1985 Particle Accelerator Conf., Vancouver, B.C., Canada, 5/13-16/85.

A METHOD FOR DETERMINING THE POSITION, ANGLE AND OTHER INJECTION PARAMETERS OF A SHORT PULSED BEAM IN THE BROOKHAVEN AGS*

BNL--36490

DE85 012523

RECEIVED BY OSTI JUN 06 1985

C. Gardner and L. Ahrens
AGS Department, Brookhaven National Laboratory
Upton, New York 11973

I. Introduction

As part of the effort to improve the monitoring of the injection process at the Brookhaven Alternating Gradient Synchrotron (AGS), we have developed a beam diagnostics package which processes the signals from the plates of a pick-up electrode (PUE) located near the injection region of the AGS and provides measurements of the position and angle (with respect to the equilibrium orbit) of the injected beam at the stripping foil where the incident H^- beam is converted into protons. In addition the package provides measurements of the tune and chromaticity of the AGS at injection, and a measurement of the momentum spread of the injected beam. Since these parameters are obtained for a short-pulsed beam at injection we shall refer to the diagnostics package as PIP which stands for Pulsed Injection Parameters.

II. PUE Signal Processing

To obtain signals from which one can deduce the injection parameters, a ~2.4μs pulse of H^- is injected into the AGS and the resulting bunch of protons is observed with a PUE for approximately 40 turns around the machine. A schematic diagram of the PUE and associated electronics is shown in Fig. 1. The PUE consists of four plates and is located approximately one superperiod downstream of the injection region. As the proton bunch circles around the machine it produces in each plate a train of some 40 pulses, each pulse corresponding to the passage of the bunch through the PUE on a given turn. The signals from the upper and lower plates yield the vertical displacement of the bunch with respect to the beam pipe center, while the signals from the inner and outer plates yield the horizontal (radial) displacement. Since the period of revolution for a proton in the AGS is ~4.8 μs at injection (200 MeV), a 2.4 μs wide bunch of protons will produce in each plate pulses which are ~2.4 μs wide and are separated from each other by ~2.4 μs. The pulse trains from the four plates are amplified (unity voltage gain) in the AGS ring, transmitted 1700 feet on coaxial cables, voltage amplified x10 and then digitized using LeCroy (#TR8837F) digitizers which sample the signals every 250 ns. The digitized data are analyzed with appropriate software to determine the amplitude of each pulse. If we let A_n and B_n respectively be the amplitudes of the pulses from the upper and lower plates or from the outer and inner plates of the PUE on the nth turn, then the vertical or horizontal displacement, Y(n), of the bunch on the nth turn is

$$Y(n) = C\,\frac{A_n - B_n}{A_n + B_n} \qquad (1)$$

where C=5.0 cm is—to first order—a constant which depends only on the geometry of the PUE. Substituting the pulse amplitudes determined from the digitized PUE signals into equation (1) we then obtain a set of values of Y(n) which gives the measured position of the bunch as a function of turn.

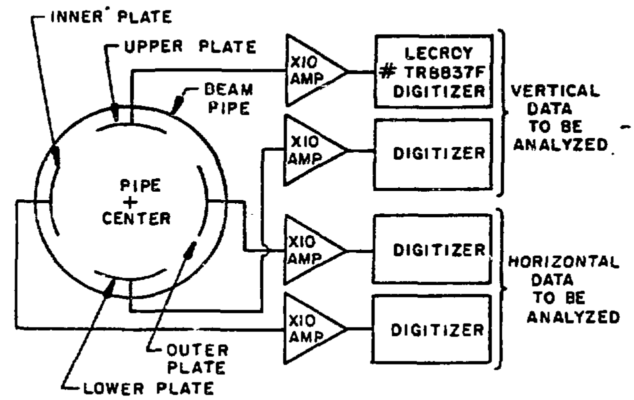

Fig. 1. PUE and Electronics

III. Analysis of Position-vs-Turn Data

Analysis of the position-vs-turn data given by Eq. (1) requires the development of a theoretical expression for the bunch position. This expression will be some function of the injection parameters of interest; a least-squares fit of the expression to the observed Y(n) will yield these parameters.

To develop the expression we consider the position at the PUE of the ith proton in the bunch on the nth turn around the machine:

$$Y_i(n) = \eta_i + A_i \cos(2\pi n\nu_i + \phi_i) \qquad (2)$$

where η_i is the position of the equilibrium orbit (E.O.) about which the ith proton is undergoing betatron oscillations, A_i and ϕ_i are the amplitude and phase of these oscillations, and ν_i is the tune of the ith proton. If we assume that A_i, ϕ_i, ν_i are uncorrelated then the average of $Y_i(n)$ over the bunch (which is what is measured by the PUE) is

$$Y(n) = \eta + A\int d\nu f(\nu)\cos(2\pi n\nu + \phi) \qquad (3)$$

where η is the position of the E.O. about which the bunch as a whole oscillates, A and φ are the amplitude and the phase of these oscillations, and f(ν) is the tune distribution of the protons in the bunch. We shall take f(ν) to be the Gaussian distribution

$$f(\nu) = \frac{2}{\Delta\nu\sqrt{2\pi}} \exp\{-2(\nu-\nu_o)^2/(\Delta\nu)^2\} \qquad (4)$$

of width Δν and with center at ν_o. Putting (4) into (3) and doing the integration we find

$$Y(n) = \eta + A\exp\{-\tfrac{1}{2}(\pi\Delta\nu n)^2\}\cos(2\pi\nu_o n + \phi). \qquad (5)$$

Thus the tune of the coherent oscillations of the bunch about the E.O. position η is ν_o and these oscillations are damped by an exponential term whose strength depends on the tune spread Δν.

* Work performed under the auspices of the U.S. Dept. of Energy.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

We must now take into account the fact that the B-field of the AGS is ramping at injection, which means that the E.O. will move in (radially) by an amount $\delta\eta$ and the tune will shift by an amount $\delta\nu$ during each turn of the bunch around the machine. These shifts may be introduced into Eq. (5) by replacing ν_0 with $\nu_0 + n(\delta\nu/2)$ and η with $\eta + n\delta\eta$. Thus the expression for the bunch position on the nth turn becomes

$$Y(n) = \eta + n\delta\eta + A \exp\{-\tfrac{1}{2}(\pi\Delta\nu n)^2\} \cos[2\pi(\nu_0 + \tfrac{n\delta\nu}{2})n + \phi] \quad (6)$$

For a given set of values of Y(n) obtained from the PUE signals, the values of the seven parameters which appear in (6) are obtained from a Least-Squares fitting code which fits the function (6) to the observed data. Figures 2 and 3 are typical plots of data points Y(n) and the corresponding fitted curves which show respectively the horizontal and vertical positions of the bunch as functions of turn. The parameters of the fitted curves and their statistical uncertainties, are listed in Table 1. We note that since the position-vs-turn data yields only the non-integer part of the tune we must assume that the tune is between 8.5 and 9.0 (which is normally the case for the AGS) to obtain the tunes listed in the table. We also note that the determination of the parameters ν_0, $\Delta\nu$, $\delta\nu$, and ϕ from the position-vs-turn data requires that the amplitude of the oscillations of the bunch about the E.O. be nonzero and in general as the amplitude of the oscillations becomes smaller the determination of these parameters becomes less precise.

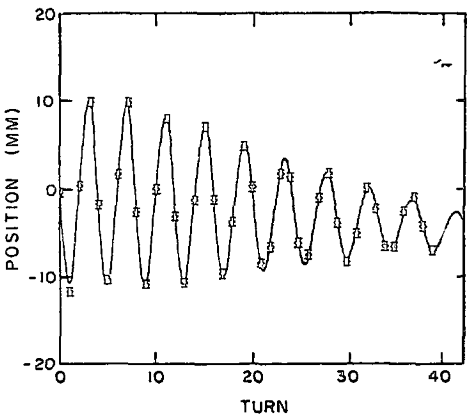

Fig. 2. Horizontal Position vs Turn

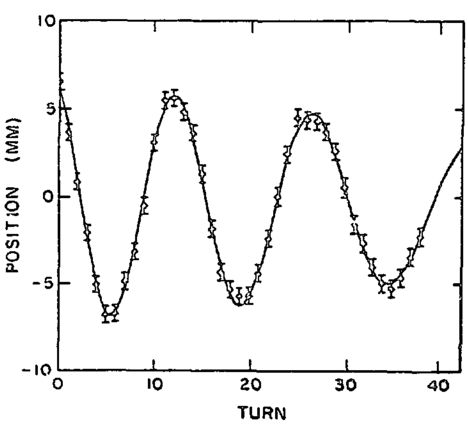

Fig. 3. Vertical Position vs Turn

TABLE 1. Fitted Parameters for Figures 2 and 3.

Parameter		Horizontal Data (Fig. 2)	Vertical Data (Fig. 3)
Tune:	ν_0	8.742(1)	8.917(1)
Tune spread:	$\Delta\nu$	0.0139(4)	0.0079(7)
Tune shift per turn:	$\delta\nu$	+0.00112(4)	+0.00070(6)
Phase:	ϕ	0.251(5) x 2π	0.050(9) x 2π
Amplitude:	A	10.7(2) mm	6.6(2) mm
E.O. position at PUE:	η	-0.1(1) mm	-0.3(2) mm
Shift of E.O. per turn:	$\delta\eta$	-0.111(6) mm	-0.005(8) mm

Note: The numbers shown in parentheses are the one-standard-deviation errors in the last digit of fitted parameter values.

IV. Position and Angle at the Foil

If the values of the AGS Twiss parameters at the PUE are known then the fitted parameters allow for a determination of not only the position but also the angle of the bunch with respect to (wrt) the E.O on each pass through the PUE after being injected into the machine. In particular the position and angle (wrt the E.O.) on the first pass through the PUE are

$$Y(PUE) = A \cos\phi \quad (7)$$

$$Y'(PUE) = -(A/\beta)[\alpha \cos\phi + \sin\phi] \quad (8)$$

where (7) is obtained by setting n=0 (first pass) in equation (6) and α and β are the values of the Twiss parameters at the PUE. We are of course primarily interested in the position, Y(foil), and the angle, Y'(foil), (wrt the E.O.) at which the bunch is injected into the machine at the foil. These are given in terms of Y(PUE) and Y'(PUE) by

$$\begin{pmatrix} Y(foil) \\ Y'(foil) \end{pmatrix} = M^{-1} \begin{pmatrix} Y(PUE) \\ Y'(PUE) \end{pmatrix} \quad (9)$$

where M is the transfer matrix from the foil to the PUE.

To obtain M and the values of the Twiss parameters at the PUE, a computer code[1,2] which models the AGS and employs detailed maps of the midplane fields of the AGS magnets is used. In general the values of α, β, and M calculated by the code will differ from those of the actual machine, depending on how the machine is modeled, and the extent to which they differ is reflected by systematic errors in the values of Y(foil) and Y'(foil) obtained from (9). By varying parameters of the model in the code we are able to estimate that these errors are of order ±1.0 mm in Y(foil) and ±0.1 mrad in Y'(foil).

Since Y(foil) and Y'(foil) are the position and angle wrt the E.O., the ability of our diagnostics package (PIP) to measure their values can be tested by varying the position and angle of the E.O. at the foil and noting the changes in values of Y(foil) and Y'(foil) obtained from (9). A set of low-field correction dipoles located near the injection region was used to vary the position and angle of the E.O. at the foil and the resulting values of Y(foil) and Y'(foil) are plotted in Figures 4 and 5.

Figure 4 shows that as the radial position of the E.O. at the foil is incremented (while keeping the angle of the E.O. fixed) Y(foil) decreases linearly with the increment and Y'(foil) remains constant. Similarly Fig. 5 shows that as the angle of the E.O. at the foil is incremented (while keeping the position of the E.O. fixed) Y'(foil) varies linearly and Y(foil) remains constant. This demonstrates that the values of Y(foil) and Y'(foil) determined by PIP vary linearly and independently as the position and angle of the E.O are varied independently. In addition, the amount by which Y(foil) changes was found to be equal (within the measurement uncertainty) to the change in the E.O. position.

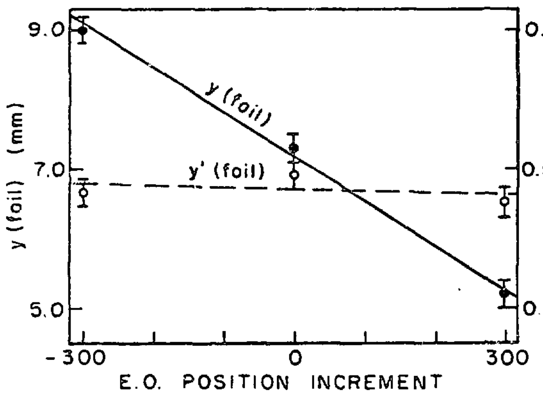

Fig. 4. Y(foil) and Y'(foil) vs E.O. Position

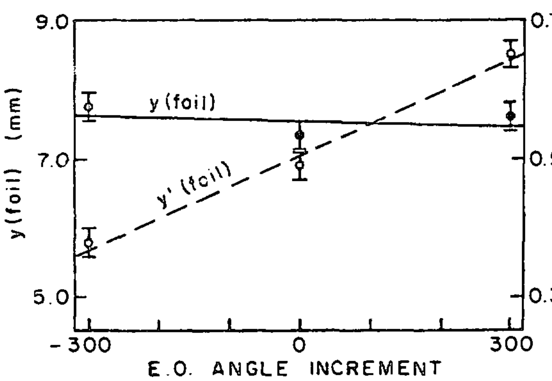

Fig. 5. Y(foil) and Y'(foil) vs E.O. Angle

V. Tune, Chromaticity, and Momentum Spread

Although the tune provided by PIP is not what one would measure for high beam intensities where wall currents and space-charge effects become important, it is nevertheless a useful parameter for characterizing the state of the machine at injection. The typical precision with which the tune can be determined is as indicated in Table I. As a test of the tune measurement the low-field quadruples in the AGS ring, used for shifting the tune at injection, were varied and the corresponding changes in the measured tune were noted. A calculation of the expected tune shifts was found to agree with the measured changes.

The measured tune ν_o may also be used along with the fitted parameter $\delta\nu$ (which is the tune-shift per turn due to the ramping B-field at injection) to obtain a value for the chromaticity at injection. If ΔB is the change in the B-field per turn and B_o is the magnitude of the B-field at injection then the chromaticity, ξ, is just

$$\xi = -\frac{\delta\nu/\nu_o}{\Delta B/B_o} \quad . \qquad (10)$$

Putting the values of ν_o and $\delta\nu$ from Table I into (10) and using the measured values of $\Delta B = .0207$ G and $B_o = 250$ G we then find that the horizontal (ξ_H) and vertical (ξ_V) chromaticities for the data plotted in Figures 2 and 3 are -1.5(1) and -0.9(1) respectively. As a check of the ability of PIP to correctly determine the chromaticity, the current in a series of 16 sextupoles was varied and the resulting changes in the measured chromaticity were compared and found to agree with a calculation of the expected shifts due to the sextupoles. Figure 6 shows the measured horizontal and vertical chromaticities as functions of sextupole current.

The value of the chromaticity obtained from $\delta\nu$ and ν_o can be used with the fitted parameter $\Delta\nu$ to obtain an estimate of the momentum spread, ΔP, of the injected beam in the AGS. Since $\Delta\nu$ is the spread in the tunes of the protons in the bunch due to the momentum spread, we have

$$\Delta P/P = (\Delta\nu/\nu_o)/\xi \qquad (11)$$

Putting the relevent numbers from Table I into (11) we find $\Delta P/P = .0010(1)$ which is consistent with independent measurements of the momentum spread.

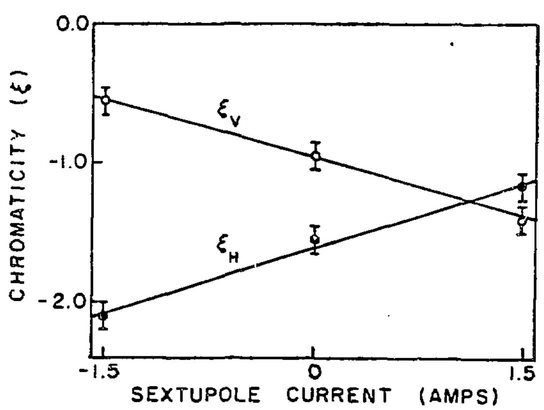

Fig. 6. Chromaticity vs Sextupole Current

References

1. E.D. Courant, Computations of AGS Orbits with 704 Computer, Brookhaven National Laboratory, Accelerator Department Internal Report EDC-36, Jan. 7, 1960.
2. G.H. Morgan, Fortran IV Revision of BEAM, the AGS Oribt Computing Program, Brookhaven National Laboratory, Accelerator Department Internal Report GHM-I, June 1, 1966.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.