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Informal Report

THE INTERNAL BUNCH COORDINATE MONITOR (IBCM)

S.P. Yamin

November 4, 1988

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INFORMAL REPORT

ALTERNATING GRADIENT SYNCHROTRON DEPARTMENT

BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, Long Island, New York 11973

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I. INTRODUCTION

An instrument has been developed and installed at the AGS for recording the transverse motion of each rf bunch. It can be operated from any node of the Apollo control system. A preliminary version of this report has appeared elsewhere.[1] Appendix A is an instruction manual.

Two digitizers, running off the same 100 MHz clock, sampled the output of either a horizontal or vertical pick-up electrode (PUE) pair. The coordinate of each rf bunch was calculated each time it passed the PUEs during a 320 microsecond interval. Thus, the motion of each bunch could be followed during this interval. Subsequent analysis computed the Fourier transform of this motion.

Bunch motion has been studied at several times during the AGS cycle: the betatron oscillations induced by the tune meter's vertical kick have been seen, and their Fourier analysis gives results consistent with the tune meter; at transition, the effect of the radial kick on each bunch has been observed; coupled-bunch oscillations have been studied; and instabilities produced by high intensities have been observed.

II. APPARATUS

The IBCM is located in the K-18 House and is connected by fast cables to the PUEs in the K-8 straight section. A logical plan of the apparatus appears as Figure 1.

A pair of LeCroy 8818 100 MHz CAMAC transient recorders is interfaced to an IBM-PC/XT computer which, in turn, is interfaced to the AGS Apollo control system via the RELWAY data link. A program in the PC converts the bunch digitizations into coordinates, passing these on to the Apollo, where Fourier analysis is performed.

Signals from a vertical or horizontal PUE pair are fed through attenuators, where small gain differences are removed, and to the LeCroy 8818 digitizers. The Apollo system starts the sampling, which continues for 320 microseconds after a "stop" signal is received. (At present, this is a standard AGS 15 V signal transmitted by dedicated cable from the control room to the IBCM.) The last 320 microseconds of data are then transferred to the IBM-PC for preliminary processing. Here, pulses

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[1] P. Yamin, "IBCM: Internal Bunch Coordinate Monitor," Proceedings 1987 IEEE Particle Accelerator Conference, Accelerator Engineering & Technol., IEEE Cat. No. 87CH2387-9, Vol 1, 603 (1987).

are identified and the 5-7 samples representing the 50-70 ns pulse from each PUE are summed to form inner/outer or upper/lower signals. The position of each bunch is then determined as X=(inner-outer)/(inner+outer) or Y=(upper-lower)/(upper+lower).

These data, representing the horizontal or vertical coordinate for each of the 12 AGS bunches as they passed the K-8 PUE during the 320 microsecond sampling interval, are transmitted via RELWAY to the Apollo.

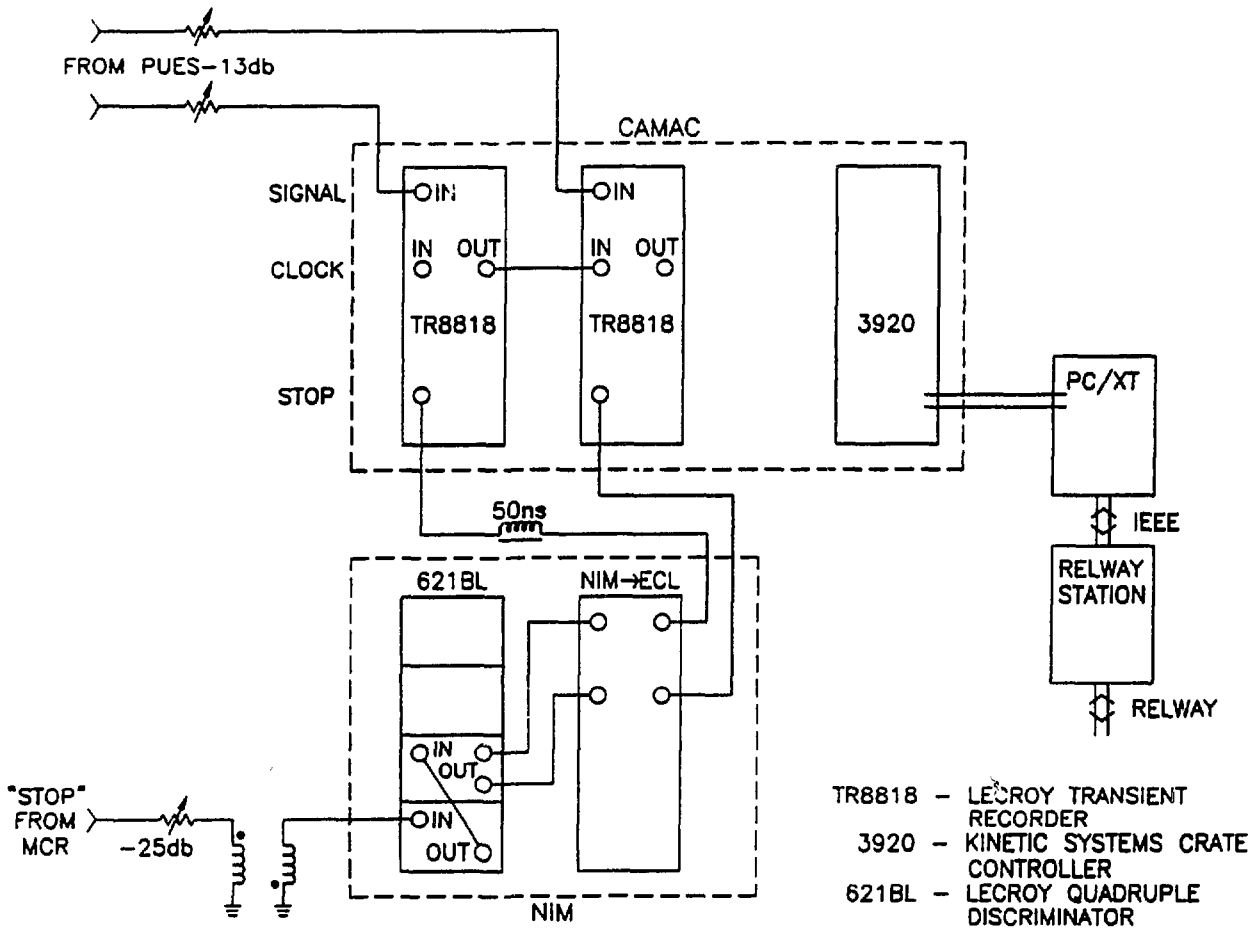


Figure 1.

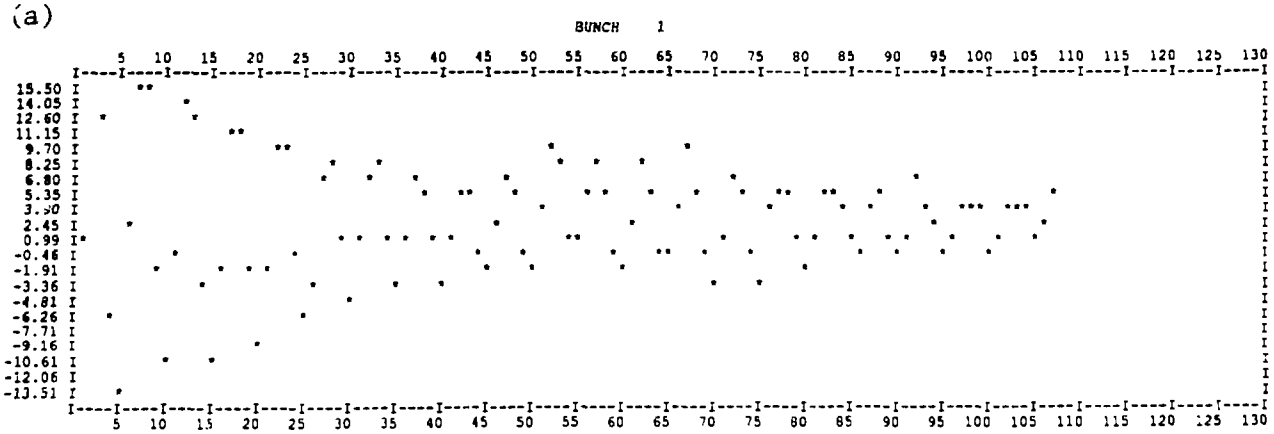
At the Apollo, the transmitted data are written to a disk file for subsequent analysis. The present analysis program reads this file and produces twelve (one for each bunch) sets of output which display: a plot of the coordinate of each bunch as it passed the PUE on successive turns; the real and imaginary parts of the Fourier transform of the first 64 points in this plot; and a plot of the power spectrum of the Fourier transform.

All of the Apollo and IBM-PC codes likely to be of interest to the physics- or operations-oriented user were written in FORTRAN by the author, and can readily be modified to suit evolving needs. (The part written by "professionals" concerns communication on the CAMAC link between the digitizers and IBM-PC, the IEEE link between the IBM-PC and the RELWAY station, and the control of the Apollo/RELWAY interface.) More information about these programs, including listings, is available from the author.

III. RESULTS

In order to reassure ourselves that we were looking at real effects, we first tested the monitor on a known phenomenon: large-amplitude betatron oscillations produced by the tune meter's vertical kicker. Figures 2a-c show data for a typical bunch taken during a 320 microsecond window beginning shortly after a kick was applied.

(a)



(b)

N	REAL	IMAGINARY
0	2.6356	0.0000
1	0.4078	-0.2839
2	0.1483	-0.0913
3	-0.1521	0.1358
4	0.1169	0.1401
5	0.2073	-0.0416
6	0.3915	-0.1921
7	0.3308	-0.1504
8	0.3306	-0.1794
9	0.3979	0.0007
10	0.4887	-0.0581
11	0.8417	-0.2098
12	1.2898	1.0865
13	-2.3713	3.0707
14	-0.7802	0.3632
15	-0.4324	0.1266
16	-0.2775	0.0959
17	-0.2168	0.1727
18	-0.2055	0.1273
19	-0.1379	0.0844
20	-0.1663	0.1061
21	-0.1445	-0.0581
22	-0.0732	0.0090
23	-0.1108	-0.0906
24	-0.0278	0.0190
25	-0.0703	0.0169
26	-0.0374	-0.0287
27	0.0489	0.0118
28	0.0003	0.0285
29	-0.0144	0.0067
30	-0.0883	0.0716
31	-0.1689	0.0389

FOURIER TRANSFORM OF FIRST 64 POINTS IN TRAJECTORY

(c)

TRAJECTORY

N	(TUNE)	POWER	
1	(0.9844)	0.2469	
2	(0.9688)	0.0303	
3	(0.9531)	0.0416	
4	(0.9375)	0.0333	
5	(0.9219)	0.0447	
6	(0.9063)	0.1902	
7	(0.8906)	0.1320	
8	(0.8750)	0.1415	
9	(0.8594)	0.1584	
10	(0.8438)	0.2422	
11	(0.8281)	0.7524	**
12	(0.8125)	2.8439	********
13	(0.7969)	15.0523	**********
14	(0.7813)	0.7406	**
15	(0.7656)	0.2030	
16	(0.7500)	0.0862	
17	(0.7344)	0.0769	
18	(0.7188)	0.0584	
19	(0.7031)	0.0261	
20	(0.6875)	0.0389	
21	(0.6719)	0.0243	
22	(0.6563)	0.0054	
23	(0.6406)	0.0205	
24	(0.6250)	0.0011	
25	(0.6094)	0.0052	
26	(0.5938)	0.0022	
27	(0.5781)	0.0025	
28	(0.5625)	0.0008	
29	(0.5469)	0.0003	
30	(0.5313)	0.0129	
31	(0.5156)	0.0300	

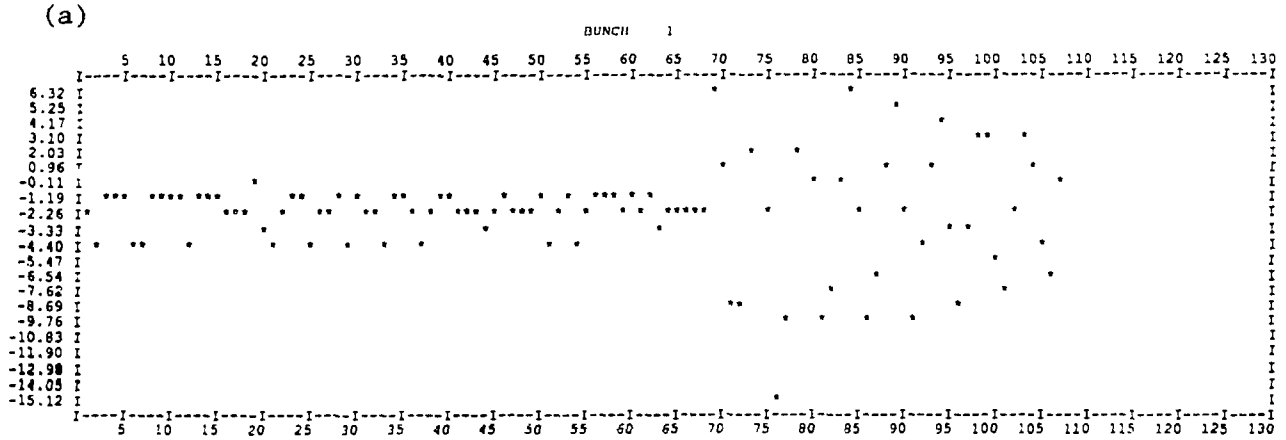
POWER SPECTRUM OF FOURIER TRANSFORM

Figure 2.

The decaying oscillation is readily apparent in Fig. 2a, where the ordinate represents amplitude as a percentage of PUE spacing and the abscissa the turn number. The period of the oscillations is about 5 turns and the decay time about 85 turns. From this we can immediately conclude that the fractional part of the tune is about 1-1/5 = 0.8 and the tune spread about 1/85 = 0.012. Figure 2b is the Fourier transform of the first 64 points in Fig. 2a. Since the Fourier transform is computed over an interval of 64 turns, the index N=0 represents the dc component of the signal, N=1 the frequency corresponding to a period of 64 turns, N=2 the frequency corresponding to a period of 32 turns, etc. These data are more readily comprehensible as a power spectrum (the sum of the squares of the real and imaginary parts of the respective amplitudes), which is shown in Fig 2c., and where we also show the fractional part of the tune in parentheses. The peak is striking, and its position agrees with both the tune meter measurement and the approximation given above.

Figures 3a-c show similar data, but the position of the timing window is such that the vertical kick is visible.

(a)



(b)

N	REAL	IMAGINARY
0	-2.2403	0.0000
1	0.0176	-0.0038
2	-0.0460	-0.0245
3	-0.0327	-0.1153
4	-0.0518	-0.1040
5	-0.0192	-0.0109
6	-0.0872	0.0784
7	0.0096	0.0602
8	0.1092	-0.0075
9	-0.0278	0.0673
10	-0.1046	0.1254
11	-0.0888	-0.0687
12	-0.1680	0.0207
13	-0.1096	-0.1558
14	0.0021	-0.2594
15	0.3196	0.0373
16	-0.1147	0.0164
17	0.2005	-0.2105
18	-0.1059	-0.0688
19	-0.0055	0.0592
20	0.1148	-0.0080
21	0.1295	-0.0153
22	-0.0260	-0.0166
23	-0.1253	-0.0730
24	-0.0611	-0.0882
25	0.1125	-0.0571
26	0.1416	-0.0711
27	0.0257	-0.0991
28	0.0225	-0.0541
29	0.0518	0.0452
30	-0.1190	-0.1039
31	0.1383	-0.0364

(c) TRAJECTORY

N	(TUNE)	POWER
1	(0.9844)	0.0003
2	(0.9688)	0.0027
3	(0.9531)	0.0144
4	(0.9375)	0.0135
5	(0.9219)	0.0005
6	(0.9063)	0.0137
7	(0.8906)	0.0037
8	(0.8750)	0.0120
9	(0.8594)	0.0053
10	(0.8438)	0.0267
11	(0.8281)	0.0126
12	(0.8125)	0.0286
13	(0.7969)	0.0363
14	(0.7813)	0.0673
15	(0.7656)	0.1029
16	(0.7500)	0.0134
17	(0.7344)	0.0845
18	(0.7188)	0.0160
19	(0.7031)	0.0035
20	(0.6875)	0.0132
21	(0.6719)	0.0170
22	(0.6563)	0.0010
23	(0.6406)	0.0210
24	(0.6250)	0.0115
25	(0.6094)	0.0159
26	(0.5938)	0.0251
27	(0.5781)	0.0105
28	(0.5625)	0.0034
29	(0.5469)	0.0047
30	(0.5313)	0.0250
31	(0.5156)	0.0205

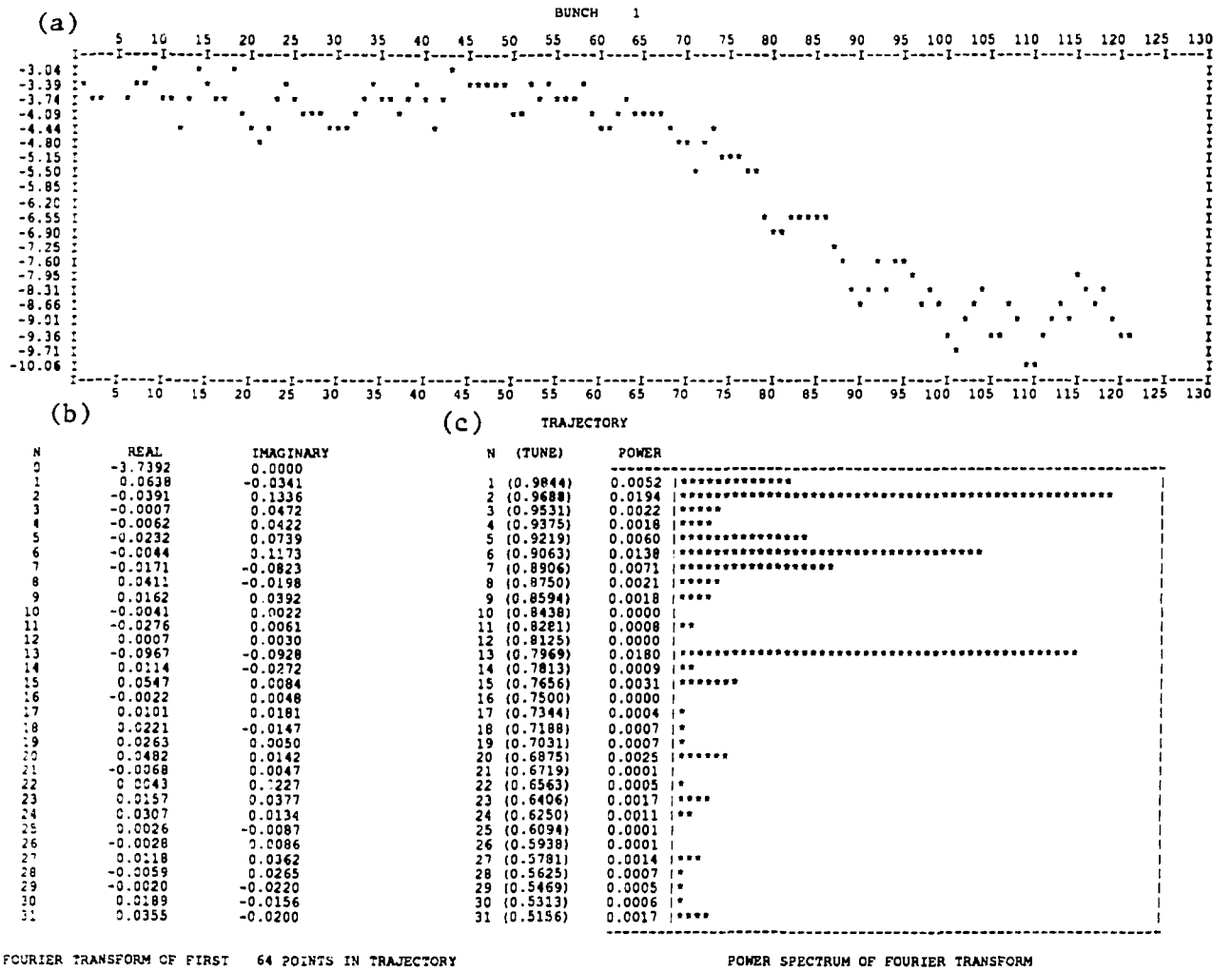
FOURIER TRANSFORM OF FIRST 64 POINTS IN TRAJECTORY

POWER SPECTRUM OF FOURIER TRANSFORM

Figure 3.

Since the Fourier transform is computed only for the first 64 turns, where no large betatron oscillations are present, we cannot expect a sharp peak. Nevertheless, the tune can be identified as the broad peak centered at about 0.8 in Fig. 3c.

Next, we studied the transition region, and representative data may be found in Figs. 4a-c.



N	REAL	IMAGINARY
0	-3.7392	0.0000
1	0.0638	-0.0341
2	-0.0391	0.1336
3	-0.0007	0.0472
4	-0.0062	0.0422
5	-0.0232	0.0739
6	-0.0044	0.1173
7	-0.0171	-0.0823
8	0.0411	-0.0198
9	0.0162	0.0392
10	-0.0041	0.0022
11	-0.0276	0.0061
12	0.0007	0.0030
13	-0.0967	-0.0928
14	0.0114	-0.0272
15	0.0547	0.0084
16	-0.0022	0.0048
17	0.0101	0.0181
18	0.0221	-0.0147
19	0.0263	0.0050
20	0.0482	0.0142
21	-0.0068	0.0047
22	0.0043	0.0227
23	0.0157	0.0377
24	0.0307	0.0134
25	0.0026	-0.0087
26	-0.0028	0.0086
27	0.0118	0.0362
28	-0.0059	0.0265
29	-0.0020	-0.0220
30	0.0189	-0.0156
31	0.0355	-0.0200

N	(TUNE)	POWER
1	(0.9844)	0.0052
2	(0.9688)	0.0194
3	(0.9531)	0.0022
4	(0.9375)	0.0018
5	(0.9219)	0.0060
6	(0.9063)	0.0138
7	(0.8906)	0.0071
8	(0.8750)	0.0021
9	(0.8594)	0.0018
10	(0.8438)	0.0000
11	(0.8281)	0.0008
12	(0.8125)	0.0000
13	(0.7969)	0.0180
14	(0.7813)	0.0009
15	(0.7656)	0.0031
16	(0.7500)	0.0000
17	(0.7344)	0.0004
18	(0.7188)	0.0007
19	(0.7031)	0.0007
20	(0.6875)	0.0025
21	(0.6719)	0.0001
22	(0.6563)	0.0005
23	(0.6406)	0.0017
24	(0.6250)	0.0011
25	(0.6094)	0.0001
26	(0.5938)	0.0001
27	(0.5781)	0.0014
28	(0.5625)	0.0007
29	(0.5469)	0.0005
30	(0.5313)	0.0006
31	(0.5156)	0.0017

Figure 4.

The notable feature in Fig. 4a is the shift in orbit as transition is crossed, moving inward by about 6% of the 4" horizontal PUE spacing--about 0.25". The peaks in the power spectrum, shown in Fig 4c and centered in channels 2, 6, and 13, are probably oscillations induced by the (perturbing) orbit bump used to speed up passage through transition.

Coupled-bunch oscillations[2] have been observed. Here, the wakefield of each bunch perturbs following bunches. This effect is caused by sharp peaks in the accelerator impedance--resonances with high enough Q-values to sustain the wakefield for the 220 ns interval between bunches. For M circulating bunches, M coupled modes are possible, with a phase shift of 2π n/M between bunches for mode n.

Each bunch can also oscillate transversely in several modes, which are usually denoted by the integer m. For example, m=0 corresponds to rigid motion of the bunch as a whole and m=1 to "head-tail" oscillations about the center of the bunch. In the case of zero chromaticity, m=0 oscillations appear at the betatron frequency. Finite chromaticity produces a frequency shift.

Because the tune depends on momentum, the betatron frequency varies cyclically as particles undergo synchrotron oscillations. This has the effect of modulating the betatron frequency signal and shifting its frequency spectrum by an amount ξ/η, where ξ is the chromaticity and $\eta=1/\gamma_t^2 - 1/\gamma^2$ is the dispersion in revolution frequency. However, since the algorithm used to determine the bunch position (which is described in Section II) integrates over the entire bunch length and the frequency response of the PUE electronics is limited, the IBCM as presently constituted is not sensitive to the effects of chromaticity or modes other than m=0.

Coupled bunch oscillations can be used to study the AGS impedance. The presence of these oscillations at a particular point in the AGS cycle indicates a peak in the impedance at the corresponding revolution frequency and mode. Figure 5 is an example of vertical coupled-bunch oscillations. Here, only trajectories for the first four bunches are shown, together with the Fourier analysis for Bunch 4. Oscillations at the same frequency are obvious, and the systematic bunch-to-bunch phase shift is emphasized by the diagonal line.

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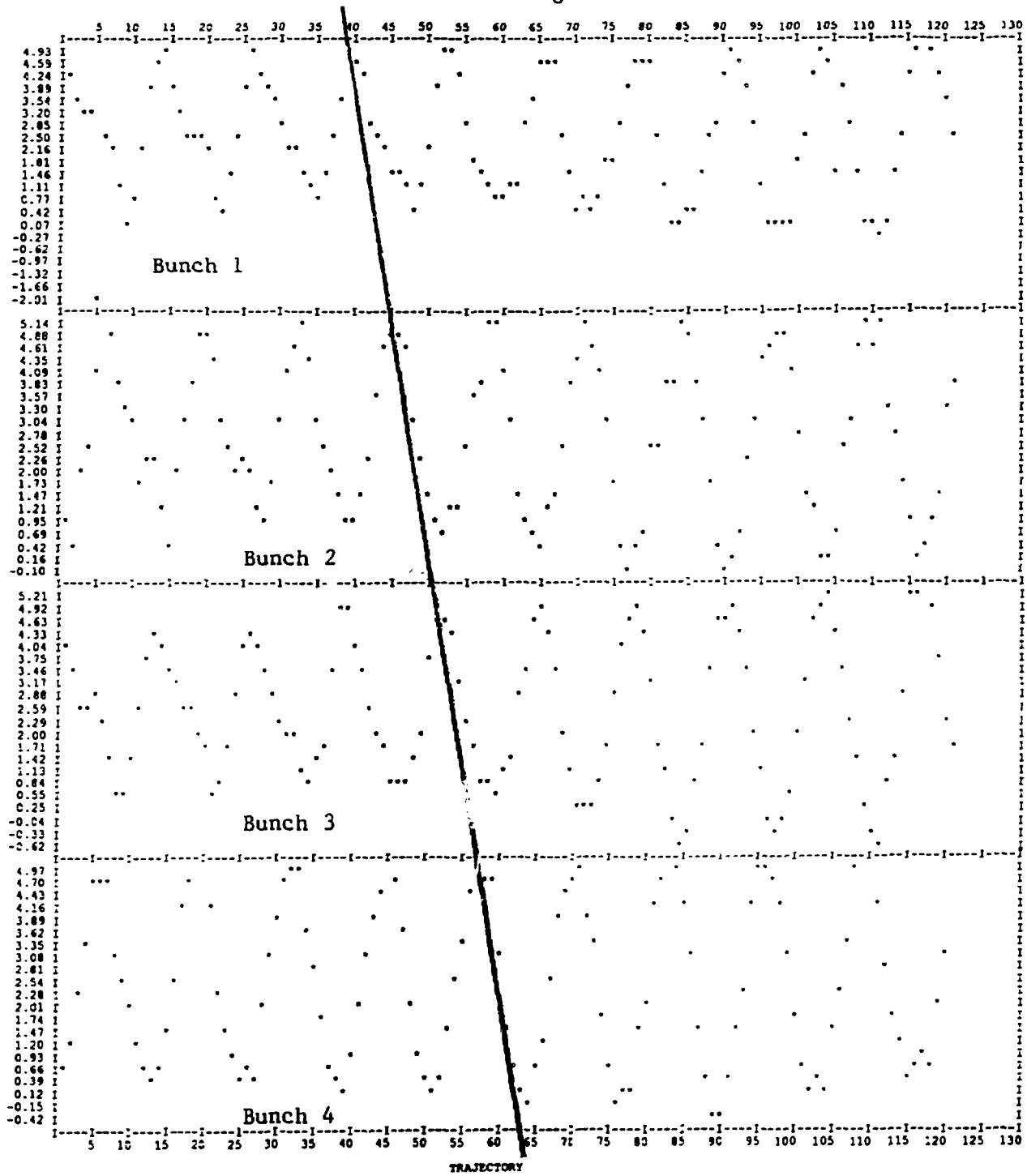
[2]F. Sacherer, "Bunched Beams," Theoretical Aspects of the Behavior of Beams in Accelerators and Storage Rings, CERN (Ettore Majorana, 198, (1976)



N	REAL	IMAGINARY
0	2.5363	0.0000
1	-0.0556	0.0152
2	-0.0279	-0.0131
3	-0.0370	-0.0224
4	0.0109	0.0208
5	-0.9999	0.6772
6	0.0322	0.0455
7	0.0400	0.0079
8	-0.0230	0.0421
9	-0.0452	0.0219
10	0.0272	-0.0448
11	0.0387	-0.0321
12	0.0032	-0.0240
13	0.0433	-0.0255
14	0.0324	0.0029
15	-0.0434	-0.0026
16	0.0133	0.0220
17	-0.0019	0.0207
18	-0.0267	-0.0146
19	-0.0056	0.0083
20	0.0087	0.0021
21	0.0137	0.0476
22	0.0129	-0.0019
23	0.0526	0.0040
24	0.0021	0.0080
25	-0.0228	0.0017
26	0.0023	-0.0006
27	-0.0504	-0.0232
28	0.0235	-0.0119
29	-0.0263	0.0065
30	0.0064	-0.0148
31	0.0211	-0.0021

N	(TUNE)	POWER
1	(0.9844)	0.0033
2	(0.9688)	0.0010
3	(0.9531)	0.0019
4	(0.9375)	0.0006
5	(0.9219)	1.4583
6	(0.9063)	0.0031
7	(0.8906)	0.0017
8	(0.8750)	0.0023
9	(0.8594)	0.0025
10	(0.8438)	0.0027
11	(0.8281)	0.0025
12	(0.8125)	0.0006
13	(0.7969)	0.0025
14	(0.7813)	0.0010
15	(0.7656)	0.0019
16	(0.7500)	0.0007
17	(0.7344)	0.0004
18	(0.7188)	0.0009
19	(0.7031)	0.0001
20	(0.6875)	0.0001
21	(0.6719)	0.0025
22	(0.6563)	0.0002
23	(0.6406)	0.0010
24	(0.6250)	0.0001
25	(0.6094)	0.0005
26	(0.5938)	0.0000
27	(0.5781)	0.0031
28	(0.5625)	0.0007
29	(0.5469)	0.0001
30	(0.5313)	0.0003
31	(0.5156)	0.0009

FOURIER TRANSFORM OF FIRST 64 POINTS IN TRAJECTORY

POWER SPECTRUM OF FOURIER TRANSFORM

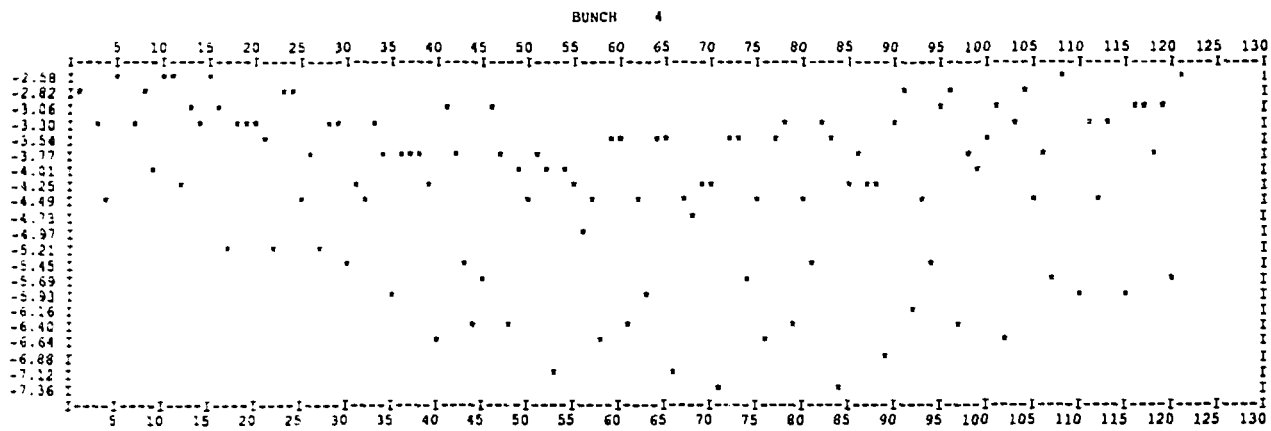
Figure 5.

The phase of any spectral component is the arctangent of the ratio of its imaginary-to-real parts, and the phase shift between bunches is the difference between the two phase angles. Table I shows the Fourier transforms for Bunches 1 - 3 plotted in Fig. 5. The principal line in the spectrum occurs at N=5, so for the first bunch the angle is 15.5° and for the second 171.4°. The phase shift is therefore 155.9°. Since there are twelve bunches in the AGS this means we are looking at the mode which corresponds to n=5. The data were taken 320 ms after t_o, so we can infer a peak in the transverse impedance at the frequency corresponding to this AGS energy and mode, 23.93 MHz.

Table I

	Bunch 1		Bunch 2		Bunch 3	
N	REAL	IMAGINARY	REAL	IMAGINARY	REAL	IMAGINARY
0	2.4862	0.3000	2.7600	0.0000	2.5150	0.0000
1	-0.1230	0.0177	-0.0381	0.0351	-0.0341	0.0202
2	-0.0750	-0.0161	-0.0166	0.0269	0.0163	0.0193
3	-0.0639	-0.0452	-0.0159	0.0145	0.0045	-0.0031
4	-0.0167	-0.0376	-0.0466	-0.0268	0.0631	0.0735
5	0.8343	0.2320	-0.9643	0.1459	0.8414	0.0265
6	0.0485	-0.0759	-0.0150	0.0989	-0.0707	-0.0695
7	0.0115	-0.0630	-0.0417	0.0251	-0.0579	-0.0187
8	-0.0222	-0.0180	-0.0302	0.0627	-0.0602	-0.0003
9	-0.0476	0.0576	-0.0909	0.0306	-0.0832	0.0213
10	0.3045	-0.0925	0.1103	-0.1708	0.0913	-0.2379
11	0.1110	0.0468	0.0702	0.0285	0.0218	-0.0293
12	0.0026	0.0801	0.0425	-0.0176	0.0235	-0.0286
13	-0.0183	0.0567	0.0287	0.0032	-0.0035	-0.0208
14	-0.0289	0.0695	0.0145	-0.0039	0.0598	0.0016
15	-0.0826	0.0260	0.0025	-0.0643	0.0126	-0.0123
16	-0.0859	-0.0184	0.0356	0.0138	-0.0175	-0.0066
17	-0.0599	-0.0307	-0.0171	0.0234	0.0270	0.0094
18	-0.0239	-0.0799	-0.0213	0.0401	0.0012	-0.0029
19	-0.0417	-0.0805	-0.0665	-0.0327	0.0100	0.0042
20	0.0291	-0.1035	0.0176	-0.0345	-0.0213	-0.0263
21	0.0376	-0.0503	0.0448	-0.0289	0.0344	0.0317
22	0.0146	-0.0457	0.0073	-0.0427	0.0017	-0.0237
23	0.0662	-0.0317	-0.0223	-0.0267	-0.0031	0.0036
24	0.0900	0.0335	-0.0054	0.0071	-0.0032	-0.0019
25	0.0712	0.0870	-0.0027	-0.0060	-0.0244	0.0136
26	0.0336	0.0818	0.0207	0.0035	0.0076	-0.0173
27	0.0519	0.0891	0.0143	-0.0011	0.0061	-0.0137
28	0.0082	0.0713	0.0483	-0.0319	-0.0171	-0.0292
29	0.0148	0.0800	0.0503	-0.0058	-0.0139	-0.0161
30	-0.0420	0.0578	0.0237	0.0249	0.0092	-0.0247
31	-0.0597	0.0535	0.0012	0.0182	-0.0177	0.0075

Finally, Fig. 6 shows data taken during an as yet not understood instability. Although the motion appears chaotic, the Fourier spectrum shows striking regularities. Perhaps further study will prove illuminating.



N	REAL	IMAGINARY
0	-4.0758	0.0000
1	0.1041	0.3775
2	0.0240	0.1545
3	-0.0090	0.0977
4	0.0438	0.1145
5	0.0424	-0.0037
6	-0.0021	0.0515
7	0.0234	0.0692
8	0.0627	0.0017
9	0.0388	0.0068
10	0.0796	0.0330
11	0.0894	0.0270
12	0.0320	0.0268
13	0.0911	0.0461
14	0.4035	-0.1204
15	-0.1870	-0.0058
16	-0.0409	0.0786
17	0.0125	-0.0080
18	-0.0487	0.0227
19	-0.0147	0.0716
20	0.0134	0.0217
21	-0.0259	0.0500
22	-0.0043	0.0486
23	0.0421	0.0800
24	0.0748	0.0529
25	0.3071	-0.4260
26	-0.0068	-0.0419
27	-0.0450	-0.0604
28	-0.0435	0.0125
29	0.0067	-0.0097
30	-0.0340	-0.0539
31	-0.0510	0.0262

N	(TUNE)	POWER
1	(0.9844)	0.1534
2	(0.9688)	0.0244
3	(0.9531)	0.0096
4	(0.9375)	0.0150
5	(0.9219)	0.0018
6	(0.9063)	0.0027
7	(0.8906)	0.0053
8	(0.8750)	0.0039
9	(0.8594)	0.0016
10	(0.8438)	0.0074
11	(0.8281)	0.0087
12	(0.8125)	0.0017
13	(0.7969)	0.0104
14	(0.7813)	0.1773
15	(0.7656)	0.0350
16	(0.7500)	0.0079
17	(0.7344)	0.0002
18	(0.7188)	0.0029
19	(0.7031)	0.0053
20	(0.6875)	0.0007
21	(0.6719)	0.0032
22	(0.6563)	0.0024
23	(0.6406)	0.0082
24	(0.6250)	0.0084
25	(0.6094)	0.1815
26	(0.5938)	0.0018
27	(0.5781)	0.0057
28	(0.5625)	0.0021
29	(0.5469)	0.0001
30	(0.5313)	0.0041
31	(0.5156)	0.0033

FOURIER TRANSFORM OF FIRST 64 POINTS IN TRAJECTORY

POWER SPECTRUM OF FOURIER TRANSFORM

Figure 6.

IV. CONCLUSION

I believe that the IBCM has proved itself a useful aid in better understanding AGS behavior. Since it is now integrated into the Apollo control system, it is hoped that it will be helpful to others. Increasing the frequency response of the PUE system to at least 200 MHz and replacing the 100 MHz transient recorders with state-of-the-art 1 GHz units would enable the IBCM to detect the effects of finite chromaticity on coupled-bunch oscillations.

V. ACKNOWLEDGMENTS

It is a pleasure to thank some of the people who helped me:

Sue Kennell wrote the IBM-PC code which connects my FORTRAN to the Apollo/RELWAY world and Tom Clifford wrote the code which reconnects to FORTRAN on the Apollo end. Both of these people endured my often uninformed pestering, and I am grateful. Elliot Auerbach was a living reference manual for the Apollo system.

Discussions with Gene Raka elucidated some of the subtle (and not so subtle!) points of machine theory of which I was ignorant. Willem van Asselt bugged me about the test with the tune meter until we did it. Ed Gill made sure I got the signals I needed, while John Post and Carl Eld strung many of the cables which conduct these signals to where they are wanted.

APPENDIX A: RUNNING THE IBCM

Running the IBCM involves getting the electronics in the K-18 House going, starting the IBM-PC there, establishing a timing "stop" signal, and connecting to an Apollo node.

In the K-18 House

Please refer to Fig. 1 for a logical plan of the apparatus.

1. Turn on the power for the CAMAC crate, the NIM crate, and the IBM-PC. Make sure that all voltages come up.

2. Set the CAMAC crate Controller to "off line" and initialize the dataway. Return the Controller to "on line."

3. The IBM-PC should display the prompt "C\BUNCHMON>." Type "BUNCH2 [carriage return]," the name of the resident program.

4. The computer screen should display:

```
INITIAL STATUS = 0100 0001 0000
WAIT
GOGO
```

This means that the IEEE interface to RELWAY is alive and that the system is awaiting commands from an Apollo node via RELWAY.

In the AGS Control Room

Arrange to have a standard 15 V "stop" signal hooked up to the dedicated line running to the K-18 House. (You will probably get this from a predet.) Remember that the interval being digitized begins at "stop" and lasts for 320 microseconds.

At An Apollo Node

Log on. From the area YAMIN/HOME/USER get the executable files READBUNCHMON and TURNS3.

To begin digitizing, type:

READBUNCHMON > filename [carriage return],

where the "filename" is the name of the Apollo file in which the results of the digitization are to be stored. Digitizing begins and continues until the IBCM receives a "stop" signal. It will take about a minute for the computer in the K-18 House to complete the preliminary analysis and to transmit the data back for storage in "filename." (The IBCM is now ready for collecting more data. You may proceed again as above or continue with the analysis.)

To continue the analysis, type:

TURNS3 < filename [carriage return]

This applies the Fourier analysis to the data in "filename," and produces the plots described in Section II of this report. Using standard Apollo data manipulation techniques, you can copy all or part of the final output file to a laser printer.