected: 1) miscalibration of the BPM gain; 2) finite size of the LSB (least significant bit) of the ADC; 3) system nonlinear behaviour; and 4) incorrect electrical offsets.

A. BPM Calibration

In principle, the calibration of a particular BPM (ratio between beam position and ADC counts) depends only on the geometry of the pickup. However due to phase mismatches and other imperfections in the electronics, the calibration also depends on the particular amplifiers used, and therefore each individual BPM must be separately calibrated to obtain submillimeter accuracy. The absolute calibration of a high dispersion BPM (@Q10, Q11, Q14) was obtained by using the 4-8 Ghz momentum cooling pickup located at A20. The beam was bunched and moved in increments of several millimeters by varying the RF frequency. At each step the 4-8 pickup was moved such that the characteristic notch signal was symmetric (see Fig. 2), thus insuring that the beam was centered under the pickup. Even though the 4-8 pickup is directional, a strong notch signal is evident due to an impedance mismatch in the pickup signal leads.[3] Fig. 3 shows a plot of BPM position vs. 4-8 pickup position. The 4-8 pickup itself is calibrated with a dial indicator mounted on the cooling tank.

An absolute calibration of a low dispersion BPM (@Q1, Q3, Q4, Q6, Q8) was obtained using the accurately calibrated scraper A:RJ500 at A50. Fresh beam was placed at different horizontal locations at A50 (using a local bump), and its position measured with the BPMs at A5Q1 and A4Q1. A scraper scan with RJ500 was then performed and the extinction point measured. Fig. 4 shows a plot of BPM position vs. extinction point.

The relative calibration of the remaining BPMs was obtained by inputting a differential test signal to each BPM and recording the resultant output position. Since the magnitude of the test signal varies from BPM to BPM, this had to be measured also (see Table II). The absolute calibration of a single BPM and the relative calibration of each BPM are combined to give an absolute calibration of each BPM. These numbers are entered as constants in P76 (E760 Closed Orbits). Fig. 5 shows the percentage change from the original calibration constants for each of the 48 Accumulator horizontal BPMs. Note that A1Q4, A1Q8, A2Q4, and A2Q8 are of a different geometry and have not been recalibrated by this method. The calibration was only done for preamp attenuation = 46 dB and amplifier gain = 20 dB.

A partial check on the accuracy of the new calibration constants was made by measuring the dispersion at the low dispersion and high dispersion straight sections using

$$D = \eta(\Delta x) f_R / df_R \qquad (5)$$

where η is known, Δx is measured with the BPMs and df_R/f_R is the relative change in RF frequency. The dispersion measured this way should be consistent from sector

[3]Private communication, D McGinnis.

to sector and close to the design values. This is in fact the case (see Table III).

B. ADC Sensitivity

The final BPM signal is digitized by an 8 bit ADC which has 3 different sensitivity settings—4, 2, and 1. (This is actually just a programmable attenuator in the BPM Gain and Offset Module.) Traditionally, only sensitivity = 1 had been used, which yields an ADC LSB of 1.2 mm for the high dispersion BPMs and .33 mm for the low dispersion BPMs. The sensitivity = 4 setting was tested and found to give valid position measurements, although it requires a different set of electrical offsets than sensitivity = 1. The LSB is thus reduced to .3 mm for the high dispersion BPMs and .08 mm for the low dispersion BPMs. However, this sensitivity setting limits the full range of BPM measurements to $\sim \pm 40$ mm, which does not cover the full aperture of the Accumulator.

C. Nonlinear Behaviour

The amplitude of the signal from the BPM pickup depends on 3 parameters—the beam current, the RF voltage, and the frequency spread of the beam. Attenuation settings of 0 and 46 dB for the preamplifier, and gain settings of 0, 20, 40, and 60 dB for the amplifier permit, in principle, a dynamic range of 106 dB. However, it was found that the 60 dB gain setting for the amplifier (actually a 20 dB and 40 dB cascaded pair) yields very unreliable position measurements, and that the 40 dB gain setting yields position measurements with poor accuracy. Furthermore, for the settings, preamp = 46 dB attenuation and amp = 0 dB gain, the test signal is not large enough to generate reliable electrical offsets. There remains only 3 reliable overall gain settings:
preamp = 46 dB atten, amp = 20 dB gain;
preamp = 0 dB atten, amp = 0 dB gain;
preamp = 0 dB atten, amp = 20 dB gain.
In each configuration there is a linear dynamic range of about 20 dB in amplitude, giving a total dynamic range of ~ 66 dB. Varying the RF voltage effectively increases this dynamic range. We have been able to measure accurate (repeatable) closed orbits with as little as .05 mA of beam

As an aid to finding the most appropriate gain and attenuation settings, an Application Program (P57) has been written which "plateaus" the BPMs as a function of RF voltage: the RF voltage is varied over a given range and BPM measurements are taken and displayed as a function of RF voltage. Fig. 6 shows these plateaus for a suitable set of gain and attenuation, and Fig. 7 shows plateaus for a less suitable choice of gain and attenuation.

D. Electrical Offsets

It was found that different electrical offsets are required for different gain and attenuation settings. In addition, a different test signal is required for generating electrical offsets for different configurations. A new Accumulator Closed Orbit program (P76) has been written which allows the user to create, access, and save multiple offset files for different beam conditions. Electrical offsets cannot be accurately generated while there is beam in the machine because beam Schottky noise produces a finite BPM signal even when the beam is not bunched. (In fact, with 60 mA in the machine, fairly good (repeatable) closed orbits measurements may be made with the beam unbunched.)

III. New Procedures

A complete set of procedures for taking closed orbits in the Debuncher and Accumulator has been written and placed in the AP10 Accumulator Operations Manual and Debuncher Operations Manual. Procedures are described for testing the BPM system, generating electrical offsets, changing parameters, and taking closed orbits correctly. Hopefully, this will eliminate most of the past confusion in taking closed orbit measurements.

BPM	C
Q1	0.000
Q3	0.069
Q4	0.019
Q6	0.000
Q8	0.291
Q10	0.614
Q11	-0.088
Q14	0.000

TABLE I: Constants for calculating orbit length from BPM measurements

SECTOR

BPM		10	20	30	40	50	60
	Q1	620	622	646	670	618	642
	Q3	582	592	608	632	582	608
	Q4	562	566	582	604	560	580
	Q6	528	532	552	566	524	546
	Q8	578	590	638	650	584	612
	Q10	548	550	590	604	548	580
	Q11	534	536	570	582	530	558
	Q14	522	516	556	556	512	532

TABLE II: Test signal peak-to-peak amplitude (in mV) at input to preamp for differential test $91

PBEAM= 8834 Mev/c   ETA=-0.0236   DP/P=-0.00408   dF=.00509 Hz

sector	BPM	DX calib.	DXave calib.	DISP (m) calib.	DX uncalib.	DXave uncalib.	DISP (m) uncalib.
A1	A6Q1	-1.19	-0.77	0.19	-1.00	-0.67	0.17
	A1Q1	-0.34			-0.33		
A2	A1Q14	-44.02	-39.03	9.56	-50.02	-47.41	11.61
	A2Q14	-34.05			-44.80		
A3	A2Q1	-0.72	-0.94	0.23	-0.67	-0.84	0.21
	A3Q1	-1.16			-1.01		
A4	A3Q14	-39.19	-38.73	9.49	-42.60	-42.80	10.49
	A4Q14	-38.27			-43.00		
A5	A4Q1	-1.23	-1.14	0.28	-1.00	-1.00	0.25
	A5Q1	-1.05			-1.00		
A6	A5Q14	-43.52	-39.05	9.57	-46.30	-42.80	10.49
	A6Q14	-34.58			-39.30		
AVERAGE			low disp=	0.23			0.21
			high disp=	9.54			10.86

TABLE III: Dispersion measurement with calibrated and uncalibrated BPMs

CONSOLE LOCATION 08; AP10   18-DEC-1990 06:54

ACCUMULATOR CLOSED ORBIT (HORIZONTAL)

A:R1LLFS 52.792   A:R3HLFB 258.8615
A:IBEAM 4.57

CO Date/Time: 12/18/90 0653:52
AVG OVER 20 FRAMES (20 20 20 20 20 20 20) FILE 168 HAS BEEN SUBTRACTED
Deltap/p = 0

BEAM POSITIONS (mm)

A1Q1	-1	A2Q14	1.21	A3Q1	.67	A4Q14	-2.4	A5Q1	-2.01	A6Q14	1.21
A1Q3	0	A2Q11	2.41	A3Q3	1	A4Q11	-2.41	A5Q3	-2.33	A6Q11	1.21
A1Q4	-.5	A2Q10	2.41	A3Q4	-.33	A4Q10	-1.2	A5Q4	-1.32	A6Q10	0
A1Q6	-1.34	A2Q8	-1.5	A3Q6	-3.67	A4Q8	1.69	A5Q6	1.33	A6Q8	-2
A1Q8	2.47	A2Q6	3.99	A3Q8	-4.65	A4Q6	1.99	A5Q8	4.07	A6Q6	2.33
A1Q10	-1.21	A2Q4	3.53	A3Q10	1.21	A4Q4	.33	A5Q10	-2.41	A6Q4	-2.67
A1Q11	-2.41	A2Q3	-.33	A3Q11	1.21	A4Q3	-.66	A5Q11	-2.41	A6Q3	-3.99
A1Q14	-2.41	A2Q1	0	A3Q14	1.21	A4Q1	-1	A5Q14	-1.2	A6Q1	-3.34

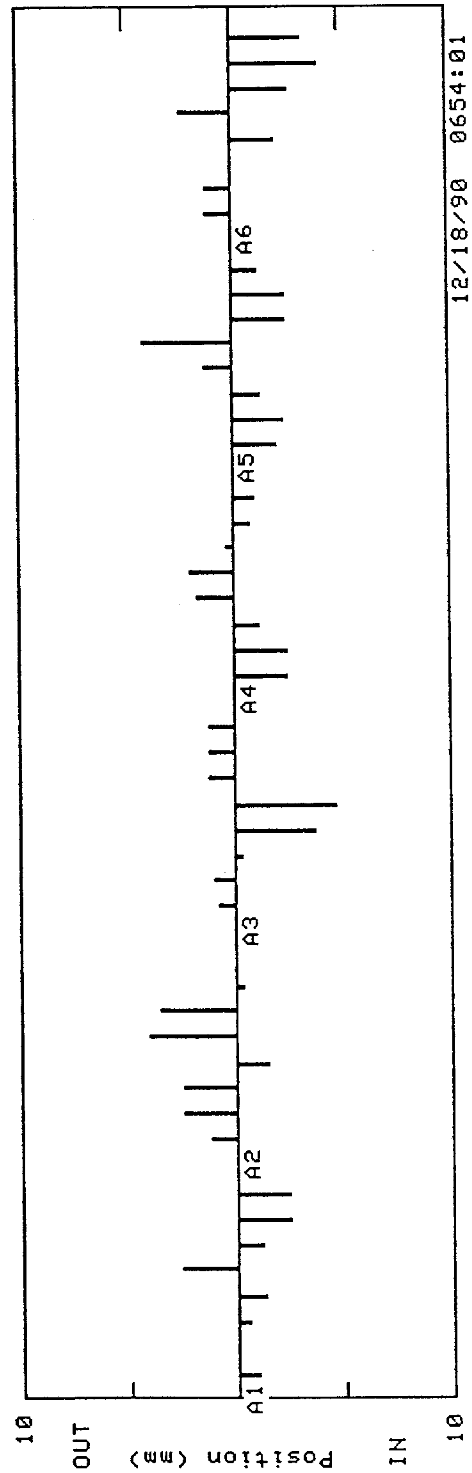

FIG. 1: Typical Accumulator closed orbit horizontal difference orbit for energy calculation

CONSOLE 15, 12-DEC-1990 17:58
Char SA Plot
NORMAL blue/yellow

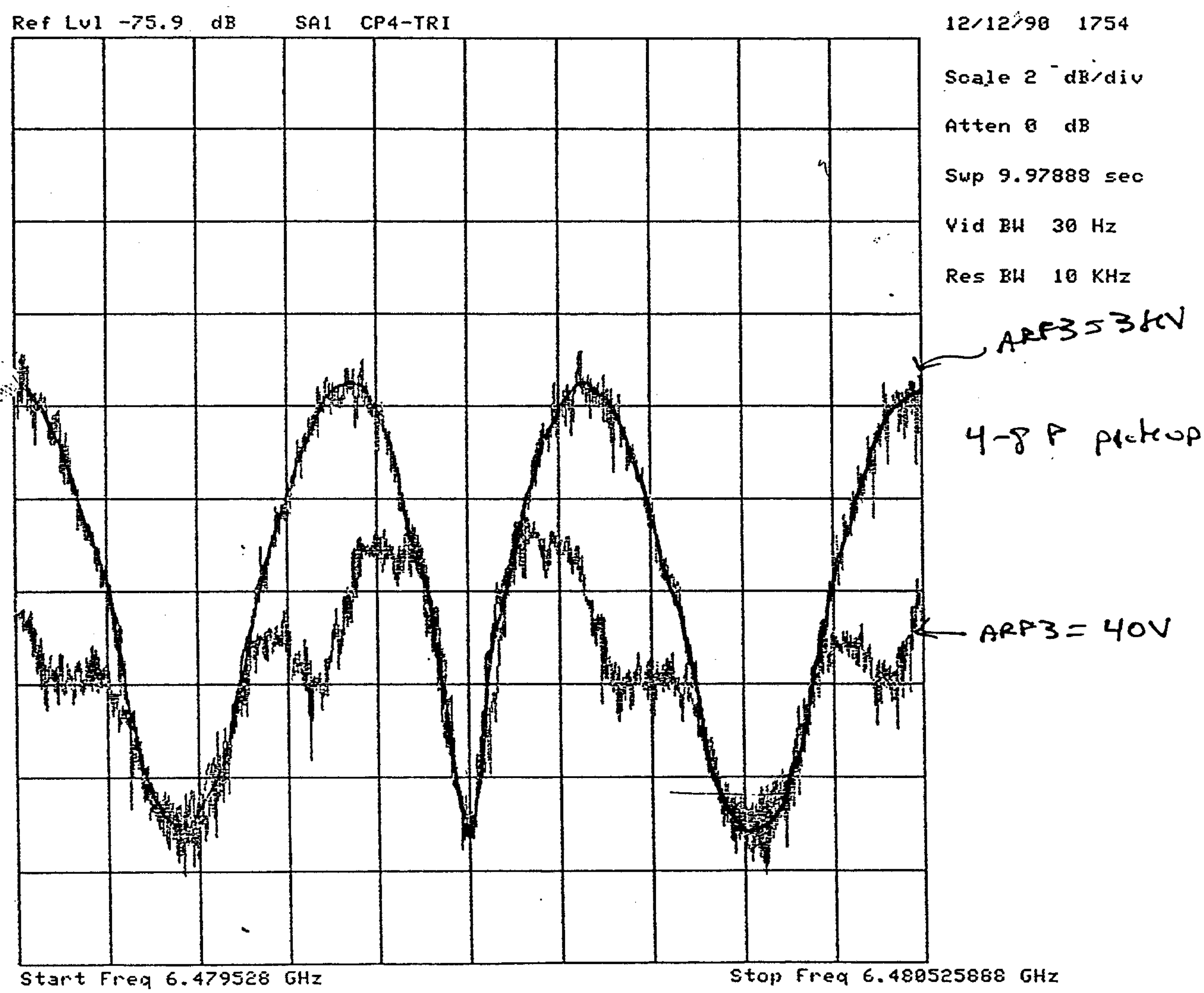

FIG. 2: Notch signal from 4-8 momentum stochastic cooling pickup; bunched and unbunched beam, reverse protons

CONSOLE LOCATION 22; AP10   12-DEC-1990 19:18
Curve fitter II

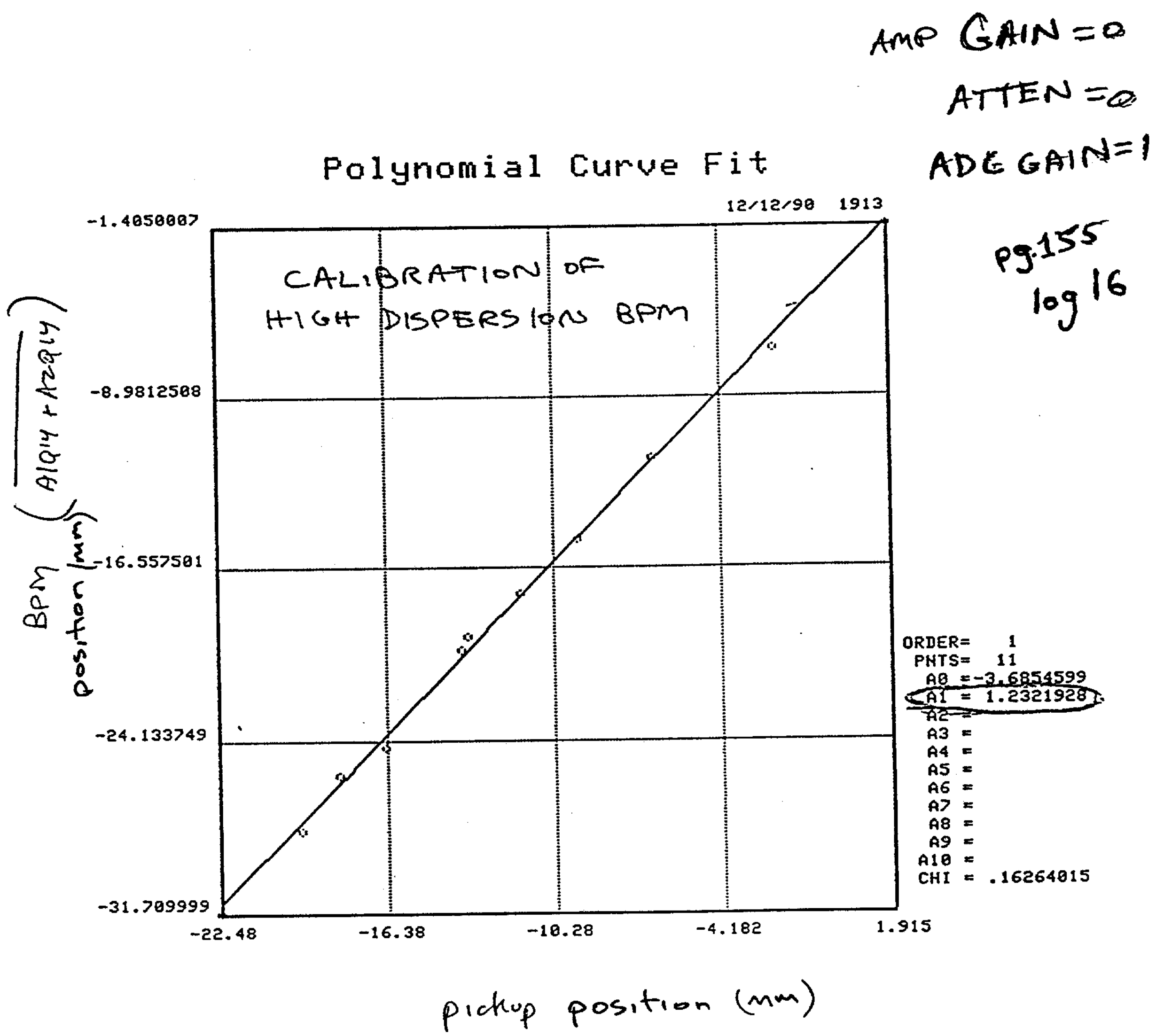

FIG. 3: Calibration of high dispersion BPM with 4-8 momentum cooling pickup

CONSOLE LOCATION 14; AP10 25-JAN-1991 15:31

Curve fitter II

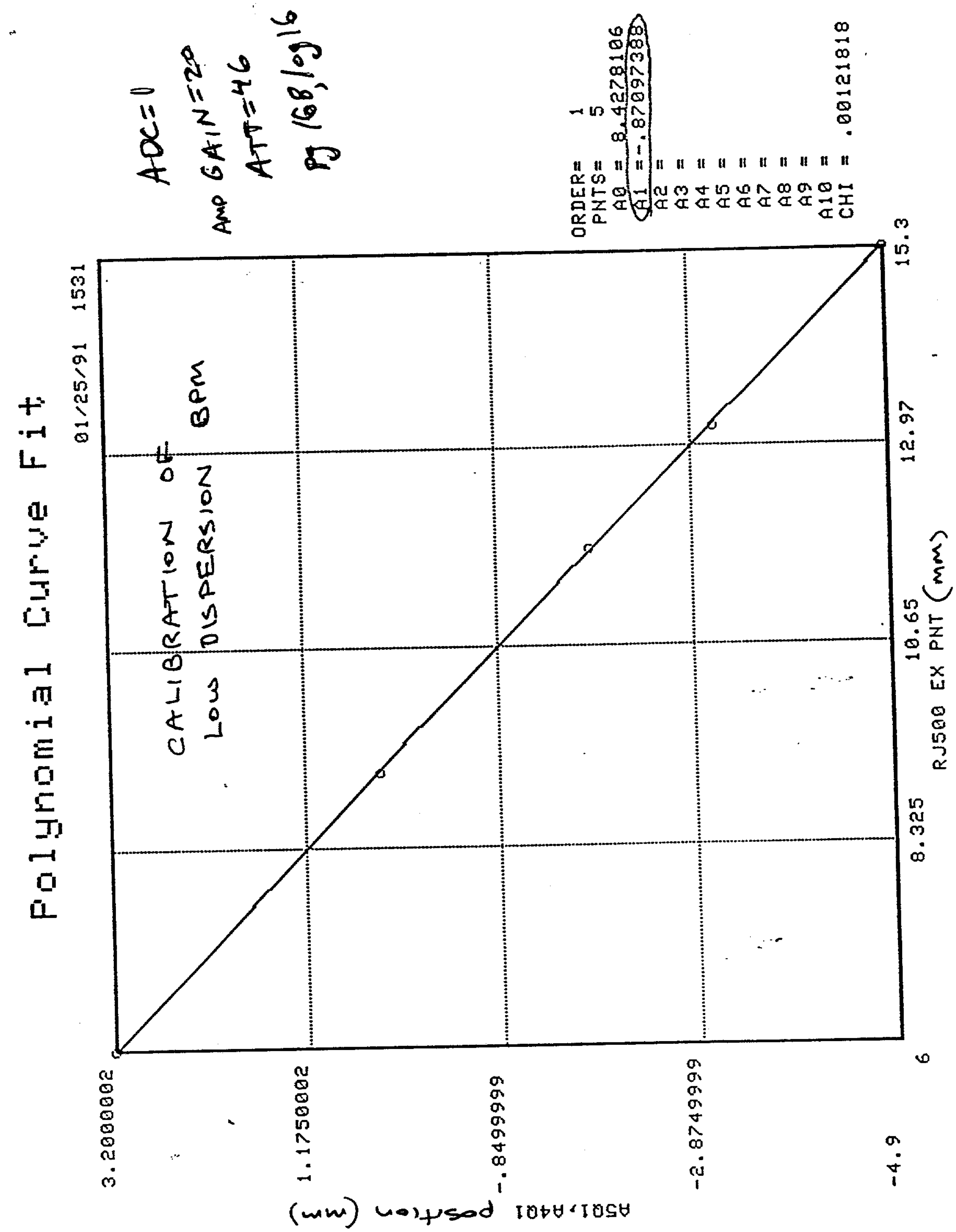

FIG. 4: Calibration of low dispersion BPM with low dispersion momentum scraper

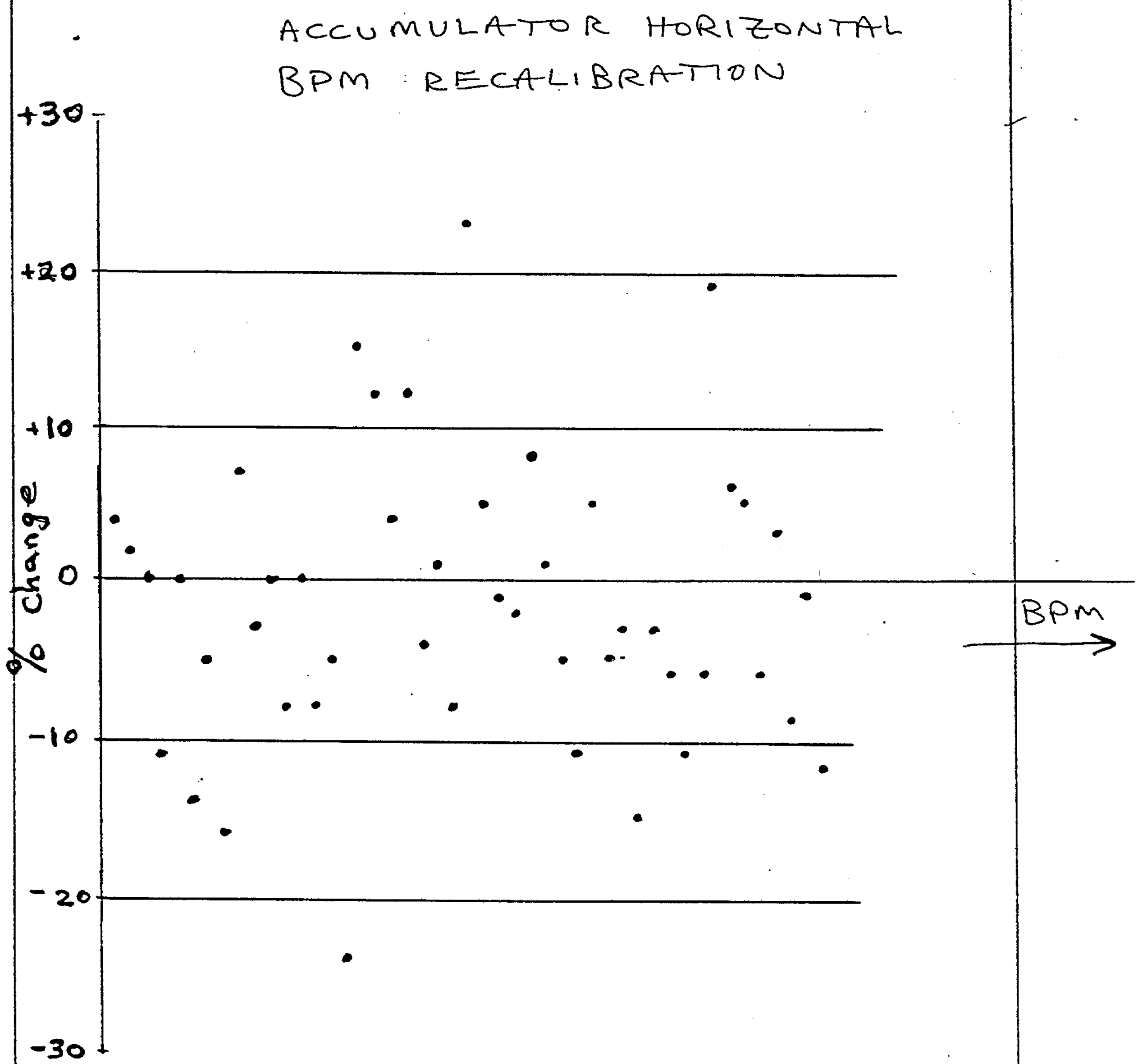

FIG. 5: % change between old BPM calibration and new BPM calibration

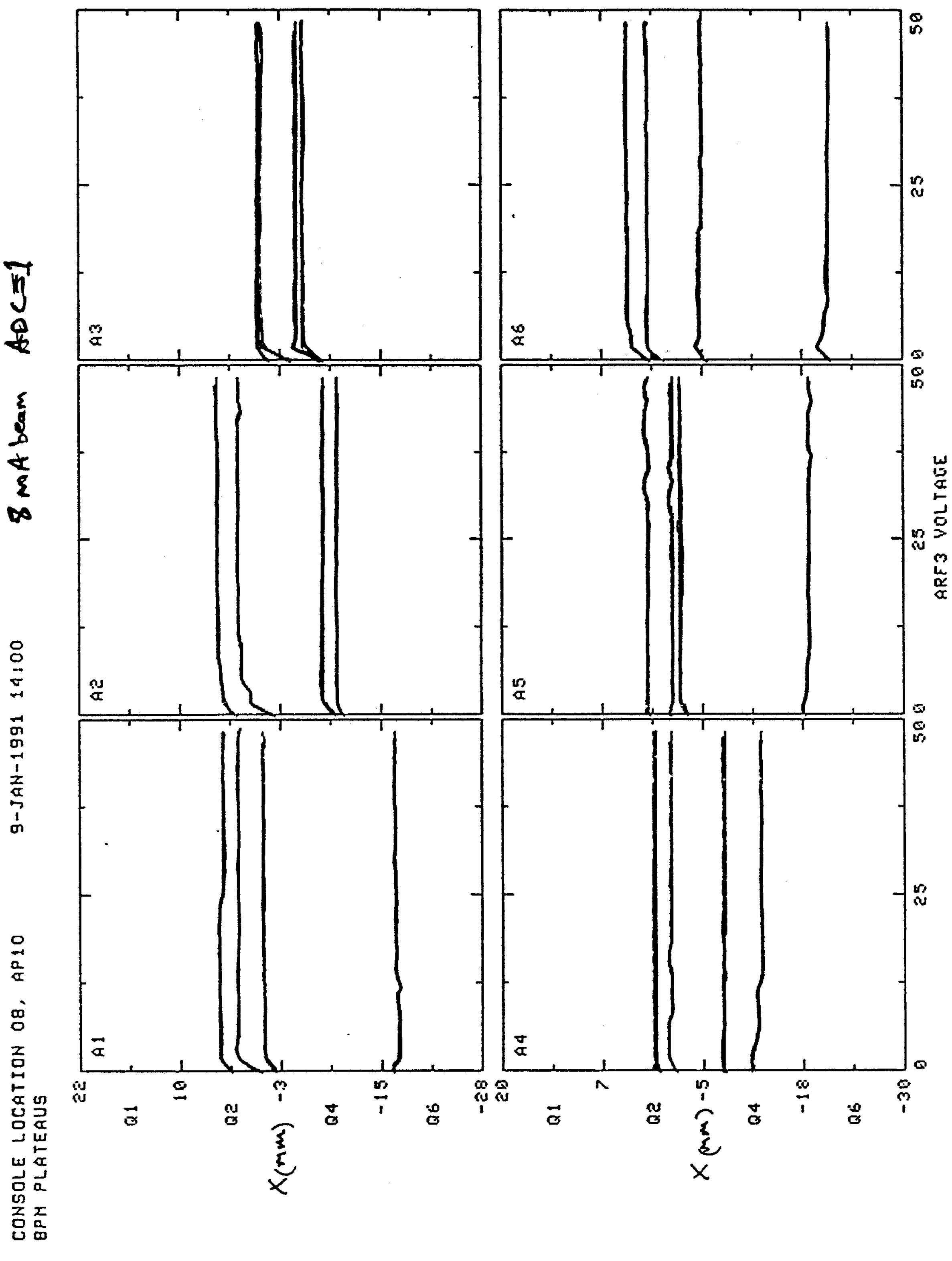

FIG. 6: Accumulator horizontal BPM readings as a function of RF voltage for a suitable configuration of amp gain and preamp attenuation

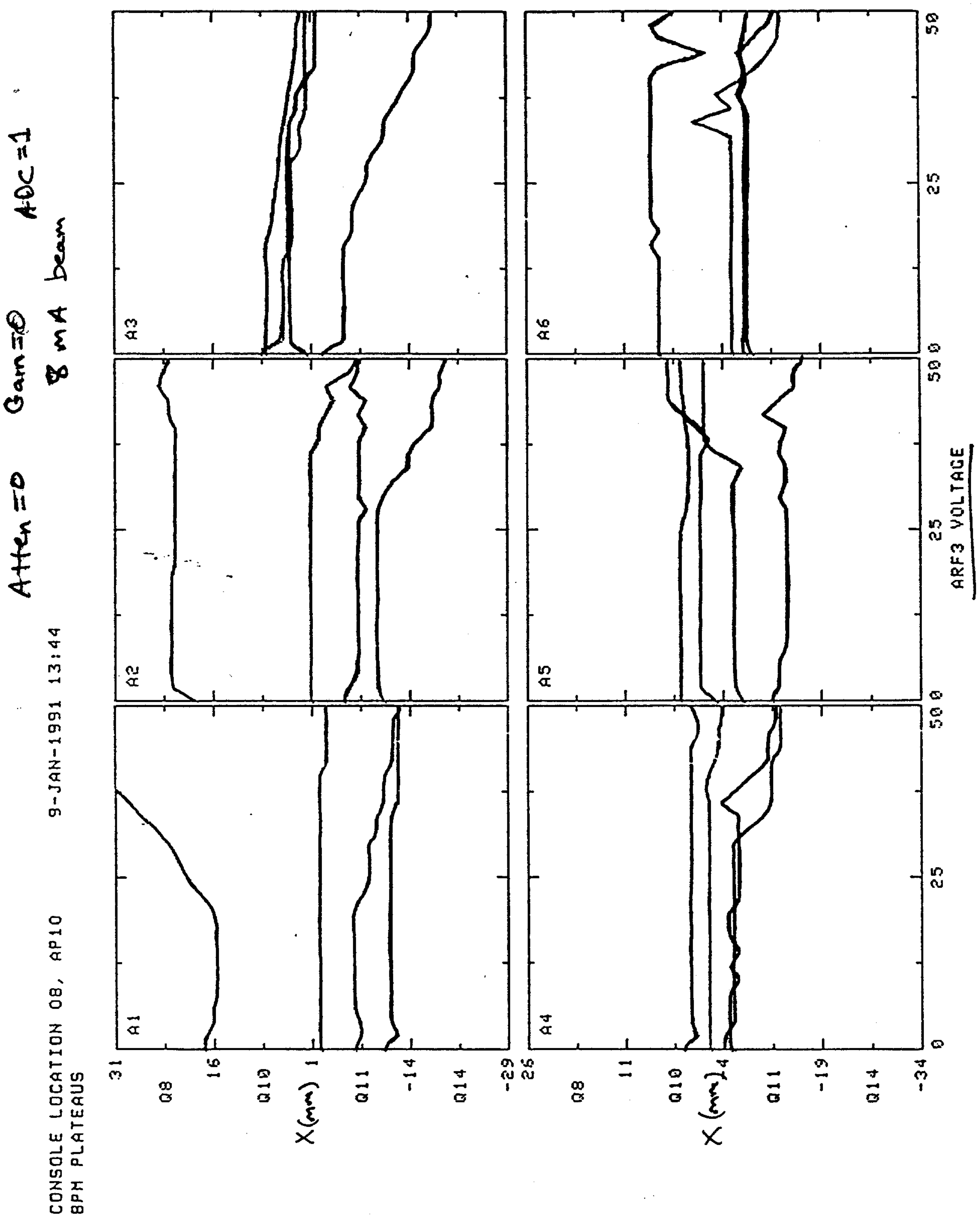

FIG. 7: Accumulator horizontal BPM readings as a function of RF voltage for an unsuitable configuration of amp gain and preamp attenuation