BNL-105198-2014-TECH

Booster Technical Note No. 154;BNL-105198-2014-IR

TOLERANCE OF BEAM EXTRACTION ELEMENTS FOR THE AGS BOOSTER

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December 1989

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U.S. Department of Energy

USDOE Office of Science (SC)

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DECEMBER 15, 1989

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Abstract

We analyzed the sensitivity of the beam extraction for the AGS Booster. We found that (1) the systematic difference of the slopes of the extraction orbits between heavy ion and proton should be compensated properly by the septum about ± 0.27 mr. (2) the orbit at the stripper location is sensitive to the focusing quadrupole QF2. Assuming a ± 1% error in the kicker and 0.1% in the septum, we expect yms orbit excursion of 2.8 mm at the stripper location. Since the orbit error depends on the kicker and septum excitations, orbit correction will not be useful. Yet ± 2.8 mm orbit error should be tolerable. Improvement on kicker and septum stability would certainly be helpful also.

I. Introduction

The beam extraction from Booster to AGS requires (1) slow local orbit bump excited by backleg winding of four main dipoles F2, F4, F7 and A1 and (2) a fast kicker at F3 straight section fired within 120 ns rise time to kick the beam onto the septum at F6.

The excitation of F2, F4, F7 and A1 dipoles are respectively $\Delta\Phi$, $\xi\Delta\Phi$, $\xi_3\Delta\Phi$ and $\xi_4 \Delta\Phi$ respectively. The corresponding closed orbit at the septum is given by:

$$\begin{aligned} X_{co} &= -(6.7058 + 9.1069\,\xi)\,\Delta\Phi \\ X'_{co} &= (1.5973 + 0.9921\,\xi)\,\Delta\Phi \end{aligned} \tag{1}$$

with $\xi_3 = 1.160 + 0.171\,(Q_x - 4.83) + [0.240 + 0.855\,(Q_x - 4.83)]\,\xi$

$\xi_4 = -0.238 - 0.884\,(Q_x - 4.83) + [1.075 - 0.333\,(Q_x - 4.83)]\,\xi$

figure 1 shows an example of closed orbit at $\xi = 0.6$.

When the particle on the closed orbit are kicked at F3, the orbit excursion at the septum location at F6 can be expressed as

$$X_{sept} = X_{co} - 10.748\,\Delta\Phi_k$$
$$X'_{sept} = X'_{co} + 1.41\,\Delta\Phi_k \tag{2}$$

where $\Delta\Phi_k$ is the kick angle of the fast kicker.

If we assume that the beam fills up the aperture of 4" at the injection, the beam size at the extraction will be (1.8"H x 0.8"V) for proton and (1.1" H x 0.3" V) for heavy ions. Normally, the actual beam size should be smaller. The septum with 7.6 mm thickness is located 2" from the Booster center orbit. To optimize the operation, the thickness of the septum is distributed onto both side of 2". The resulting available aperture becomes 47 mm for the Booster unless local orbit bumps at injection is used.

Assuming that beam displacement x_{sept} = 76.2 mm, i.e. 3 inches, the acceptable beam size at the extraction will be 1.7"H, which is sufficient to contain the beam which fills up 95% of the aperture of 3.8" at injection.

To minimize the kicker strength, we choose x_{co} = 25.4 mm for proton and x_{co} = 38.1 mm for heavy ions. The actual closed orbit required will depend on the actual beam size. The kicker strength required can be solved from Eq. (2) as

$$\Delta\Phi_k = - \frac{0.0762 - X_{co}}{10.74813} \tag{3}$$

where x_{sept} = 3" = 0.0762 mm is used.

Table 1 lists the angular kicks needed for closed orbit for ξ = 0.6 and kicker strength needed for 3" beam displacement at the septum location.

Table 1 $\Delta\Phi$ for F2 Dipole and $\Delta\Phi_k$ for Kicker

x_{co} (mm)	$\Delta\Phi$ (mr)	$\Delta\Phi/\Phi$ (%)	$\Delta\Phi_k$ (mr)
25.4	-1.978	-1.13	-4.726
38.1	-2.967	-1.70	-3.545

The beam slope x'_{sept} of Eq. (2) can be calculated to be

$$x'_{sept} = -10.01 \text{ mr} - x_{co}\,[0.1313 + (1.597 + 0.992\xi)/(6.706 + 9.107\xi)] \tag{4}$$

where x_{sept} = 76.2 mm is used. Because of different closed orbit x_{co} for protons and heavy ions, we will expect

$$\Delta X'_{sept} \simeq \pm 2.74 \times 10^{-4} \text{ rad.} \tag{5}$$

Similarly, assuming ± 1% regularity in the kicker strength, we obtain

$$\Delta X_{sept} \simeq \pm 0.5 \text{ mm} \tag{6}$$

2. Error Analysis of the Transfer Line

The particle beam in the presence of the error field, ΔB, follows the equation of motion,

$$X'' + k(s)x = \frac{\Delta B}{B\rho} \tag{7}$$

When the particle beam starts at the septum location with (x_{sept}, x'_{sept}) and propagates along the extraction line given by the following elements

Sept S1 QD1 S2 D1 S3 QF2A QF2B S4 QD3 S5 T

where Sept is the 2.5 m long septum with total bending angle around 142mr, the lengths of the drift spaces S1, ... S5 are respectively 2.3 m, 0.5 m, 0.5 m, 0.9444m and 0.4 m.

The 4" quadrupoles Q D1, QF2A, QF2B and QD3 are 0.5 m in length. D1 is a 0.5 m dipole. T is the stripper for heavy ion beam.

The possible chance of error in the elements are septum field error of order 10^{-3}, quadrupole misalignment error of about ± 0.1 mm. Equation (7) can be integrated with these errors to find the beam displacement at the stripper location as

$$x_T = x_{sept} + 10.698\, x'_{sept} + 1.349 \frac{\Delta\Phi_S}{\Phi_S} + 0.167 \frac{\Delta\Phi_T}{\Phi_T}$$
$$+ 2.627A - 3.325B + 0.820\, C \tag{8}$$

with

$$A = x_{sept} + 5.65375\, x'_{sept} + 0.62533 \frac{\Delta\Phi_S}{\Phi_S} + \Delta_1$$

$$B = x_{sept} + 7.354\, x'_{sept} + 0.874 \frac{\Delta\Phi_S}{\Phi_S} + 0.045 \frac{\Delta\Phi_T}{\Phi_T}$$
$$+ 0.983\, A + \Delta_2$$

$$C = x_{sept} + 9.048\, x'_{sept} + 1.114 \frac{\Delta\Phi_S}{\Phi_S} + 0.107 \frac{\Delta\Phi_T}{\Phi_T}$$
$$+ 1.816A - 1.685B + \Delta_3$$

where Δ_1, Δ_2 and Δ_3 are the misalignment errors of QD1, QF2, QD3 respectively and

$\Delta\Phi_S/\Phi_S$, $\Delta\Phi_T/\Phi_T$ are the percentage error of the septum magnet and the dipole D1 respectively. Equation (8) can be reduced to the following:

$$\Delta x_T = -3.398\, \Delta x_{sept} - 19.387\, \Delta x'_{sept} - 2.170 \frac{\Delta\Phi_S}{\Phi_S}$$
$$+ 0.0412 \frac{\Delta\Phi_T}{\Phi_T} + 0.511\Delta_1$$
$$- 4.707\, \Delta_2 + 0.820\, \Delta_3 \tag{9}$$

The angular divergence of $\Delta x'_{sept}$ discussed in Section 1 between the proton and heavy ion operation is a systematic effect, the effect can be compensated by proper chosen $\Delta\Phi_S/\Phi_S$ systematically. Once the systematic effect of Eq. (5) is properly compensated, the expected orbit deviation from the ideal one will be

$$\sigma^2_{\Delta x_T} \cong (3.40\ \sigma_{\Delta x_{sept}})^2 + (2.17\ \sigma_{\Delta\Phi_S/\Phi_S})^2 + (4.71\ \sigma_{\Delta_2})^2 + \ldots \quad (10)$$

where we assume a perfect compensation $\Delta x'_{sept}$ by $\Delta\Phi_S/\Phi_S$ terms.

When $\sigma_{\Delta_i} \simeq 0.1$ mm, $\sigma\Delta x_{sept} \simeq 0.5$ mm; $\sigma\Delta\Phi_S/\Phi_S \simeq 10^{-3}$ are used, the orbit placement will be $\sigma\Delta x_T \simeq 2.8$ mm. This means that the transfer line orbit at the stripper location is expected to have ± 2.8 mm orbit movement from shot to shot due to the strengths variation of the kicker at 1% and the septum at 0.1%. Since the orbit displacement is much sensitive to the quadrupole QF2 in Eq. (9), alignment of QF2 is important.

Similarly, the vertical orbit displacement is given by

$$Z_T = Z_{sept} + 10.698\, Z'_{sept} + 1.349\, \Psi_S + 0.1671\, \Psi_T - 2.627A + 3.325B - 0.8203C \quad (11)$$

where

$$A = Z_{sept} + 5.654\, Z'_{sept} + 0.6253\, \Psi_S + \Delta_1$$

$$B = Z_{sept} + 7.354\, Z'_{sept} + 0.8738\, \Psi_S + 0.04545\, \Psi_T - 0.9832A + \Delta_2$$

$$C = Z_{sept} + 9.048\, Z'_{sept} + 1.114\, \Psi_S + 0.107\, \Psi_T - 1.816A + 1.685B + \Delta_3$$

Ψ_S and Ψ_T are angular rotation of dipole from the vertical axis, Δ_1, Δ_2 and Δ_3 are the vertical misalignment of quadrupoles QD1, QF2 and QD3 respectively. The effect is similar to that of Eq. (9) for the horizontal motion.

3. Orbit Correction Scheme

Since there are limited available space between the septum and the stripper location, there is no steering magnets. Based on our analysis in Section 2, we should have no trouble in the beam transfer line from the Booster to the stripper location at ± 2.8 mm within the ideal orbit. since the variation depends on the power supply regularity of the kicker and the septum, orbit correction will not be useful. The orbit information at the stripper location will be useful to obtain an on line correction scheme for the rest of the BTA line. since the correction depends specifically on the actual alignment error in the transfer line, the correction scheme in the downstream could be adjusted accordingly. The analysis of the BTA from the stripper to the AGS injection septum will be studied in the future.

Since the magnetic orbit correction can correct only the systematic error in the transfer line, we should rely on proper alignment and survey to obtain good beam line transfer.

A special possible systematic error corresponds to the radius error in the machine. The error in the particle radius is related to the momentum error of the bunch. The orbit error at the septum is given by

$$\begin{aligned} \Delta x_{sept} &= x_p \delta \\ \Delta x'_{sept} &= x_p' \delta \end{aligned} \tag{12}$$

where $\delta = \Delta p/p$ is the momentum error and x_p and x_p' are dispersion functions evaluated at the septum location, i.e. $x_p = 2.763$m, $x_p' = -0.435$. Substituting Eq. (12) into Eq. (9), we obtain

$$\Delta x_T = (-3.4 x_p - 19.4\, x_p')\, \delta \simeq -0.35 x_p \delta \tag{13}$$

This means that 1mm radial error is translated into -0.35mm at the stripper location.

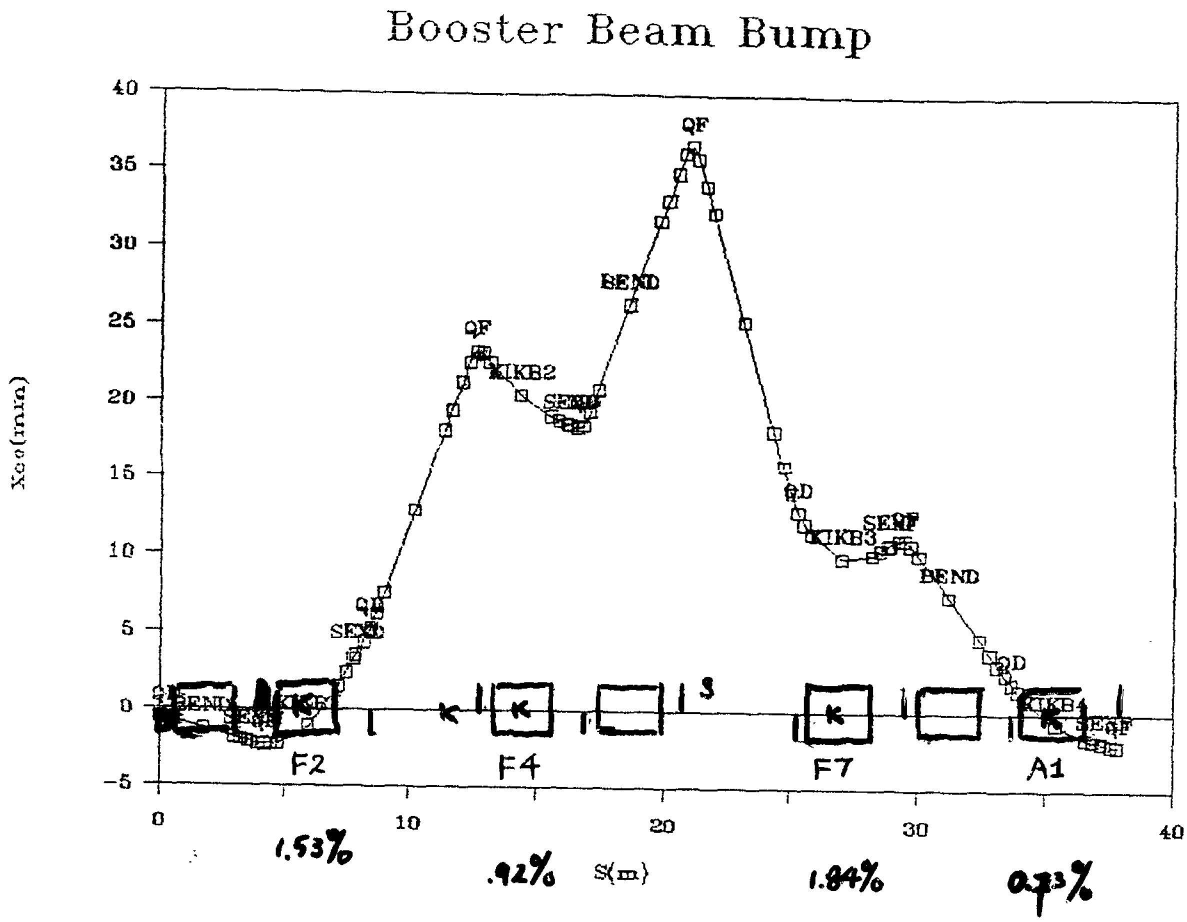

Fig. 1 An example of orbit bump backleg winding.

$$F2 = \Delta\phi$$

$$F4 = \xi\,\Delta\phi$$

$$F7 = \left\{1.160 + 0.171\,(Q_x - 4.83) + [0.240 + 0.855\,(Q_x - 4.83)]\,\xi\right\}\Delta\phi$$

$$A1 = \left\{-0.238 - 0.884\,(Q_x - 4.83) + [1.075 - 0.333\,(Q_x - 4.83)]\,\xi\right\}\Delta\phi$$

THE CLOSED ORBIT AT SEPTUM location becomes

$$X_{co} = -(6.706 + 9.107\,\xi)\,\Delta\phi$$

$$X'_{co} = (1.597 + 0.992\,\xi)\,\Delta\phi$$