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Study of the Effect on Injection of D.C. Powering F10 Extraction Septum Magnet

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Reported by E. Gill and L. Ahrens

Subject Study the Effect on Injection of D.C. Powering F10 Extraction Septum Magnet

Observations and Conclusion

Setup

Required high intensity above 1×10^{13} using the L20 beam monitor for time losses. The AGS was tuned up at typical running value of F10 current (F10FN) = 2600 which gives a current of 4700 Amps.

Procedure

The F10 magnet current was lowered from 5000 Amps down to 0 without retuning and the machine intensity at 100 ms was recorded (See Figure A). The intensity was observed to be very sensitive to the F10 current. The behavior near zero current, namely a return to high intensity, is not understood. The loss occurred at the beginning of the acceleration cycle (see Figure C).

Tunes

Tune measurements were made horizontally and vertically in on and off conditions; the result was horizontal 8.706 (no change), vertical 8.831 to 8.795. The vertical tune would not repeat very well, but one could always see a change.

It was found that beam intensity lost near injection, due to changes in the F10 septum magnet current, could be regained by adjusting the QH = 8.5 and QV = 8.5 resonance stopband corrections. This presumably means that the fringe fields of the septum magnet introduce quadrupole fields which contribute to sin 17θ and cos 17θ quadrupole field harmonics in the ring. These harmonics open up the QH = 8.5 and QV = 8.5 resonance stopbands and can be corrected with the program labelled QN17 in the Ortho library of AGAST's ring area. By determining the amount of correction which must be applied to regain the beam lost for a given change in the septum magnet current, we can calculate the strength of the quadrupole field introduced into the ring by the septum magnet. Knowing the strength of the quadrupole field we can calculate the tune shift due to these fields and compare with the measured tune shifts.

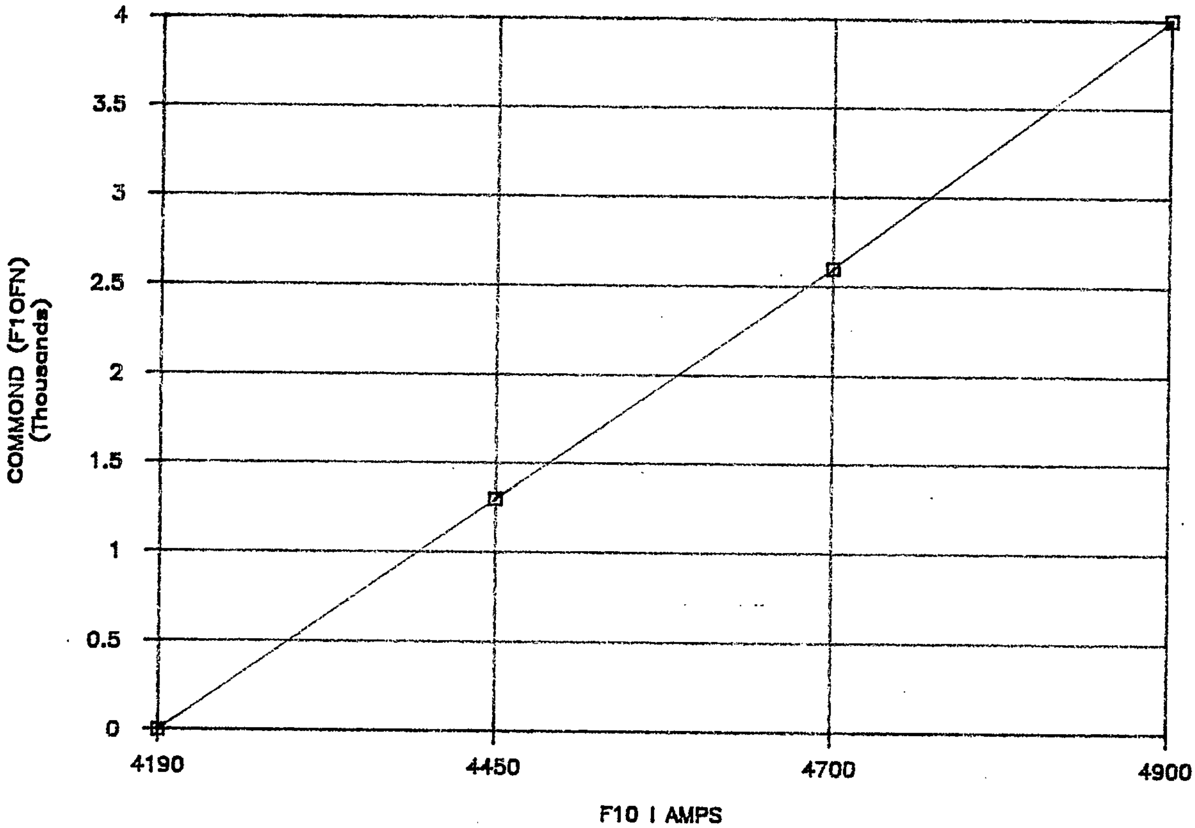
When the command issued to the F10 septum magnet was changed from 2550 (4700 Amps) to 1050 (4300 Amps), it was found that the QN17 stop-band correction had to be changed as follows to regain lost intensity. Sin 17Z = 80, Cos 17Z = 0, Sin 17X = 100, Cos 17X = 20. The scheme of 16 quadrupoles used to produce these corrections is discussed in an unpublished Technical Note by E. Raka. The calculation done by C. Gardner is in the Appendix to this Studies Report.

To summarize this discussion and the appendix work, the phase of the change of 17θ correction is within errors that phase expected for a "delta function" quadrupole at F10. If the deduced strength of that quad is used to calculate the tune shift to be expected, rough agreement is found for the vertical (measured shift -0.036, observed -0.048) where on first pass even the sign looks right. The horizontal tune did not appear to change though this model predicts an increase equal to the vertical decrease. The model assumes the quad is at the center of the F10 straight section which it need not be and takes the phase advance between C3 and F10 to be the same for both planes. A dipole effect was looked for (a change in the equilibrium orbit as measured by PUE's); no effect was observed in either plane.

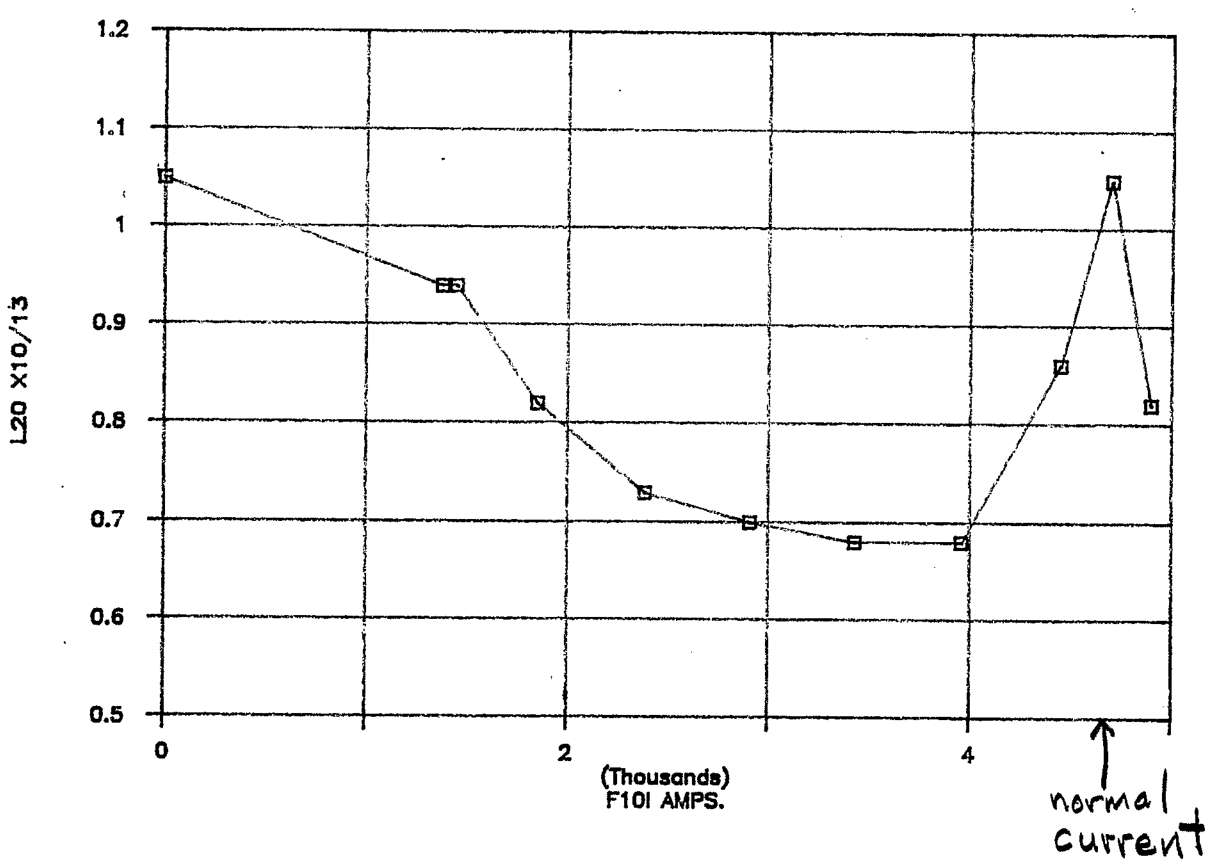
Conclusions

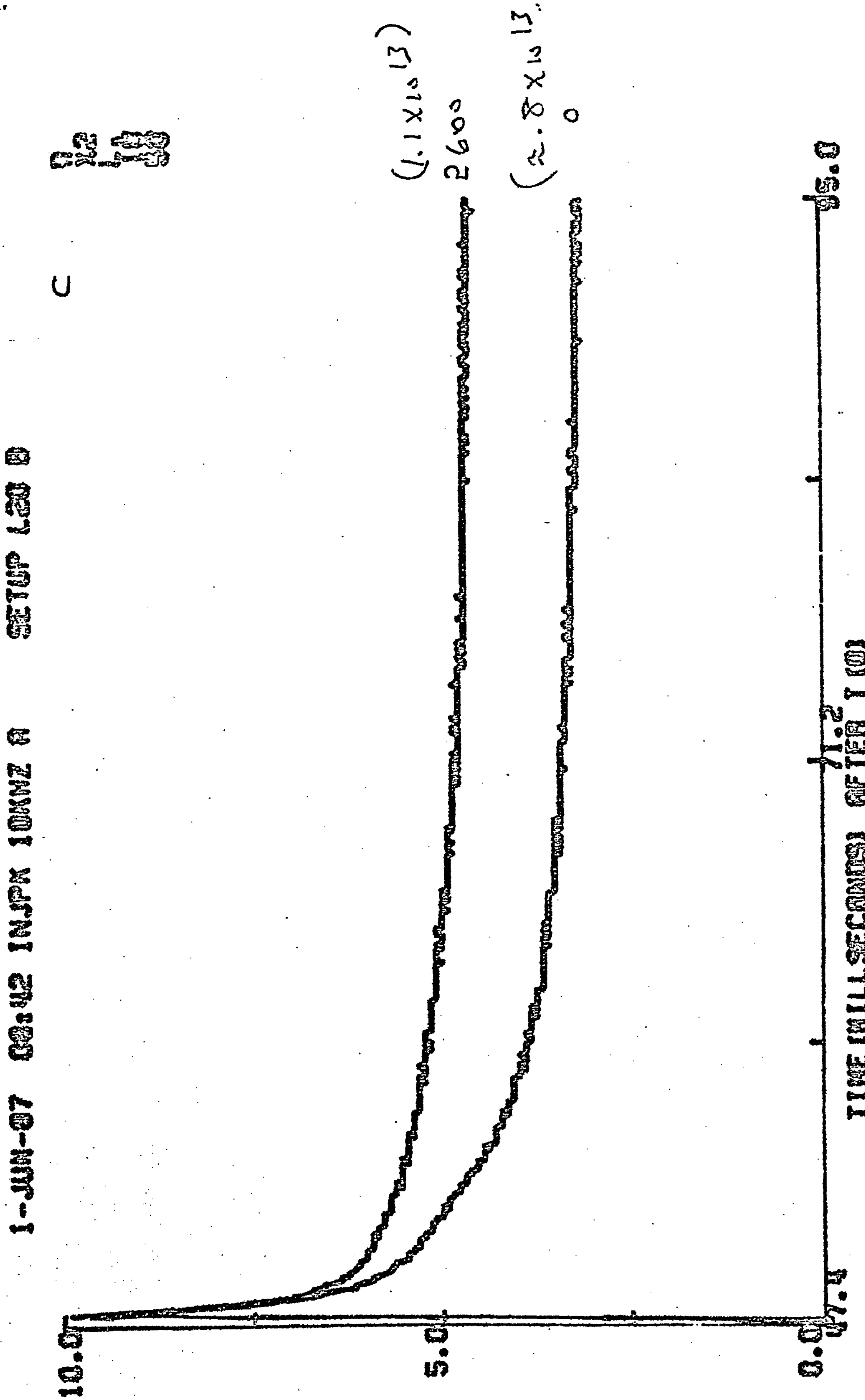
The F10 magnet powered to full field at injection affects (almost certainly reduces) the intensity of beam accelerated. One should review the decision to abandon pulsing the septum, or make a local correction to cancel out the fringe fields. Also, one should attempt to measure on the bench the F10 fringe fields. The change in 17θ quadrupole component required by a change in the F10 current to regain intensity agrees in phase with a quad kick at F10 and roughly in magnitude with the vertical tune shift observed. This encourages the simple model of the fringe field having a quadrupole component. Presumably, the fringe field introduces other components which are not easy to eliminate or to quantify and whose effect on intensity depend strongly on injection parameters and in particular on the early radius. Finally, the curious return of intensity as the F10 current goes to zero and the lack of observed tune shift in the horizontal plane, are not understood.

F10 COMMAND VS CURRENT AMPS. *FIG B*



F10I VS L20 *FIG A*





1-JUN-87 08:42 INJPK 10KHZ 0
SETUP L20 0
C
2600 (1.1x10^13)
0 (≈.8x10^13)
10.0
5.0
0.0
7.4
71.2
95.0
TIME (MILLSECONDS) AFTER T (0)

APPENDIX

(from Notes of C. Gardner)

When the command issued to the F10 septum magnet is changed from 2550 to 1050 counts, it is found that the QN17 stopband corrections must be changed as follows to regain lost beam:

$$\begin{aligned} \text{Sin } 17Z &= +80 \\ \text{Cos } 17Z &= 0 \\ \text{Sin } 17X &= +100 \\ \text{Cos } 17X &= +20 \end{aligned} \tag{1}$$

"Sin 17Z" is the change in the amplitude of the vertical (Z) quadrupole harmonic varying as (17θ) around the ring. θ is the betatron phase divided by the tune. The scheme of 16 quadrupoles used to produce these corrections is discussed in an unpublished Technical Note by E. Raka. If the sin 17X correction is incremented by N counts in this scheme, then

$$\sin 17X = \frac{N}{1000} \frac{4Q}{\beta_m} \left(\beta_m^2 - \beta_M^2\right) \tag{2}$$

Where

$$Q = 47.49 \text{ Gauss/A} \tag{3}$$

is the integrated strength of each of the 16 quads, and

$$\begin{aligned} \beta_m &= \text{Beta minimum} = 412'' \\ \beta_M &= \text{Beta maximum} = 854'' \end{aligned} \tag{4}$$

Similarly, if the sin 17Z correction is incremented by N counts, we have

$$\sin 17Z = -\frac{N}{1000} \frac{4Q}{\beta_m} \left(\beta_m^2 - \beta_M^2\right). \tag{5}$$

Substituting the values for Q, β_m, β_M into (2) and (5) we have

$$\begin{aligned} \sin 17X &= -258 \text{ N} \quad (N = 100) \\ \sin 17Z &= +258 \text{ N} \quad (N = 80) \end{aligned} \tag{6}$$

We note that in this scheme of stopband corrections, the betatron phase advance at each of the 16 quads is referenced with respect to the C3 straight section.

Now, the 17θ harmonic components of the quadrupole fields produced by the F10 septum magnet are

$$\sin 17X = I_{F10}\, Q_{F10}\, \beta_{F10} \sin 17\phi$$
$$\cos 17X = I_{F10}\, Q_{F10}\, \beta_{F10} \cos 17\phi \tag{7}$$

$$\sin 17Z \doteq - \sin 17X$$
$$\cos 17Z \doteq - \cos 17X \tag{8}$$

Where

$$\phi = 90^\circ + 10.8^\circ$$

is the normalized (i.e., divided by the tune) betatron phase advance between C3 and F10,

$$\beta_{F10} = 609",$$
(at the center of the straight section)

Q_{F10} is the integrated strength of the quadrupole fields produced by the septum magnet in Gauss per Amp, and I_{F10} is the F10 current in Amps. Thus, we have

$$\sin 17X = I_{F10}\, Q_{F10}\, (598)$$
$$\cos 17X = I_{F10}\, Q_{F10}\, (-114). \tag{9}$$

Now, when the commands issued to the F10 septum magnet changed from 2550 to 1050 (-1500 counts), I_{F10} changed by

$$\Delta I_{F10} = -\ 1500 \left(\frac{640}{4000}\right) = -\ 240 \text{ A}$$
$$= -\frac{1500}{4000}\, 640 \text{ A} = -\ 240 \text{ A} \quad (4000 \text{ counts} = 640 \text{ A}) \tag{10}$$

Thus,

$$\Delta \sin 17X = \Delta I_{F10}\, Q_{F10}\, (598) = -\, 143520\, Q_{F10}$$
$$\Delta \cos 17X = \Delta I_{F10}\, Q_{F10}\, (-114) = +\, 27360\, Q_{F10}. \qquad (11)$$

Comparing (11) and (6) with N = 100, we find

$$-\, 143520\, Q_{F10} = +\, 25800$$

$$\boxed{\therefore Q_{F10} = -\, 0.18 \text{ Gauss/A}} \qquad (12)$$

This is the desired quadrupole field strength which can be used to calculate tune shifts. We find

$$|\Delta Q_H| = \frac{1}{4\pi}\, \beta_{F10}\, \frac{|\Delta I_{F10}\, Q_{F10}|}{1313244.574\, P(GeV/c)}, \qquad (13)$$

$$|\Delta Q_H| = 6.6 \times 10^{-6}\, \frac{|\Delta I_{F10}|}{P(GeV/c)}, \qquad (14)$$

$$\Delta Q_V \doteq -\, \Delta Q_H. \qquad (15)$$

For $\Delta I_{F10} = -\, 4710$ AMps and P = 0.65 GeV/c, we have

$$|\Delta Q_H| = +\, 0.048,$$

$$|\Delta Q_V| = +\, 0.048.$$

$\Delta Q_V = 8.831 - 8.795 = 0.036$ was observed.

$\Delta Q_H \doteq 0$ was observed.