BNL-104094-2014-TECH

AGS.SN218;BNL-104094-2014-IR

Polarized Proton Quad Positions I

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December 1986

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U.S. Department of Energy

USDOE Office of Science (SC)

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1/8/87

Number 218

AGS Studies Report

Date(s) December 18, 1986 Time(s) 0800 - 1600

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Reported by L. Ahrens

Subject Polarized Proton Quad Positions I

Motivation

The beam transverse emittance both horizontal and vertical is seen to increase dramatically (nearly tenfold) if the polarized proton quadrupoles are pulsed in the normal fashion to avoid depolarizing resonances as the beam is accelerated. The cause for the blowup is not yet understood, but a prime candidate because the pulse is non-adiabatic is the misalignment between beam and quad centers. This study was a first step in determining the significance of this misalignment and correcting it if possible.

Procedure

Individual quads were pulsed (6 were available) and the resulting distortions in the equilibrium orbits (horizontal and vertical) were measured. The amplitude and phase of the distortions then gave a measure of the lack of alignment between quad and orbit. In addition to offset, the amplitude depends on momentum, quad current, and machine betatron tune, all of which were measured for each point. In order to get a calibration from the machine, a first run was carried out using a single quad at low momentum where the beam position could easily be adjusted in the quad using correction magnets. Then all the available quad kicks were documented at a reasonably high momentum. Following this, one quad was actually physically moved by 1 mm and the resulting change in orbit measured. Finally a series of documentation orbits were taken at an intermediate momentum.

Figure 1a gives a typical equilibrium difference orbit (quad on - quad off) this at 1 GeV/c, a pulse in the A15 quad, and with the unperturbed orbit at its nominal position. Figure 1B is taken under identical conditions except the quad is not pulsed. The difference orbit is seen to contain the usual residuals from a kick at A15. The

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***** DIFFERENCE DATA USING FILE PPREF*****   N     COS     SIN    AMP
NORM BY L20CT = 369   REFER L20CT = 321       1    0.00    0.00   0.004
AVERAGE DIFF=  0.010                          2   -0.00   -0.00   0.005
A  0.05                0.01 -0.04 -0.03 A     3    0.00   -0.00   0.004
B        0.08          0.01  0.01 -0.09 B     4    0.01    0.02   0.017
C              0.02    0.09  0.09       C     5   -0.00    0.01   0.010
D             -0.03   -0.02  0.02  0.09 D     6   -0.00   -0.00   0.002
E  0.10  0.07 -0.01   -0.05 -0.11 -0.07 E     7   -0.01    0.01   0.009
F -0.01  0.04          0.04  0.01  0.00 F     8   -0.01   -0.01   0.011
G -0.04 -0.09 -0.02    0.05  0.10       G     9    0.06    0.02   0.062
H -0.01                     -0.02  0.04 H    10   -0.00    0.00   0.005
I  0.07  0.06         -0.07 -0.05 -0.02 I    11   -0.00    0.01   0.010
J  0.01  0.07  0.05    0.08  0.04 -0.02 J    12    0.00    0.00   0.005
K       -0.03          0.05 -0.01  0.06 K
L  0.03 -0.05 -0.02         -0.06  0.04 L
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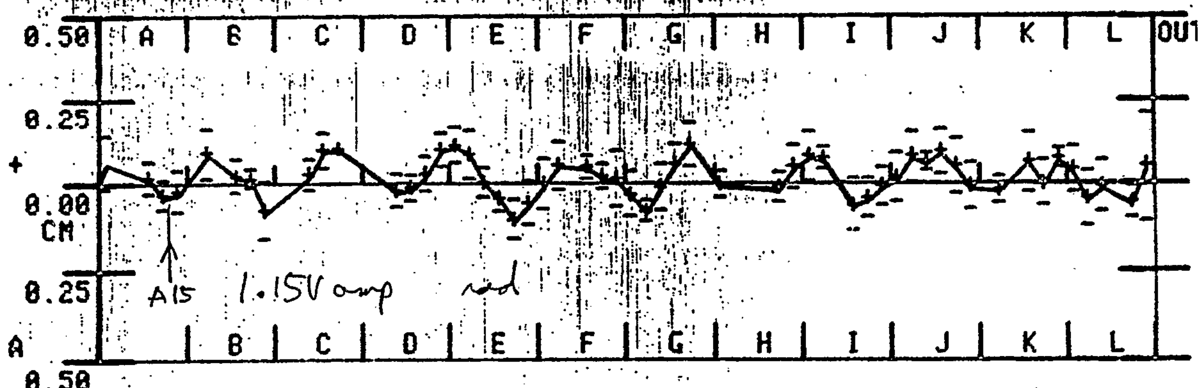

R(RESTART),E(EXIT),S(SAVE FILE),N(NO OUTPUT),L(LOOP),C(NORMC),<CR>(LOO
NCE):

Figure 1a P↑ quad kick at A15

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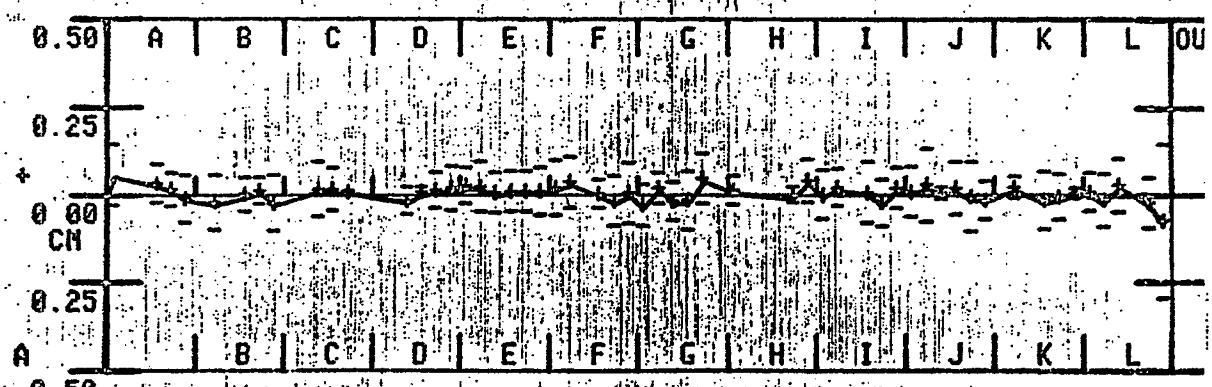
***** DIFFERENCE DATA USING FILE PPREF*****   N     COS     SIN    AMP
NORM BY L20CT =  321  REFER L20CT =  321      1   -0.00   -0.00   0.005
AVERAGE DIFF= -0.003                          2    0.00   -0.00   0.003
A  0.05                0.02  0.01 -0.02 A     3    0.01    0.00   0.009
B       -0.03         -0.01  0.00 -0.03 B     4    0.00    0.00   0.003
C              0.01    0.01  0.00       C     5    0.01    0.00   0.007
D             -0.03   -0.00  0.00  0.01 D     6   -0.00    0.01   0.009
E  0.02  0.01 -0.00    0.00  0.00  0.00 E     7    0.00    0.01   0.009
F  0.01  0.03         -0.01 -0.03 -0.00 F     8   -0.01    0.00   0.011
G -0.04  0.01 -0.03   -0.03  0.04       G     9    0.01    0.01   0.011
H  0.00                     -0.01  0.03 H    10   -0.01    0.00   0.008
I -0.01  0.01         -0.00 -0.03  0.01 I    11   -0.01    0.01   0.013
J  0.00  0.02 -0.00    0.01 -0.01 -0.02 J    12   -0.00    0.01   0.007
K        0.01         -0.02 -0.01 -0.00 K
L  0.00 -0.02  0.02         -0.03 -0.08 L
```



R(RESTART),E(EXIT),S(SAVE FILE),N(NO OUTPUT),L(LOOP),C(NORMC),<CR>(LO(
NCE):

Figure 1b P↑ quad off

dominant harmonic in the residual is 9 (closest integer to the tune) and since harmonic analysis of the orbit is available, we simply use the reported amplitudes to measure the effect--here ($0.06 \cos 9\theta + 0.02 \sin 9\theta$) cm. The cosine term dominates and this amplitude is plotted against the beam position at A14 PUE as the beam is varied radially and vertically in Figure 2. Also shown are the amplitudes measured for orbit shifts with no quad pulse. One point here is that the radial shift itself is not causing the variation in the 9th. A null effect occurs with the beam at about + 0.2 cm horizontally and - 0.1 cm vertically in A14 PUE with the precision set by the reproducibility of the PUE array (Fig. 1b) (and/or of the machine). The effect is not linear with A14 position over more than 2 mm. The non-linearity is not yet understood. To fit the PUE difference result to an equilibrium orbit distortion due to a kicker at the powered quad would greatly improve the signal to noise. This will be tried in the future.

The data plotted in Figure 2 yield (eye fit) a value of K_o = - 0.25 (cm of 9th/cm of orbit-quad offset) horizontally and + 0.4 vertically. Given that the quad is at a vertical β maximum (horizontal β minimum) and the PUE used for position measurement is at a β average, these slopes should differ by a factor $\beta_{max}/\beta_{min} \simeq -2$. For our calibration work, since the horizontal is better determined we use that value. Reviewing, we measure that a 4 cm offset measured at a β_{avg} (PUE) produces 1 cm of 9th horizontally and a 2 cm vertical offset produces 1 cm of 9th vertically. This is at 1 GeV/c, with a 345 Amp pulse in the A15 quad, and with tunes (H,V) of 8.698 and 8.783 (quad on). Now these numbers can be transformed to other momenta (K') and tunes:

$$K_1 = K_o \left(\frac{P_o}{P_1}\right) \left(\frac{I_1}{I_o}\right) \left(\frac{\sin \pi \nu_o}{\sin \pi \nu_1}\right)$$

and the orbit-quad offset can be measured at the quad rather than at the PUE:

$$KQ = K_1 \times \left(\frac{\beta_{avg}}{\beta_Q}\right)^{1/2}.$$

The results of the measurements are given in Tables 1 and 2.

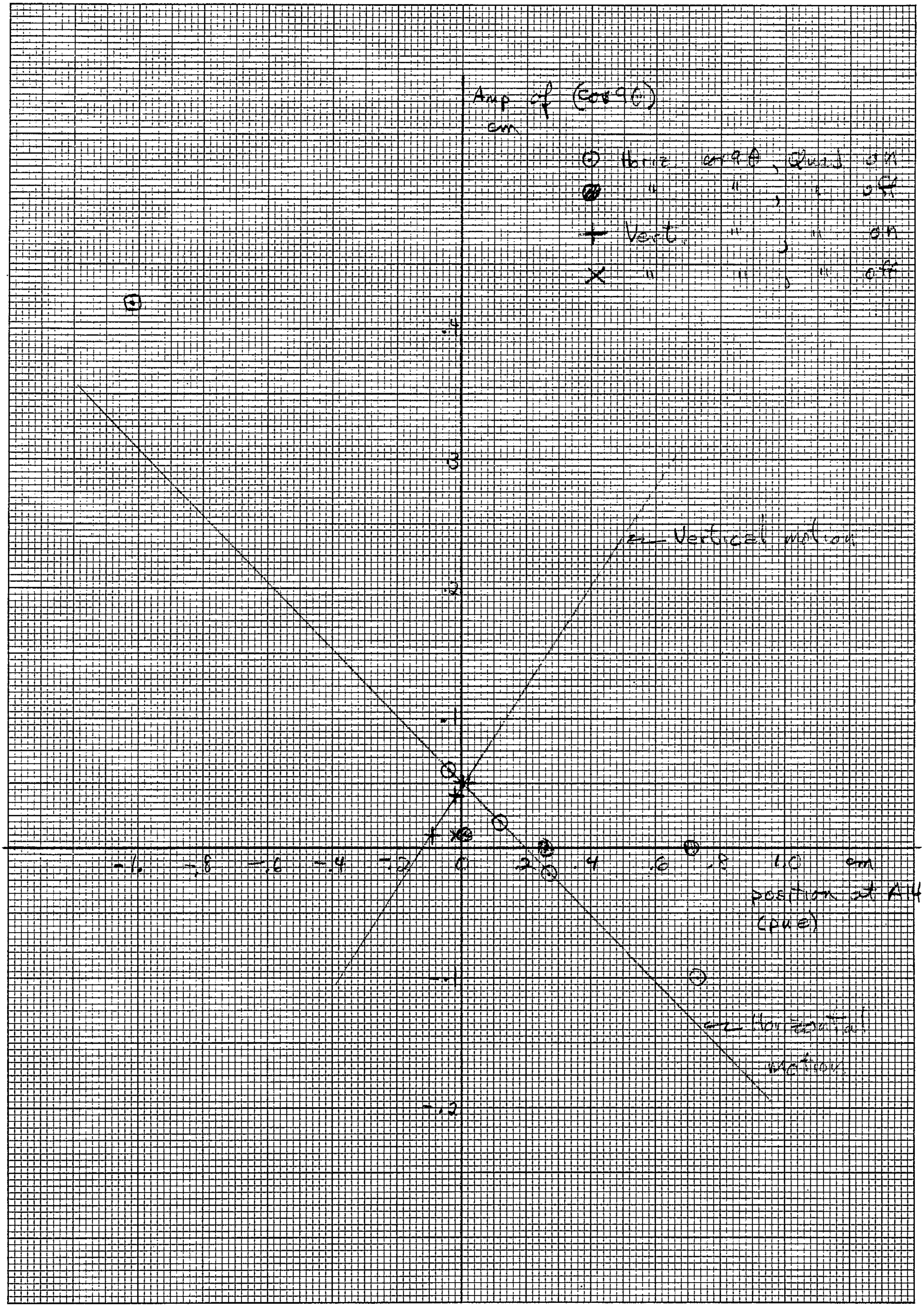


Figure 2 Effect of A15 quad on equil. orbit

Table 1
Measurement Conditions & Derived Sensitivities
KQ = [Change in orbit distortion per change in (quad orbit) position]

Condition	P (GeV/c)	ν_V (quad on)	ν_H (quad on)	I	K_V	K_H
0	1.07	8.788	8.798	345	+ 0.50	- 0.25*
1	9.2	8.792	8.646	- 1800	- 0.31	0.10
2	14.5	8.783	8.698	- 1800	- 0.19	0.07

*Measured	KQ_V	KQ_H
0	0.21	- 0.31
1	- 0.26	0.12
2	- 0.16	0.086

Table 2
Measured Orbit Distortions
(9th Harmonic Amp in cm)

Quad	Horizontal 9.2 GeV/c	Horizontal 14.5 GeV/c	Vertical 9.2 GeV/c	Vertical 14.5 GeV/c
A15	---	small	---	- 0.032
C15	+ 0.068	+ 0.048	+ 0.145	+ 0.080
D15	+ 0.057	+ 0.043	+ 0.134	+ 0.079
G15	+ 0.089	+ 0.055	+ 0.163	+ 0.102
I15	+ 0.040	+ 0.023	- 0.037	- 0.028
K15	+ 0.085*(2)	+ 0.062, 0.054*	+ 0.059*	+ 0.053(1),0.044*(1)
Null	0.004	0.005	0.009	

Ratios & Calculated Quad Offsets

	Amp (14.5/9.2) Horiz.	Amp (14.5/9.2) Vert.	Predicted Beam Offset (14.5 GeV/c)(cm) Horiz.	Predicted Beam Offset (14.5 GeV/c)(cm) Vert.
A15	--	--	--	+ 0.2
C15	1.42	1.81	+ 0.56	- 0.5
D15	1.33	1.70	+ 0.5	- 0.49
G15	1.62	1.60	+ 0.64	- 0.64
I15	1.74	1.32	+ 0.27	+ 0.18
K15	1.57	1.34	+ 0.72,+ 0.63*	- 0.33,-0.28*

Predict ≈ (14.5/9.2) = 1.58
(if quad-offset unchanged)

*After 1 mm "down and out" move.

Note: The numbers in parentheses are the error in least significant digit when more than one measurement was carried out under fixed conditions.

From Table 2, the beam is seen to be horizontally to the outside by between 3 and 6 mm in the quads, the 1 mm move is properly measured. Vertically, the beam is low by as much as 6 mm in some quads, but a bit high in others. The 1 mm move is measured correctly as to sign but underestimated. Considering the assumptions, this is consistent.

Conclusions and Plans

It is clear that to eliminate these kicks, the quads will have to be moved by substantial amounts (up to 0.7 cm); the liklihood of making such moves without causing damage is not known and deserves some study. The offsets measured are of the same order of magnitude as the equilibrium orbit distortions in the AGS at high field and presumably any changes in that orbit (moving of the main ring magnets) would change these results. These two efforts must be coordinated. The ultimate goal of the study, of which this is the first part, requires that the quad equilibrium orbit differences for all ten quads be minimized and then that the emittance growth measurement, pulsing ala polarized proton acceleration, be repeated. To this end, the remaining four quads must be measured and then the quads all repositioned. The present study, except for the magnet moving, was essentially invisible to the HEP program as would be the measure of the remaining quads. The Main Control Room was fully utilized however.

We appreciate the help of W. van Asselt in making the tune measurement, C. Eld for getting the quads powered, and the Survey Group (F. Karl, et al.), Beam Components Group (G. Racket, et al.), and the Vacuum Group (J. Barry, et al.) for a quick and successful magnet move.

mvh