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Booster Extraction (F3) Kicker: Kick Measurement Using the Beam

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AGS STUDIES REPORT

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Introduction

In preparation for the extraction test during the June 1991 Booster commissioning period, the amount of kick given to the injected beam for each of the four sections of the extraction kicker was measured. An apparent change in the behavior of the kicker--which was being used to abort the beam at injection energy as part of a beam fault test--led to some anxiety as to whether all of the four sections were working in harmony or at all. The study proved this worry to be unfounded. The change mentioned above in our ability to abort all of the beam cleanly locally was probably due to radial or other equilibrium orbit changes in the Booster. Nevertheless, the measurements were made and are reported here. The results are consistent with expectations for the relative kicks for the four kicker sections. We see a larger kick than expected for all sections, but the increase in our uncertainty in extracting an absolute value is unfortunately large enough to cover the discrepancy. The raw data can be found in Booster Commissioning Book II, p. 36.

Experimental Setup

The Booster main magnet power supply was ramping symmetrically (i.e., equal magnitude for dI/dt up and down) to 5 KGauss at a 25 Gauss/ms rate, but had a 300 ms front porch at a magnetic field 5% above the injection field. The study reported here was carried out on that porch. Five chopped turns were being injected from the Linac into rf buckets in the Booster and then accelerated through the cycle. The Booster F3 kicker is made up of four sections, each of which can be fired independently. These sections are identified by number (1 to 4); unfortunately, the No. 1 section is the most downstream section from the point of view of the beam. We took the data following this convention and will continue to use it in this note, although this may cause some confusion. The study involved recording the sum and difference signals from the C8 (horizontal) PUE for an interval of about 50 microseconds centered at the time that each of the four sections of the kicker was energized. The current waveform in the kicker section was also recorded. Different sections were fired on different beam cycles, so the intensity and other more subtle properties of the beam could be different for the different shots. Observation of many cycles showed no obvious variations except for the intensity, which was recorded for each shot. The kicker pulse is designed to be capable of rising to full value between pulses. We did not have the triggering circuitry to give the synchronization necessary to take advantage of this feature and so we partially and nonreproducibly kicked the first bunch. The flattop of the kicker pulse is about 800 ns, which covers the full beam at extraction energy but only two bunches at injection. For these reasons, only one or two of the three bunches experienced a clean kick on the first pass through the kicker. The data itself allows determination of which bunches experienced a clean kick. Further, the kicker need not immediately go back to zero field, since for normal use the beam only sees the kicker on one pass. In fact, the field probably takes a few kicker pulse widths before it has dropped to a negligible level. This possibility meant we could not use the information from the coherent betatron oscillation taken over the next 14 turns to extract the amplitude of the first turn kick. Rather, the first turn amplitude alone had to be used. This substantially reduced the precision of the extracted kick prediction. The many-turn data could be used, by dropping the first few turns, to extract a value for the horizontal betatron tune at this time, which is critical for the extraction of kick amplitude, since we needed to know the phase advance between the kicker section and the C8 PUE. Oddly enough (we wish we could say by design), this phase advance turned out to be almost exactly 2-3/4 phase oscillations; which is to say, the kick or angle given to the beam at F3 was turned into a nearly pure amplitude offset at C8, which of course is what the PUE can see.

At the conclusion of the study, the PUE difference traces associated with the four kicker sections were compared qualitatively, and we concluded that all four sections were kicking (1) in the same direction and with approximately equal strengths, (2) to the outside (provided we knew the polarity of the PUE difference signal--which we thought we did), and (3) with approximately the correct strength. The data has now been analyzed more carefully; the conclusions still hold (the fact that the beam has been extracted with this kicker is also in the book at this point). The third conclusion has been quantified and there may be some disagreement--albeit in the "right" direction--between predicted and observed kick amplitudes, but a lack of knowledge of the PUE sum and difference absolute gains precludes pushing this result.

Analysis

The difference signals for the four sections were analyzed by hand to eliminate bunches chopped by the rising edge of the kicker or by the falling edge. This left two of the original three bunches for kicker section No. 1, one for Sections No. 2 and No. 3, and two for section No. 4. The difference traces were then analyzed by hand to determine the amplitudes at each passing. In particular, these measurements included a few turns before the kick which permits, under the reasonable assumption that there was no coherence at this time, an estimation of the measurement error in the data. Figure 1 gives the difference trace for one of the kicks, Figure 2 gives current transformer signals from the kicker sections taken during the study.

These six sets of data, with the first two turns excluded (to include only data that had all suffered a full sequence of kicks) was fit to a sine wave, with amplitude, tune, a phase offset, and an overall position offset left as parameters. The results are given in Table 1. These results give an internally consistent picture. The fit offsets agree with the measured prekick offsets. The betatron tunes are all the same to 0.002. Even the increase in phase between kicker and PUE as we go from kicker section No. 1 to kicker section No. 4 has the right sign and agrees within errors with the present Booster MAD model (Booster Technical Note No. 196, A. Luccio and M. Blaskiewicz). However, because of the uncertainty about the successive kick strengths on successive passages through the kicker, the only results we take from this are the tune and the average offset. This allows calculation of the phase shift from kicker to PUE, scaling from the Booster MAD model. Actually, one could take the phase shift from the fit and not affect the answer.

The object of the exercise is to predict the kick strengths that were necessary to give the observed oscillations. The error on the measurement of the first passage sets the measurement error contribution to the result. Table 2 gives some inputs and intermediate steps in this calculation. The calibration of the PUEs is approximately: position = (difference at the plates)/(sum at the plates) x 100 mm. The signals in the MCR have additional gain factors due to the optical links between ring and MCR. Although these gains can be measured using the calibrate feature of the PUE system, this was not a high priority activity at the time of the study. The calibration data that exists suggests that the difference is amplified approximately twice as much as the sum, which means one "count" of measurement corresponds to approximately 0.37 mm of motion. This is the number used in the analysis. However, some calibration data gives 2.5 instead of 2 as the relative gain factor, which would reduce the predicted kick by 20%. All the runs save one (section No. 3, bunch 1) had intensities close enough to not require any further correction. The beta functions at kicker and PUE (note the significant variation over the kicker sections) come from the present computer model.

Table 3 gives a comparison of the kicks predicted from this PUE data with the kicks expected from the currents in the sections. The expected results for the kicker sections are derived from a Booster Kicker Data Sheet by J. Mark Stuart, dated February 22,

1989. We simply scale the number on that sheet for the total Bdl at 850 Amps to individual sections (using the physical lengths given on that same sheet (No. 1 and No. 2 are 21.5 inches, No. 3 and No. 4 are 17.9 inches) for the 200 Amps used for this study.

Conclusions

The relative predicted kicks from the beam measurements agree with the relative predicted results from the data sheet within errors. The absolute kicks measured are larger than predicted from the currents by about 30%. All the measurements show this effect. It is much larger than the 10% observed scatter over the different runs. The effect is most simply explained by a global calibration error--the relative gains or the "100 mm" for the PUEs, the scope calibration for the current transformer signals, the momentum of the beam. As we have said, the PUE gains are the weakest link in this chain.

Acknowledgements

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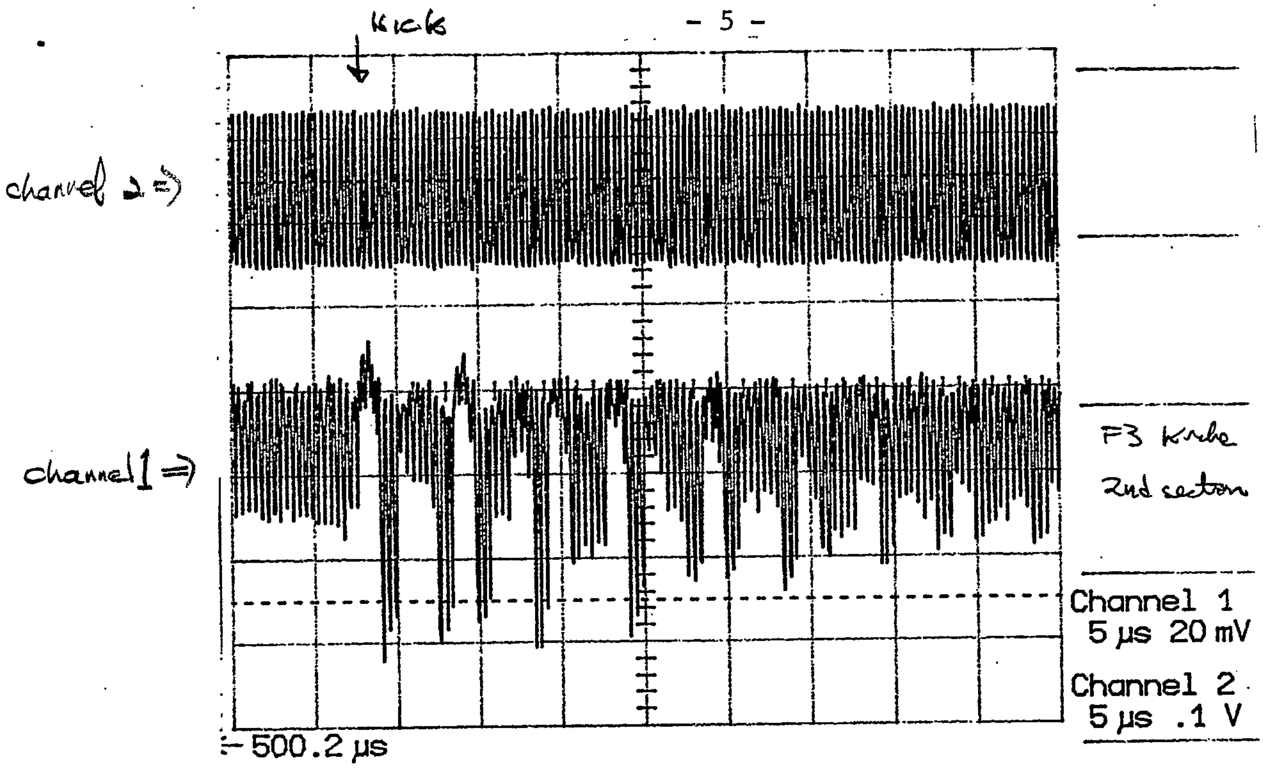
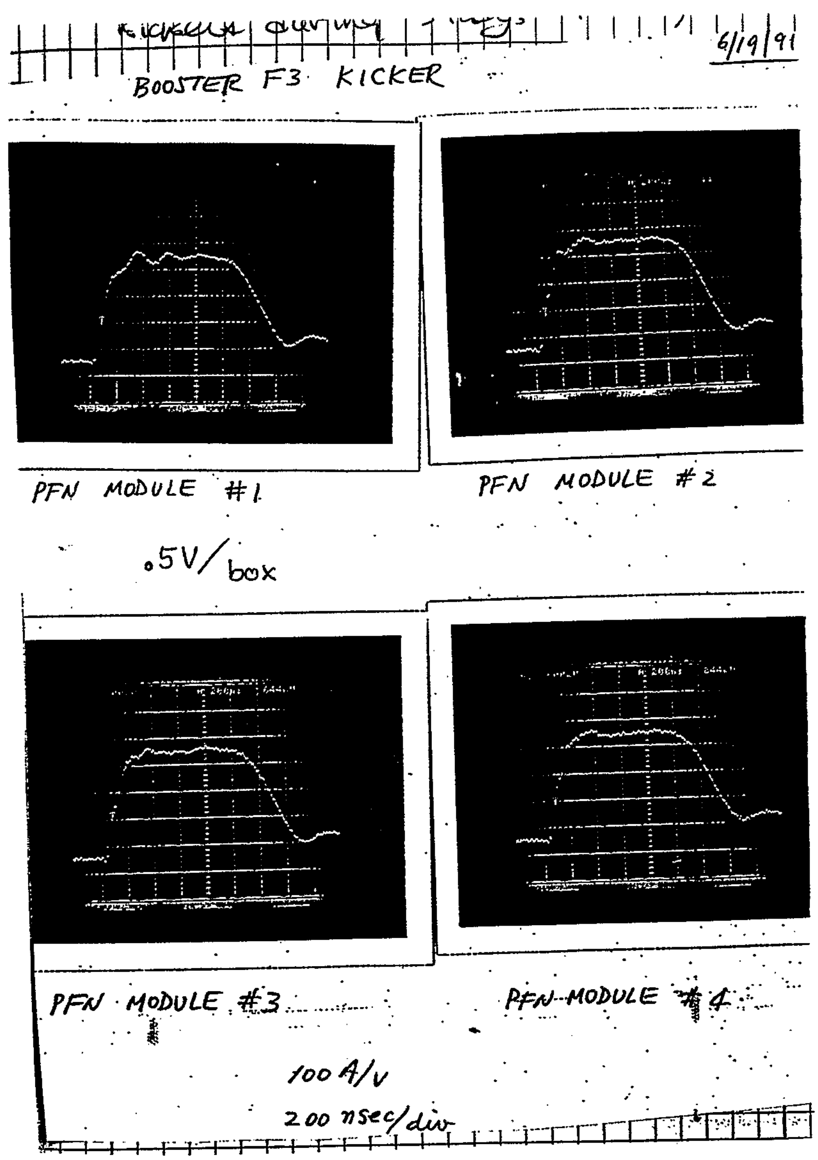


Figure 1 C8 PUE sum (top) + difference (bottom)



Currents in the four kicker sections

Figure 2

$$X(n) = \{A \sin(2\pi(nq + \Delta\psi)) + X_0\}$$

n = turn number , q = fractional part of the tune
A = osc amp X_0 = off set x = measured position
units → "measurement" 1 unit ≃ .37 mm

kick section	bunch	A	$\Delta\psi$	4+q	$q+\Delta\psi-2$ ($\equiv \Delta\Theta$)	X_0	$\langle X_0 \rangle_{meas}$ (±2)
1	1	-29.0	-1.91	4.6126	.703	-23.0	-23.5
		1.2	.02	.0017		.8	
	2	-27.7	-1.89	4.6104	.720	-22.3	-23.8
		1.0	.01	.0014		.7	
2	1	-24.9	-1.90	4.6126	.713	-23.0	-22.3
		1.3	.02	.0021		.9	
3	1	-26.3	-1.89	4.6116	.722	-26.1	-23
		1.5	.02	.0024		1.0	
4	1	-25.8	-1.85	4.6088	.761	-24.7	-25.7
		1.1	.02	.0017		.8	
	2	-24.3	-1.85	4.6087	.762	-23.8	-24.0
		1.8	.03	.0031		1.3	

↑ Q ↑ Kicker - C8 net phaseshift

Table 1 The Fit to the Oscillations

X: position 1st turn $\qquad \beta_{PUE} = 12.6$ meters

X_0 = ave position (fit)

s	b	$(X-X_0)_{K,37}$ (±2)	$=$ (mm)	β_{Kick}	$\sqrt{\beta_K \beta_{PUE}}$ CB	$(\Delta\theta)_{model}$	$\sin(\Delta\theta)$
1	1	11-(-23.0)	12.6	8.826	10.54	.701	.953
	2	9-(-22.3)	11.6	"	"	"	
2	1	5-(-23.0)	10.4	7.379	9.64	.711	.970
3	1	4-(-26.1)	11.87*	6.216	8.847	.723	.986
4	1	9-(-24.7)	12.5	5.034	7.963	.740	.998
	2	10-(-23.8)	12.5	"	"	"	

$$(x-x_0)(mm) = \underset{\uparrow}{(Kick)} * \left(\sqrt{\beta_K \beta_{PUE_{CB}}}\right) \sin(\Delta\varphi)$$

* (increased by factor 1.07 - compensate for low intensity

Table 2 Calculation of Kicks from PUE's

Kicker Section	bunch	absolute Kick: from PUE mrad (±.1)		absolute Kick: from current	Kick / (Kick)ave: PUES			Kick / (Kick)ave: Kicker Current
1	1	1.25	⇔	.94	.94	.90	.88 ⇔	.91
	2	1.15			.86			
2	1	1.11	⇔	.94	.83			
3	1	1.36	⇔	1.13	1.02		1.13 ⇔	1.09
4	1	1.57	⇔	1.13	1.18	1.18		
	2	1.57			1.18			

$$\frac{\langle \text{absolute Kick} \rangle_{PUE}}{\langle \text{absolute Kick} \rangle_{current}} = \frac{1.335}{1.035} = \underline{\underline{1.3}}$$

Table 3 The Kicks PUE vs Current