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BOOSTER INJECTION SCENARIOS AND ORBIT BUMP REQUIREMENTS

S. Y. Lee

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Collider Accelerator Department

Brookhaven National Laboratory

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S. Y. LEE

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ACCELERATOR DEVELOPMENT DEPARTMENT
BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973

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ABSTRACT

The orbit bump requirements for the AGS Booster in the injection process are analyzed. To optimize the injection efficiency for the heavy ion, the power supply may be required to obtain a large $^{di}/_{dt}$ to collapse the orbit in avoiding the injection septum.

1. Introduction

To satisfy the multiple usage of the AGS Booster, the Booster is equipped with many orbit bumps needed for proton injection, heavy ion injection and beam extraction. These orbit bumps, specified in the Booster Design Manual, can be used to optimize the injection efficiency, to avoid beam obstructions and to save the kicker strength.

In this note, some simple relationships between the orbital displacement and the bumper magnet strength are derived. These relationships serve as a guide for the operational initial setting of these hardware devices. The betatron tunes of the Booster are assumed to be Q_y = 4.82 and Q_x = 4.83. The formula relating the closed orbit to the current excitation depends on the betatron tune of the machine and the realistic machine imperfections. However, we consider that the imperfection errors are small perturbation. Instead of expressing the closed orbit as a function of the quadrupole strength, we shall give it in a numerical form (see Section 4). One may use thin lens approximation to obtain the first order estimation, which is usually valid within about 10 ~ 20%.

We divide our task in proton injection and heavy ion injection in the following sections.

2. Proton Injection

The high intensity proton injection and polarized proton accumulation are accomplished in proper use of the slow orbit bump and fast kicker. The slow orbit bumps are intended to move the beam away from the obstructions such as the stripper (for H^- injection) in the normal operation. The programmable kickers bump the orbits to the appropriate location for the control of beam and the transverse density distribution of the bunch. The slow bumps are accomplished by the backleg winding of the Booster dipoles at C4, C8 and D1 and the fast kickers are located at C3, C6 and C8. Table 1 lists the components shown in the Booster Design Manual.

Table 1 Proton Injection Components

Name	Location	Strength
PIB1C4	C4	Θ
PIB2C8	C8	$0.273\ \Theta$
PIB3D1	D1	$0.942\ \Theta$
PIK1C3	C3 (upstream)	Θ_k
PIK2C6	C6 (downstream)	$0.201\ \Theta_k$
PIK3C8	C8 (downstream)	$0.845\ \Theta_k$

(A) Slow Bump

The local slow bump orbit at the downstream of C5 dipole for the strength shown in Table 1 is:

$$X_{c5} = -7.4375\ \Theta$$

$$X'_{c5} = -1.6475\ \Theta \qquad (1)$$

To obtain a one inch orbit bump at the stripper location, we need $\Theta \simeq 3.42$ mrad $\simeq 1.96\%$ of main dipole angle.

Figure 1 given an example of 1" bump in the injecton location.

B. Fast Bump

The fast kicker should be excited according to the relative strength shown in Table 1. The bumped orbit displacement at the C5 dipole is given by

$$x_{c5} = -6.4550\ \Theta_k$$

$$x'_{c5} = -0.9449\ \Theta_k \qquad (2)$$

To bump the orbit 60 mm from the center orbit, we need $\Theta_k \approx 9.3$ mr. Since the proton is injected at $\beta\rho = 2.145$ Tm, the kicker requires $Bl \approx 0.02$ Tm or 1.3 KG for 6" kickers. Figure 2 shows the local closed orbit in the proton injection area.

3. Heavy Ion Injection

For multiturn heavy ion injection at the straight section C3, the programmable fast kicker is very important in the injection efficiency. The slow orbit bump is intended only to move the beam away from the obstacle such as the injection electrostatic septum etc. the slow bumps are located at B8, C1 and C5 while the fast bumps are located at B8, C3 and C6. Table 2 lists the injection elements.

Table 2 Heavy Ion Injection Elements

Name	Function	Location	kick $\Delta x'$
HIB1B8	Slow Bump	B8	0.743Θ
HIB2C1	Slow Bump	C1	0.275Θ
HIB3C5	Slow Bump	C5	Θ
HIK1B8	Fast Bump	B8 (downstream)	$0.879\Theta_k$
HIK2C3	Fast Bump	C3 (upstream)	$0.644\Theta_k$
HIK3C6	Fast Bump	C6 (downstream)	Θ_k

A. Slow Bump

The relation between the strengths of these orbit bump magnets are important in creating only the local orbit distortion. For the slow orbit bump, the closed orbit at the electrostatic septum (30 cm upstream of the C3 focusing quadrupole) can be expressed as

$$X_{ES} = -7.747\ \Theta$$
$$X'_{ES} = -0.7732\Theta \qquad (3)$$

Figure 3 shows the closed orbit in the local area for the slow orbit bump. since the main dipole bending angle Θ_D is $10°$ or 174.53 mrad, the corresponding slow bump excitation will be

$$\Theta/\Theta_D\ (\text{in}\%) = -1.878\ X_{ES}\ [\text{in inches}]$$

for example, the slow bump strengths needed is about 1.4%, 0.52% and 1.9% to obtain a 1" closed orbit manipulation at the septum location. Depending on the transverse location of the electrostatic septum and the final coating of the beam, we may or may not have to excite the slow orbit bump.

B. Fast Bump

Similarly, when the fast kickers are excited to bump the closed orbit onto the injection beam position, the orbit displacement at the septum location can be written as

$$X_{ES} = -7.738\ \Theta_k$$
$$X'_{ES} = -1.232\ \Theta_k \qquad (4)$$

Figure 4 shows the local closed orbit of the excited fast kicker in the injection septum region. To obtain a 60 mm orbit displacement, Eq. (4) implies that $\Theta_k = 7.754$ mrad. For heavy ion injection, the maximum $B\rho$ corresponds to deutron with $B\rho = 1.1235$ Tm. The corresponding strength needed is therefore $Bl = 0.00871$ Tm or about 0.6 KG for the 6" kicker. To obtain a proper local orbit bump, the currents in each kicker should be maintained in the ratio shown in Table 2. To obtain good injection efficiency, the closed orbit kickers should be able to collapse the orbit displacement by about 10 mm within one turn, i.e.,

$$\Delta\Theta_k/\Delta t \simeq \begin{cases} 0.32\text{mr}/\mu\text{sec for deuteron} \\ 0.092\ \text{mr}/\mu\text{sec for Au} \end{cases} \qquad (5)$$

or

$$\Delta Bl/\Delta t \simeq \begin{cases} 359\ \text{Tm/sec for deuteron} \\ 81.85\ \text{Tm/sec for Au} \end{cases}$$

This criteria is needed to avoid the first turn particles from hitting the septum. The power supply should have the capability of changing the current within the specified rate.

4. Betatron Phase Dependence of the Kicker Strength

The kicker and bumper strength listed in Tables 1 and 2 are valid only for the horizontal tune of 4.83. The relative strength of the kicker depends on the betatron tune. During the injection study, the horizontal tune Q_x will be varied to optimize the efficiency. When the horizontal tune is changed, the relative kicker strengths in Table 1 and 2 will be different as well.

The lower part of Figure 5 shows the ratio of the closed orbit displacement outside the bump region to that of maximum closed orbit inside the bump region as a function of machine tune. figure 5 shows that the horizontal orbit bump is sensitive to the horizontal tune (solid line) and is insensitive to the vertical time (dashed line). The closed orbit displacement outside the bump location can be 3 $\sim$4 mm for a 60 mm orbit bump if we do not adjust relative ratio of the kicker strength. To obtain a truly local orbit bump, we should adjust the relative ratio of the kicker strength with the changing tune (horizontal tune). The upper part of Figure 5 shows the strength of C6 kicker to that of C3 and C8 to C3 as a function of tune. These kicker strength can be written as

$$\frac{\Theta_k(PIK3C8)}{\Theta_k(PIK1C3)} = 0.845 - 0.275(Q_x - 4.83)$$
$$\frac{\Theta_k(PIK2C6)}{\Theta_k(PIK1C3)} = 0.201 + 0.626(Q_x - 4.83) \qquad (5)$$

for proton injection kicker.

Similarly, the heavy ion injection kickers strengths is given by

$$\frac{\Theta_k(HIK1B8)}{\Theta_k(HIK3C6)} = 0.879 - 0.2(Q_x - 4.83)$$
$$\frac{\Theta_k(HIK2C3)}{\Theta_k(HIK3C6)} = 0.644 + 0.734(Q_x - 4.83) \qquad (6)$$

Figure 6 shows the relative kicker strength (eq. 6) v. tune Q_x.

Equations (5) and (6) with U. (2) and (4) shall form the basic kicker control program needed for the injection process.

5. Conclusion

The orbit strength obtained in Tables 1 and 2 differ substantially from Tables 4-3 and 4-6 of the Booster Design Manual. In the computer control program of the injection orbit bump setting, we should adjust the relative ratio of these bumper properly. We express also the orbit displacement as function of the strengths of the bumper magnet. Using these relation properly, we can easily set the bumper magnet power supply to obtain a proper orbit bump. Equations (1) - (4) should be used as a look-up table in the control program.

We also discussed the requirement on the power supply for the heavy ion injection in Eq. (5). This requirement is useful to increase the injection efficiency. Careful evaluation for the power supply is important.

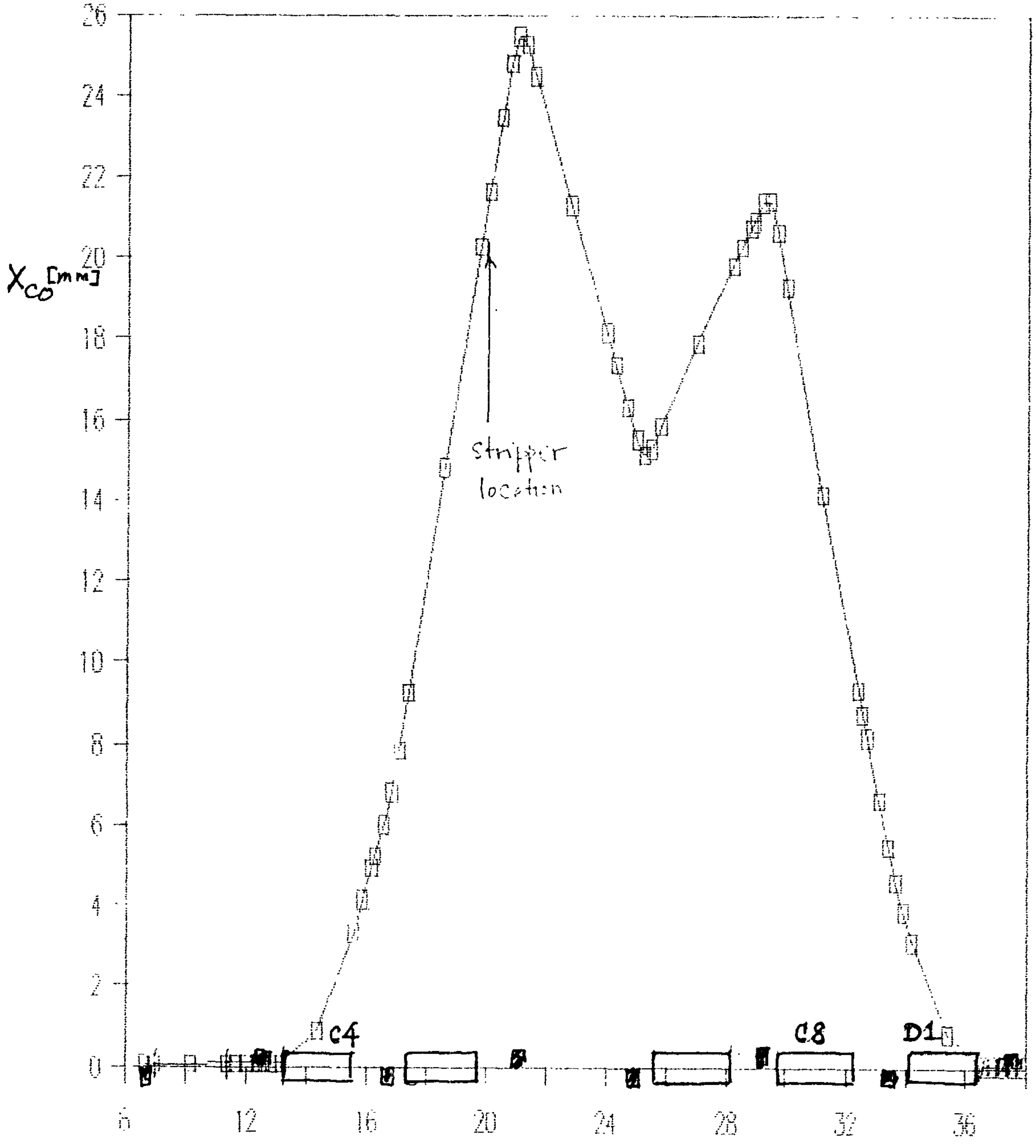

Fig. 1 slow bump orbit for proton injection

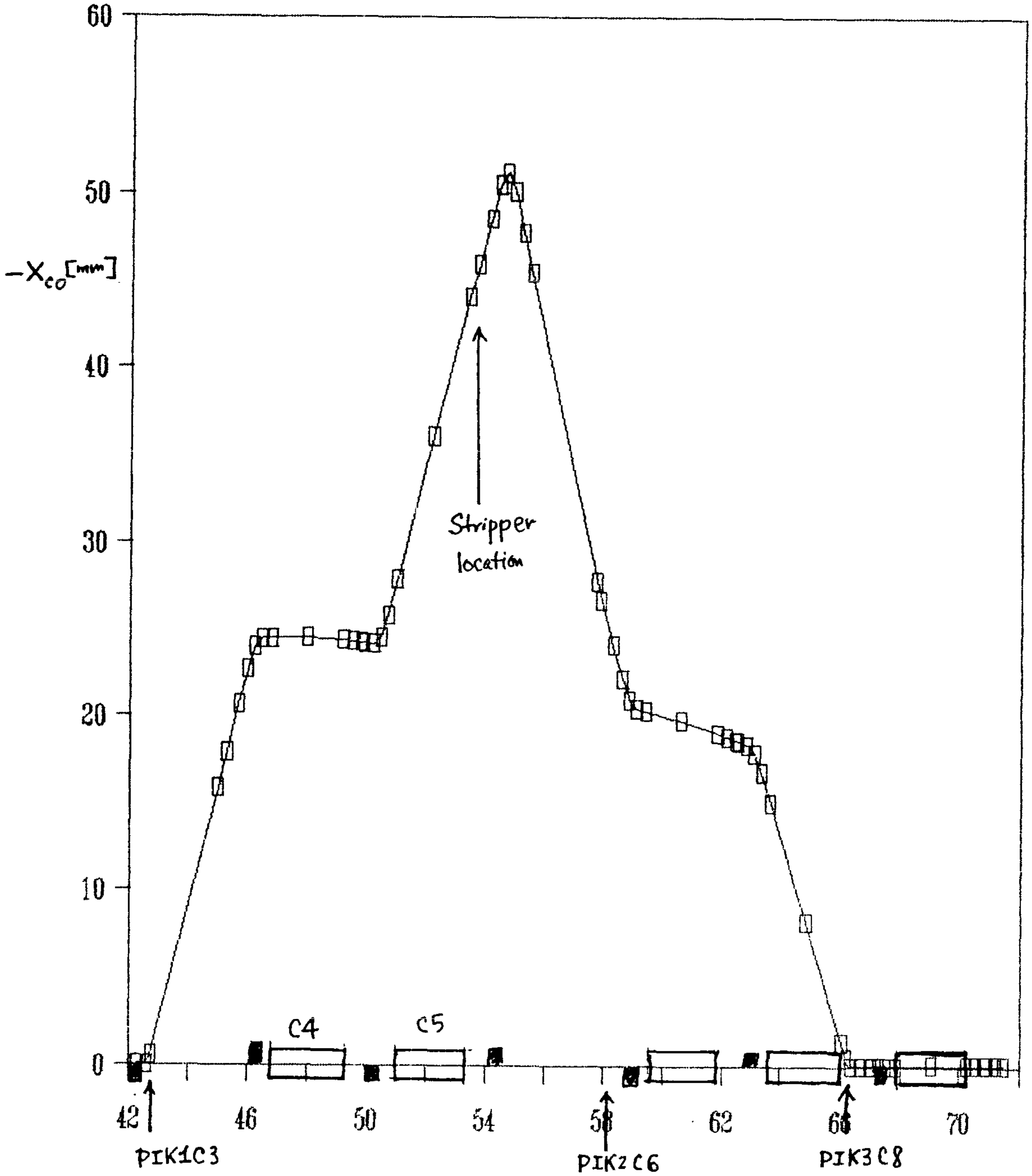

Fig. 2. Proton injection orbit bump of fast kickers

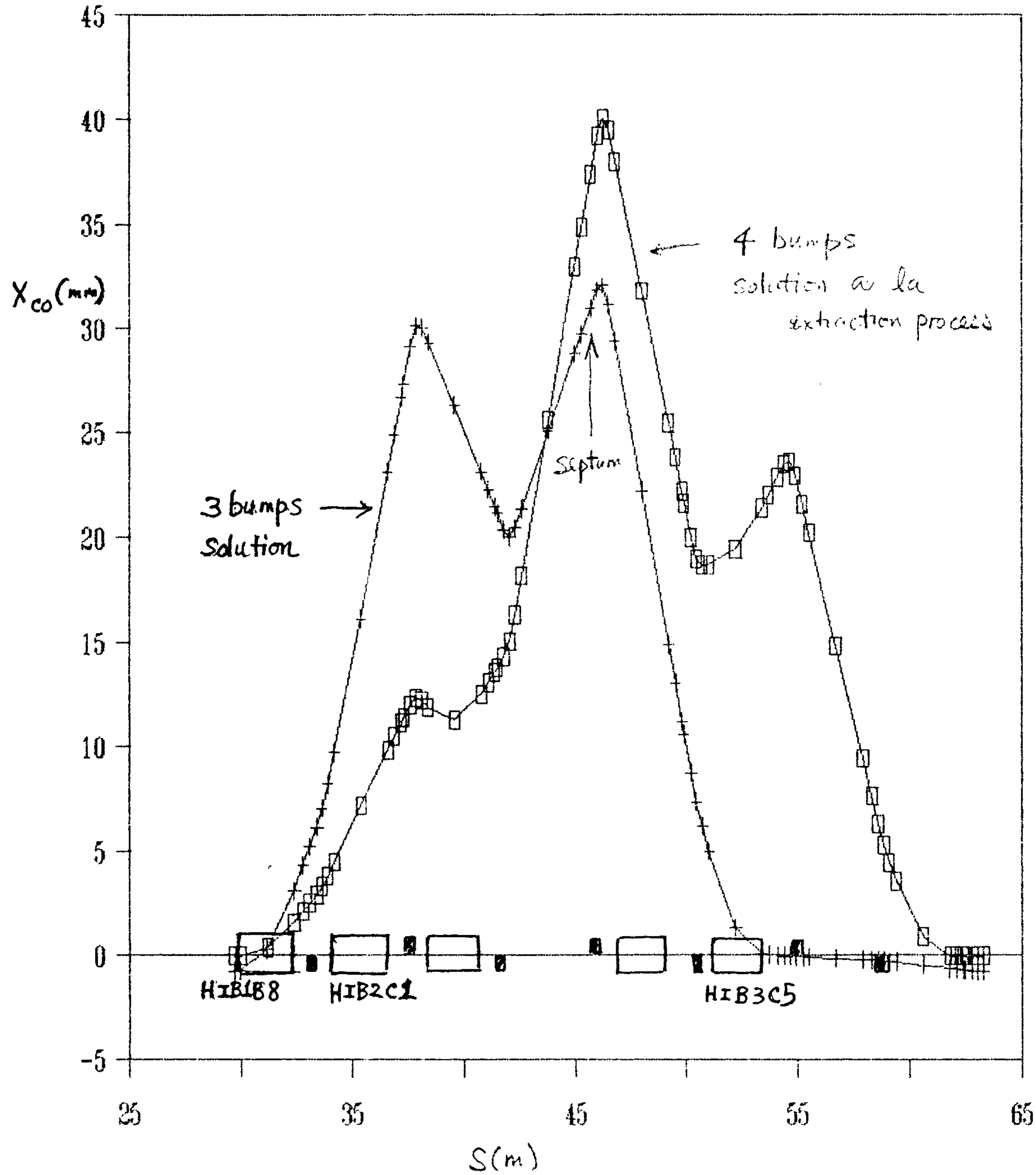

Fig.3 closed orbit of HI injection slow bumps

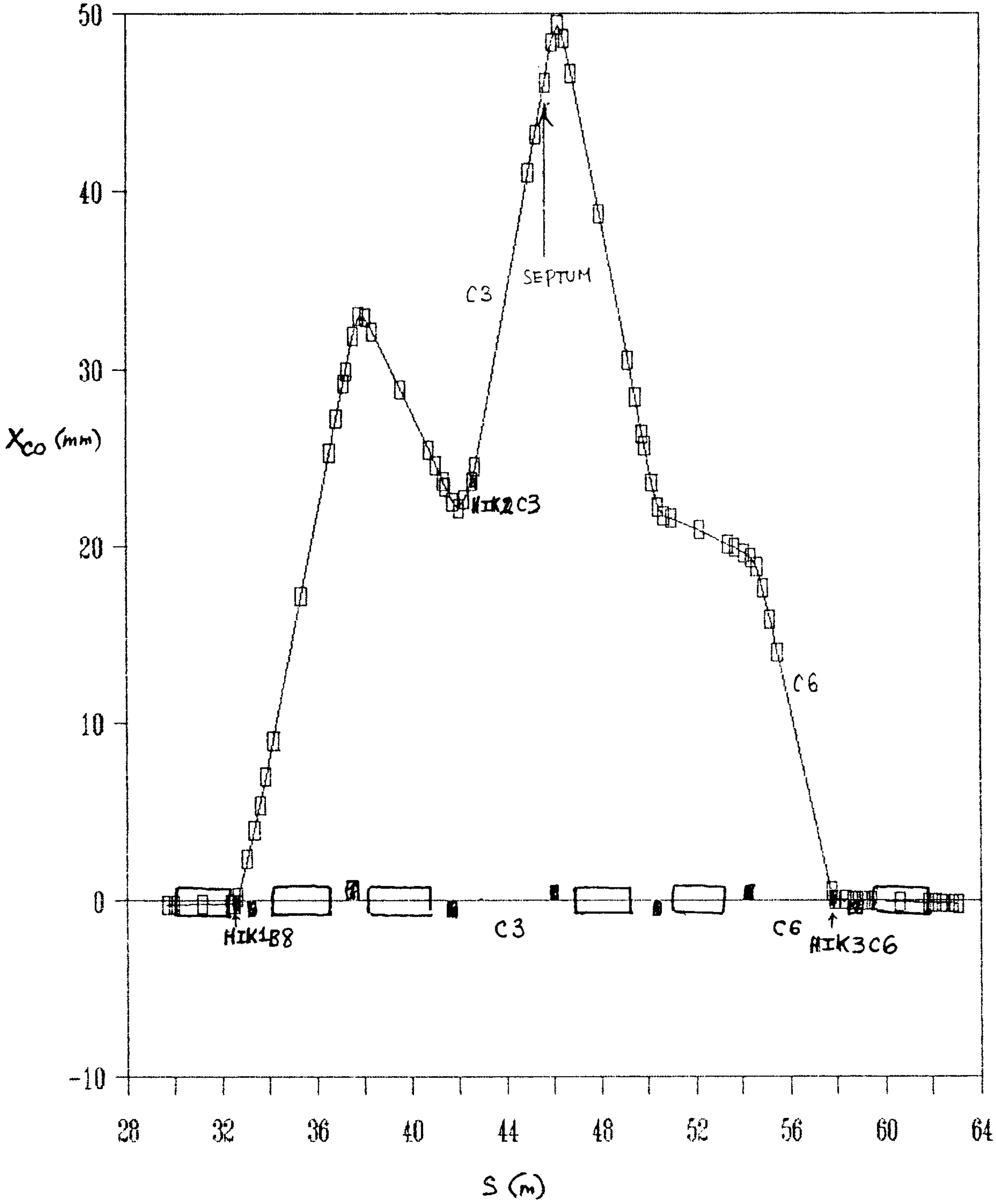

Fig. 4 closed orbit bump due to the fast bumpers

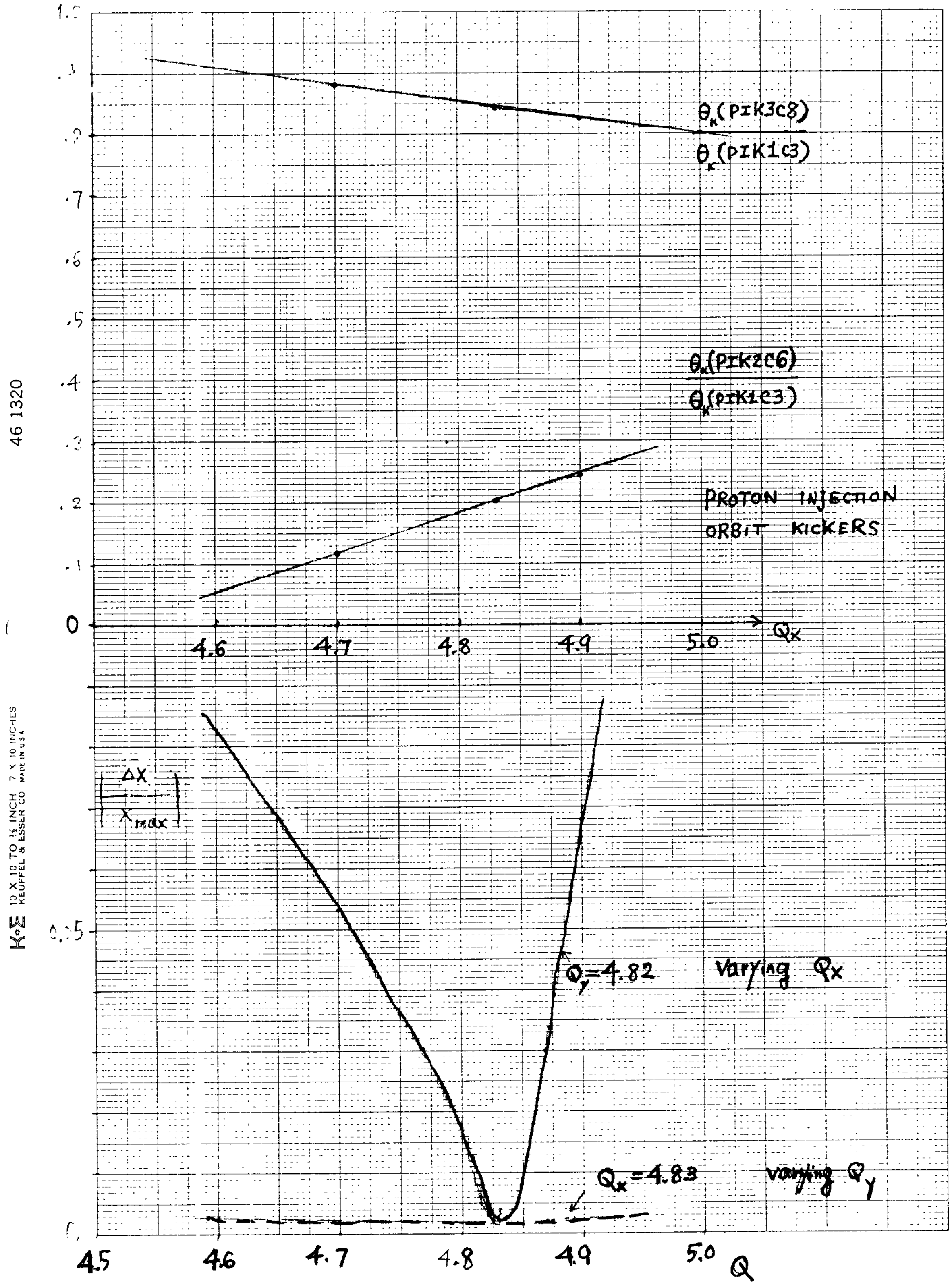

Fig. 5 Lower: Ratio of closed orbit displacement outside the bump region to the maximum displacement in the bump region is plotted as a function of tune for varying Q_x (solid) and varying Q_y (dashed line)

Upper: The relative ratio of kicker strengths are plotted as a function of the Horizontal tune.

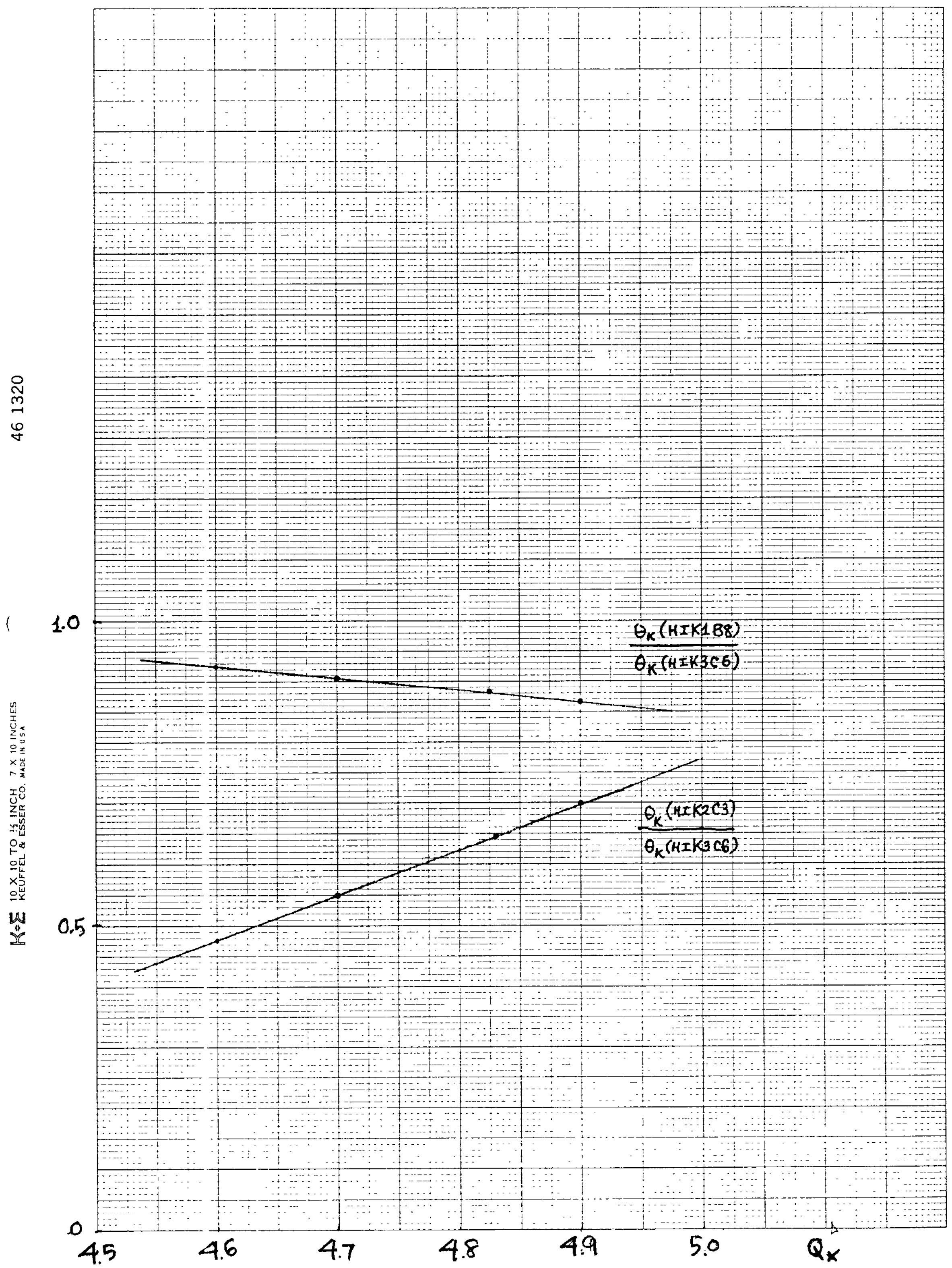

Fig. 6. The relative ratios of Heavy ion injection kickers are plotted as a function of Q_x . With the appropriate ratio, the orbit bump is local. The closed orbit displacement outside the bump region will be 0.(very small number).