ON-LINE COMPUTER PREPARATION OF TUNE PROFILES OF THE ZERO GRADIENT SYNCHROTRON*

Martin J. Knott, David H. Nordby, and Carl A. Swoboda
Argonne National Laboratory
Argonne, Illinois

Introduction

A useful tool in the operation of a circular accelerator is the tune profile. This graph of betatron oscillation frequency versus beam position is often invaluable in the study of beam dynamics when resonances are suspected. The data gathering, handling, and presentation capabilities of the Zero Gradient Synchrotron (ZGS) control computer are used to present operators and machine researchers with tune profiles measured under injection conditions. The basic information signals for both vertical and radial positions are obtained from diagonally split induction electrodes. These signals are converted to digital form and transmitted to the computer by a high-speed buffer storage system. The periodic variations in position are detected and the tune calculated for each oscillation. Both radial and vertical tune profiles can be presented to the operator as fast as they can be plotted on an on-line digital plotting system.

Data Acquisition

To make coasting tune measurements, a 1 μs chopped beam is injected into the ZGS and allowed to coast without acceleration until it hits the inside wall of the vacuum chamber. Since the time taken to go around the ring at the injection energy is about 2 μs, the beam forms a "sausage" about half the ring circumference in length.

Once each turn, the beam passes through the split induction electrode shown in Fig. 1. This electrode is a conducting box split both diagonally on the top and bottom, and longitudinally on each side. Because of the beam's proximity either in time or position to the various elements of the electrode, it is possible to find its position both radially and vertically on each turn around the machine [1] For instance, the signal obtained by connecting sections B and D together can be subtracted from the signal obtained from A and C to obtain radial position information. Similarly, CD can be subtracted from AB to obtain vertical position information.

*Work performed under the auspices of the U. S. Atomic Energy Commission

Normally, all four signals would be added to obtain a signal used to normalize the position signals because of the latter's sensitivity to beam intensity. However, in the case of tune measurements where only the frequency of the beam oscillations is important, this sum signal is useful only in providing a reliable trigger to control the sampling of the difference signals. Figure 2 is an example of a radial beam position photograph showing the first 50 μs of coasting beam. Previously, numerous photographs, such as this one, would be measured by hand and the calculations performed with a desk calculator. The disadvantages of such a procedure are numerous and obvious.

Data Conversion

A high-speed data conversion and buffer storage system is used to convert the electrode signals to digital form. A block diagram of the major components utilized in this application and trigger circuits is shown in Fig. 1. The electrode connection is that used for radial tune measurements. The positive offset shown at the input to the difference amplifier is necessitated by the converter, which has a one quadrant (+ only) input. The leading edge of the sum signal provides a trigger which is then delayed by 500 nanoseconds so that all measurements are made in the center of the difference signal pulses. A 1 μs delay provides an additional trigger so that both the signal pulse itself and the base line can be measured. The computer will later find the difference between these two measurements in order to restore the base line and be able to detect the point at which the beam crosses the chamber centerline.

The analog to digital converter used is a modified, high-speed, 8-bit (0.25%) parallel output unit. It works into a storage system employing 10 Mc/s clocked logic with parallel quartz delay lines 200 μs in length as the memory element. Since an asynchronous data source is being sampled, the delay lines can only be filled once, limiting the measurement aperture time to 200 μs. Since various guide field programs can extend the survival time of a coasting beam out to 350 μs, a preset counter is provided so that as many turns as desired can be skipped before data taking is begun. In this way, the results of two separate accelerator cycles can be "patched" together to form a complete tune profile.

Transmission to Computer

The processor used is the ZGS control computer, a Control Data 924-A computer with a memory cycle time of 4 μs, a core capacity of 32,000 words, and a specially modified high-speed I-O channel. The buffer storage system is controlled and communicated with by the means of a data I-O system called the ZGS Monitor. This control and communication is synchronized by the ZGS Programmer, the timing and control element of the Accelerator [2]. The Monitor, using the Programmer gauss and real time clocks, sends a "Master Clear" code and other mode control codes at the proper times.

A few milliseconds after injection, a "Transmit Data" code is sent to initiate transmission of the stored data from the buffer to the control computer. The data words are then transmitted serially at a word rate of 10 kc/s until the buffer memory is empty.

Calculation of Tune

Once in the computer, the data is organized according to turn number and the aforementioned base line subtraction is performed. At this time, the beam position (unnormalized) and turn numbers are printed along with a position versus turn graph. This printout is optional and is used by the operator to assess the data quality. An example is shown in the upper half of Fig. 4.

To calculate tune, it is necessary to determine how far the beam travels in each betatron oscillation cycle. Since the beam position is sampled at only one point on the circumference of the Accelerator, curve fitting must be used to find the points at which the oscillation repeats.

Although the sampled beam position curve is essentially a portion of a sinusoid (due to purposely induced radial and vertical oscillations), noise as well as varying amplitude, frequency, and base line offset make conventional curve fitting of the entire waveform far too time-consuming if at all possible. The method employed is to locate the peak and valley areas of the sinusoid and to apply a vertical-axis parabolic fit to the few points in this area. Since only the turn axis values of the maximum (or minimum) points are desired, the resulting fit formula is extremely simple. Once these turn values are found, the difference between adjacent maximas and adjacent minimas are applied in the tune formula:

$$\nu = \frac{N - 1}{N} ,$$

where N = number of turns per betatron oscillation cycle.

The turn value for each betatron oscillation is plotted at the average of the two turn values (maxima pair or minima pair) taking part in the above calculation. Because the tune is calculated for both maxima differences and minima differences of the sinusoid, approximately twice as many tune points are found as there are oscillations in beam position across the chamber width. This results in from 30 to 40 points per complete profile.

Data Presentation

These sets of turn and tune values are now printed (see Fig. 4) and at the operator's option, a precise plot is provided. An on-line digital point plotter is used and produces a tune graph in about 20 to 30 seconds. An example of a complete tune profile, including both vertical (Y) and radial (X) tune values, is shown in Fig. 3. Since the beam is moving across the chamber at a nearly uniform rate as the data is taken, the turn axis can be related to the radial position in the chamber.

The X and Y tune profiles are obtained by identical methods and plotted with different symbols. A complete set of profiles are produced in a few minutes, and it has been found that any desired tune relationship can be obtained in a short time by adjusting field correcting magnets in the ring and observing the changes in the tune profiles.

Since the data gathering and processing takes only a few tenths of a second, it will be possible, using a CRT data display device (now under development for the ZGS control computer), to provide nearly instantaneous feedback of this information, making available a valuable man-machine interactive link.

Acknowledgment

The authors would like to acknowledge the work of A. A. Brescia in the experimentation, development, and preparation of the software used.

References

[1] A. J. Sherwood, "Electrostatic Induction Electrode Systems for Beam-Position Detection," IEEE Transactions on Nuclear Science, Vol. NS-12, No. 3 (June 1965), p. 925.

[2] L. G. Lewis, "Computer Control of High Energy Accelerators," IEEE Transactions on Nuclear Science, Vol. NS-12, No. 3 (June 1965), p. 1.

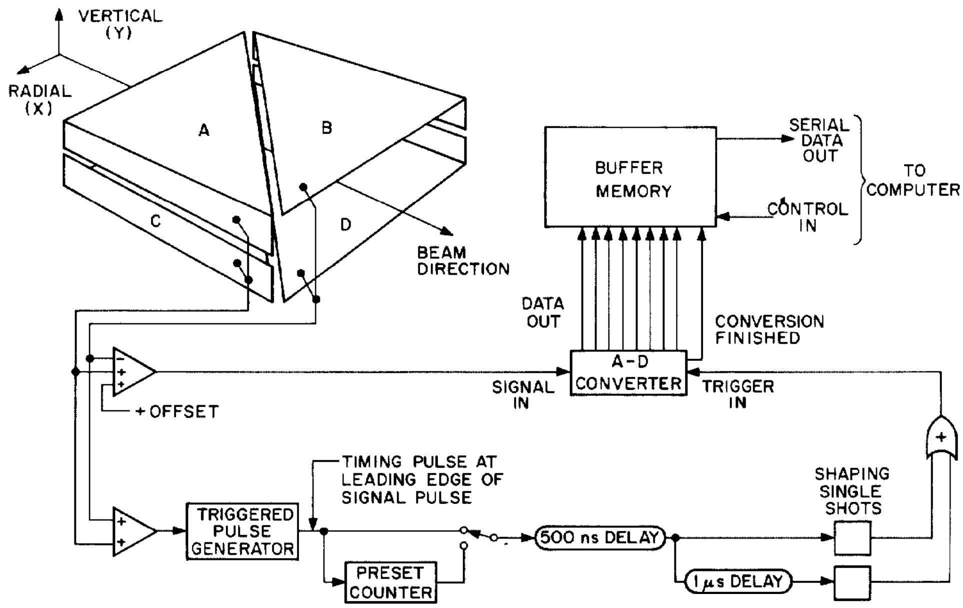


Figure 1
General Block Diagram Showing the Beam Position Electrode and Data Acquisition System Components

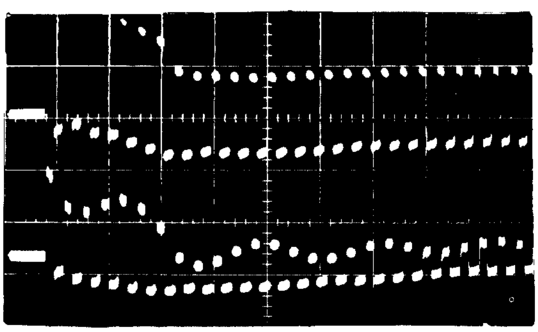


Figure 2
Radial Beam Position Photograph Showing the Sum (Top) and Difference (Bottom) Signals during the First 50 μs of Coasting Time

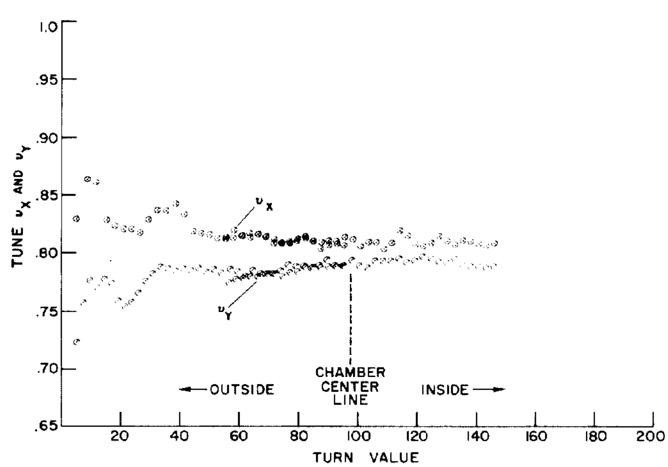
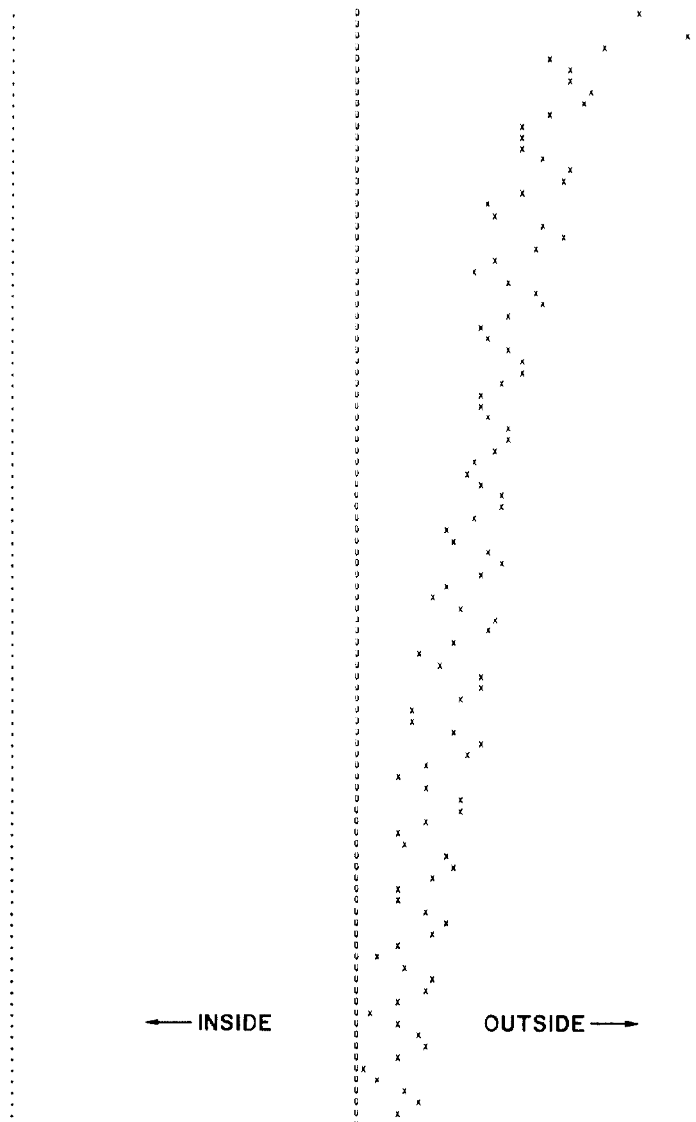


Figure 3
Final Computer-Produced Tune Profile

SET 7
SCALE RANGE IS -180 TO 180
DATE 10/10/66

TURN NO.	A-B
1	146
2	180
3	171
4	128
5	101
6	113
7	113
8	122
9	117
10	100
11	88
12	87
13	87
14	96
15	110
16	107
17	87
18	68
19	72
20	96
21	109
22	95
23	72
24	60
25	78
26	95
27	96
28	79
29	65
30	67
31	78
32	86
33	85
34	75
35	66
36	66
37	69
38	78
39	78
40	71
41	60
42	56
43	64
44	76
45	76
46	60
47	48
48	50
49	67
50	76
51	66
52	46
53	40
54	54
55	73
56	69
57	50
58	33
59	43
60	63
61	66
62	53
63	29
64	28
65	49
66	63
67	56
68	36
69	23
70	36
71	54
72	55
73	36
74	20
75	26
76	45
77	50
78	38
79	20
80	20
81	35
82	45
83	38
84	20
85	12
86	24
87	36
88	36
89	20
90	6
91	20
92	32
93	35
94	20
95	5
96	9
97	25
98	31
99	20
100	5



TUNE	TURN VALUE
.029	5.217
.063	8.846
.061	11.733
.028	15.413
.023	18.152
.021	21.113
.021	23.769
.017	26.638
.029	29.472
.037	32.437
.036	35.444
.042	38.667
.033	41.500
.019	44.595
.017	47.237
.016	50.079
.013	52.650
.012	55.465
.013	58.007
.015	60.838
.017	63.427
.017	66.273
.014	68.858
.009	71.614
.009	74.172
.010	76.864
.011	79.441
.015	82.200
.011	84.732
.004	87.450
.011	90.021
.011	92.645
.007	95.260

← FINAL TUNE DATA

Figure 4
Line Printer Output Showing Sampled Beam Position Versus Turn Number (Top) and Corresponding Computer Calculated Tune Data (Bottom)