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Measurement of Vertical Beam Size at the F6 Extraction Septum Using Radiation Losses

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AGS Complex Machine Studies

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Measurement of Vertical Beam Size at the F6 Extraction Septum Using Radiation Losses

Study Period: April 10, 1993

Participants: M. Tanaka, R. Thern, K. Zeno

Reported by: K. Zeno

Machine: Booster Extraction at 85 ms after T-Zero

Beam: PPM User 3, 4.7 x 10^{11} ppp (20 injected turns) at Ek = 1.2 GeV

Tools: Orbit Control Program, Orbit Display Program, Booster IPM, MW006 in BTA, Loss Monitors, General Purpose Monitor

Aim: To obtain a rough measurement of the beam's vertical size at the F6 septum (at extraction) using radiation losses at the septum and its designed geometrical vertical aperture. This is compared to the size obtained using the IPM for consistency.

I. Introduction

The F6 septum was constructed to have a vertical aperture of 27.43 mm centered in the Booster's vertical midplane. The vertical beam size at the septum can be measured by scanning the beam vertically through the septum and looking at radiation due to beam loss. This beam size can be compared with that measured by the IPM for consistency.

II. Setup and Data Taking

Booster extraction was accomplished with a 30mm,-2mr horizontal 4 magnet extraction bump. The F3 kicker was set to 27.5 kV, and the F6 septum was set to 8989 A. The vertical tune was 4.80. This was the setup typically used for extraction at that date.

The vertical position of the beam at F6 in the Booster was altered by adjusting the amplitude and phase of the vertical 5th harmonic of the equilibrium orbit at extraction. The orbit's vertical 5th harmonic was controlled by changing the amplitude and phase of the dipole field's vertical 5th harmonic by adjusting the dipole correctors through the orbit control program. These dipole correctors placed a harmonic centered at 85 ms. The current in the correctors ramped up to the value at 85 ms for 20 ms, and likewise ramped down from these values over 20 ms.

The phase of the orbit's vertical harmonic oscillation relative to an initial reference orbit was adjusted so that a maximum occurred roughly at the septum. This could be seen from difference orbits taken with the orbit display program. The F5 and F7 bpms are placed in an approximately symmetric manner about the F6 septum. If the vertical displacement at the F6 septum is at a maximum, the positions at F5 and F7 should be about equal (if the values of the beta function at these two points are about equal), but the slope of the orbit (dy/ds) should be about opposite. This was the criteria that was used to determine that the orbit had a maximum at F6. However, it should be emphasized that this was done in a coarse manner, with the difference in the positions at F5 and F7 typically about 5 to 15% of the orbit's peak to peak amplitude (as seen on the bpms). It was accomplished by sending 5th harmonic corrections with a ratio of 5:2 in cosine to sine parts.

The position at F6 relative to the reference orbit is approximated by assuming the following:

1). The phase advance from the F5 bpm to the F6 septum is equal to the phase advance from the F6 septum to the F7 bpm. The MAD model predicts $\Delta\phi$ from the F5 bpm to the septum is 2π*0.127, and $\Delta\phi$ from the septum to the F7 bpm is 2π*0.075. A value of 2π*0.1 (the average) is used.

2). The values of the vertical beta function at the F5 bpm and the F7 bpm are equal. The MAD model predicts $\beta_{F5}=12.82$ m and $\beta_{F7}=12.54$ m. So the average, a value of $\beta_{av}=12.68$ m, is used.

3). The orbit from F5 to F7 has a peak at the F6 septum aside for its modulation by the beta function.

With these approximations in mind, the position at F6 can be approximated by the following relatively simple equation,

$$\Delta y_{F6}=\frac{\sqrt{\beta_{F6}}}{2\sqrt{\beta_{av}}}\frac{1}{\cos\Delta\phi}(\Delta y_{F5}+\Delta y_{F7})$$

The value of β^v at the septum is $\beta_{F6}=4.203$ m. So, this equation becomes,

$$\Delta y_{F6}\approx 0.36(\Delta y_{F5}+\Delta y_{F7})$$

A set of 12 data points were taken. Each data point was at a different vertical 5th harmonic value with a 5:2 ratio in cosine to sine. The data consisted of the readbacks from the loss monitors at F5, F6, F7, F8, and downstream F5 for each data point. The orbits were taken at 85.3 ms, within 1 ms of extraction.

Using the Booster Loss Monitor program the losses during extraction time throughout the ring were checked to see if any scraping was occurring other than near the septum. At the largest vertical harmonic amplitude there were no significant losses observed except in the extraction area (see figure 1).

III. Results and Analysis

Figure 3 shows the results of the experiment. The data was plotted using a GPM correlation plot of F6 position versus losses. Each unit on the horizontal axis is equal to 0.72 mm. The graph shows that within a range from as little as 12*(0.72 units/mm)= 8.64 mm to possibly as much as 18*(0.72 units/mm)=12.96mm there are essentially no losses. This implies that the beam in the vertical plane is between (27.43-8.64)mm=18.9 mm and (27.43-12.96)mm=14.47mm wide at the septum (27.43 mm is the height of the septum aperture). If one assumes that (18.9+14.47)/4=8.34 mm is the half width of 95% of the beam then σ_v=8.34mm/2.45= 3.41 mm +/- 0.45 mm. Using the following formula the 95% normalized emittance can be calculated (where $\beta\gamma$=2.05):

$$\epsilon^n(95\%) = \frac{6\sigma^2}{\beta_{F6}}(\beta\gamma)_{rel}\pi[mm\text{-}mrad]$$

The result is 34.0π mm-mrad (upper limit=43.6π, lower limit=25.5π). An IPM scan was also taken during this study. It indicated that the normalized vertical emittance was 22π mm-mrad near extraction.

The beam size at the septum can be determined from the IPM emittance data by the following equation:

$$\sigma_{v(ipm)} = \sigma_{v(losses)}\sqrt{\frac{\epsilon^n_{ipm}}{\epsilon^n_{losses}}}$$

This gives an answer of (0.80)*(8.34 mm)=6.71 mm for the 95% vertical half width at the septum as measured by the IPM. This is in rough agreement with the value of 8.34 mm +/- 1.1 mm obtained using the radiation loss technique.

FBI.1	24	M	C1	2	F1	-16
FBI.2	24	M	C2	6	F2	-2
FBI.3	21	M	C3	4	F3	-13
FBI.4	14	M	C4	3	F4	-12
FBI.5	12	M	C5	7	F5	5
FBI.6	20	M	C6	27	F6	1092
FBI.7	19	M	C7	26	F7	1043
FBI.8	20	M	C8	9	F8	102
GLI.1	893		D1	-7	LCH.1	10
GLI.2	92		D2	1	LCH.2	182
GLI.3	-26		D3	-8	LCH.3	15
GLI.4	-13		D4	-5	LCH.4	11
GLI.5	364		D5	-8	SMSK1.5	48
GLI.6	91		D6	15	SMSK1.6	6
GLI.7	-1		D7	38	SMSK1.7	12
GLI.8	0		D8	6	SMSK1.8	8
A1	26		E1	0	SMSK.1	338
A2	28		E2	6	SMSK.2	60
A3	1		E3	-2	SMSK.3	246
A4	-2		E4	2	SMSK.4	75
A5	-5		E5	3	SMSK.5	101
A6	40		E6	3	SMSK.6	28
A7	-4		E7	2	SMSK.7	52
A8	0		E8	11	CIRC_XFMR_NORM	
B1	0					
B2	5					
B3	-2					
B4	-1					
B5	0					
B6	2					
B7	3					
B8	2					

Figure 1: Booster Losses During Extraction. Significant losses occur only near extraction area.

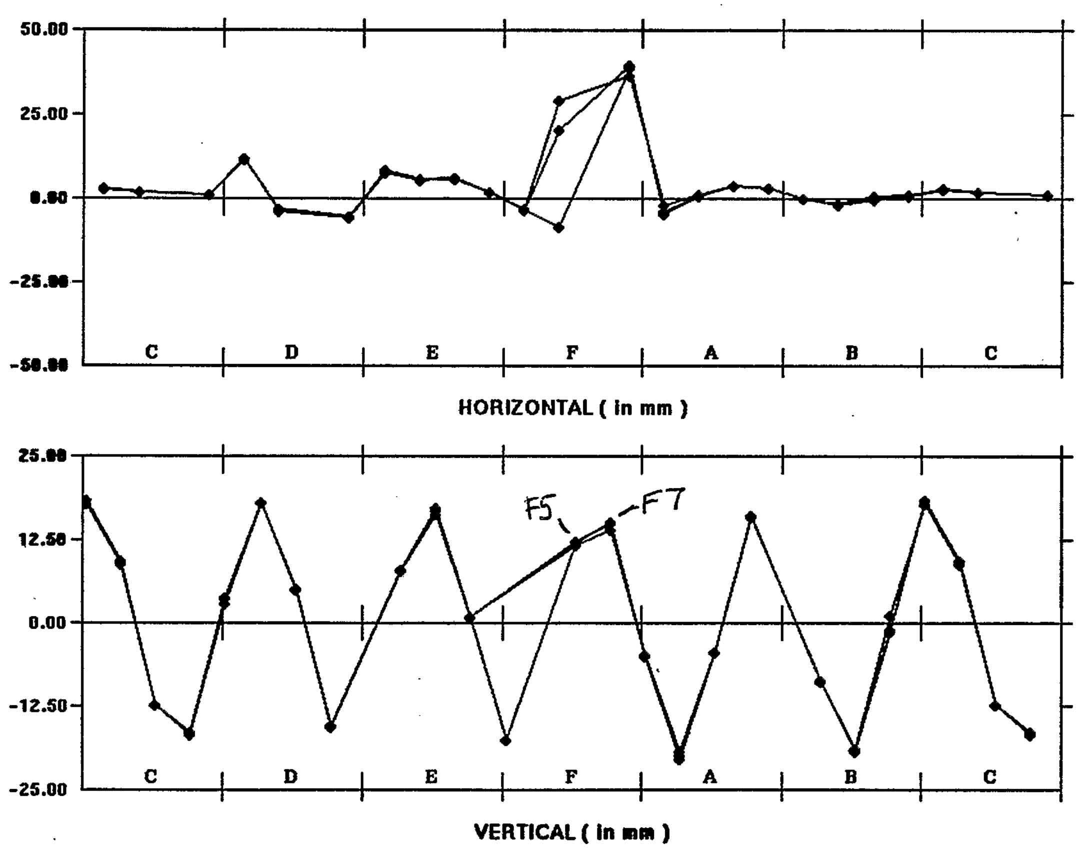

Figure 2: Typical difference orbit used to obtain F6 position.

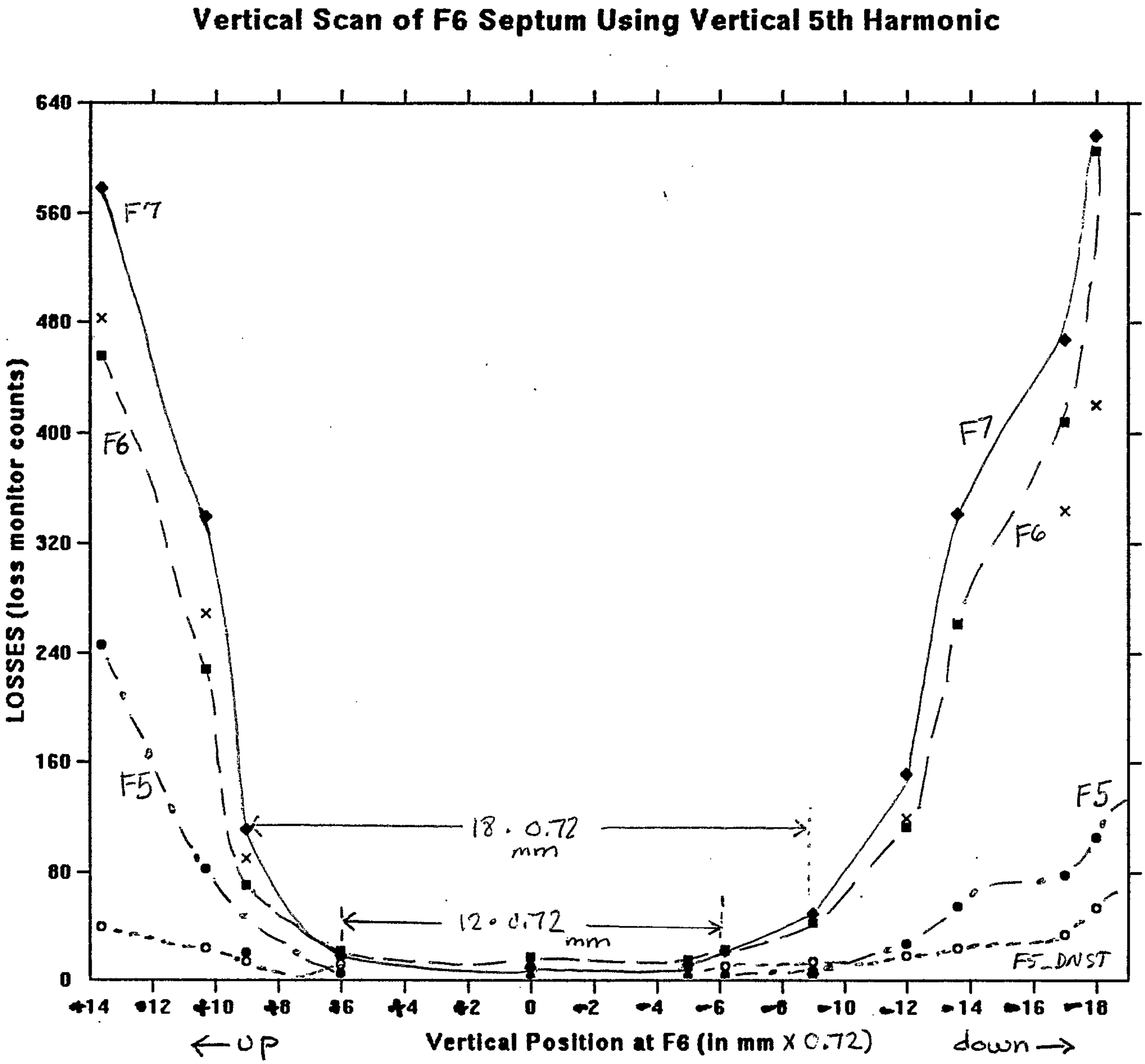

Figure 3: F6 position versus Losses at F5, F6, F7, and F5 downstream.