DECELERATION ORBIT IMPROVEMENTS

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I. Motivation

During the accelerator studies period of 12/90 - 1/91 much study time was dedicated to improving the E760 deceleration ramps. 4 general goals were in mind:

- 1) Reduce the relative orbit deviations from the nominal reference orbit as much as possible. This reduces the potential error in the orbit length calculation—which is the primary source of error in the beam energy calculation (see Pbar Note "BPM System Improvements").
- 2) Maximize the transverse apertures. This minimizes beam loss during deceleration and during accidental beam blow-ups.
- 3) Measure and correct lattice parameters. Knowledge of γ_T , η , Q_h , Q_v , and the dispersion in the straight sections allows for a more accurate energy calculation and reliable SYNCH calculations.
- 4) Minimize the coupling. This allows one to discern between horizontal and vertical tunes.

II. Deceleration Ramps

The E760 deceleration ramps consist of up to 64 momentum points above transition and up to 64 momentum points below transition. At each point the currents of 78 devices are defined (plus RF frequency, RF voltage, 2 skew quad polarity switches, 4 damper delay switches, and 2 Hall probe parameters). Deceleration between points is a linear interpolation. Another ramp table defines momentum as a function of time (Fig. 1). A subset of the 64 ramp points are denoted as "primary" ramp points, and in practice most ramp corrections are made at these primary points only. The currents at other ramp points are derived from a linear interpolation between primary points. An exception to this is the RF frequency, which must be corrected at every ramp point near transition and below transition since frequency is not proportional to momentum at low energies.

III. Studies

A. Closed Orbit Corrections

A horizontal reference orbit was chosen at $P_{beam} = 8374 \text{ Mev/c}$ with an aperture of $A_H = 12\pi \text{ mm-mrad}$; and a vertical reference orbit was chosen at $P_{beam} = 8834 \text{ Mev/c}$ with an aperture of $A_V = 10\pi \text{ mm-mrad}$ (Fig. 2). It is required that this orbit be approximately centered in the machine, but more closely centered at A50 (interaction region) and A60 (2-4 momentum pickup). The 4-8 momentum pickup is at A20 and can be moved to be centered on the beam.

Orbits at other energies were adjusted so as to minimize the deviation from the reference orbit. Horizontal deviations were kept to $< \pm 5 \text{ mm}$, and vertical deviations were kept to $< \pm 2 \text{ mm}$. The RF frequency was adjusted to keep $|\Delta p/p| \leq .0001$. A typical difference orbit is shown in Fig. 3.

The general procedure used to correct orbits was the following. First a global orbit correction was made using P53 "FIX CLOSED ORBIT." This usually left a few excessively large local bumps which were then eliminated using P53 "4-BUMPS AND 3-BUMPS." Both these procedures were often iterated; and after a few corrections, the beam would be dumped, busses recycled, and new beam decelerated to the energy of interest. This was necessary to overcome the problem of hysteresis in the main dipole magnets. As beam momentum was lowered, "FIX CLOSED ORBITS" became less and less effective for horizontal corrections and eventually all corrections had to be made with local bumps. "FIX CLOSED ORBITS" was generally very effective in smoothing the vertical orbit and only occasionally was it necessary to make local bumps to smooth the vertical orbit. Fig. 4 shows the above-transition ramps for A:IB and A:BS310. The erratic nature of the BS310 ramp at the beginning of the ramp is typical of horizontal trims and shunts and has two probable causes: saturation of the dipoles and large quadrupoles at high currents, and inadequate orbit correction software.

B. Apertures

After smoothing the orbits to the above criteria, the apertures were measured and typically found large enough such that no more corrections were necessary. Fig. 5 shows the horizontal and vertical apertures compared with the apertures obtained with the ramps used during the E760 run of 5/90 to 9/90. During E760 running, emittances are typically kept at about $1 \pi \text{ mm-mrad}$ and during deceleration they typically grow to $\sim 4\pi \text{ mm-mrad}$. The dramatic drop in apertures just after transition is due to the large quadrupoles mis-steering the beam during transition crossing (no trims or shunts are ramped during transition crossing). This also reduces the momentum aperture from $> 1\%$ above transition to $.75\%$ below transition with the beam positioned only $\sim 9 \text{ Mev}$ from the edge of the momentum aperture. For this reason, care must be taken when bunching the beam below transition. This problem would be greatly mitigated if the beam could be accurately and easily centered in the quadrupoles.

C. Tunes, chromaticity, γ_T , and Coupling

At each primary ramp point the tunes were adjusted using the mults shown in Fig. 6. These mults worked well at all energies. The tunes were kept at $Q_h = .614 \pm .003$ and $Q_v = .611 \pm .003$. Adjusting the tunes had some effect on the orbits and vice versa, therefore these two corrections often had to be repeated.

The chromaticity was only occasionally adjusted. The mults shown in Fig. 6 were used, although the horizontal and vertical are not at all decoupled with these mults. For the most part, the sextupoles are ramped down linearly with momentum

γ_T was adjusted by changing the LQ current a large amount and QT, QD, QF smaller amounts to maintain constant tune. The change in γ_T is given approximately by

$$d\gamma_T = (dLQ/60amps) \cdot P_{beam}/5174 \quad (1)$$

where P_{beam} is in Mev/c. Fig. 7 shows γ_T as a function of momentum.

An attempt was made to decouple the tunes at all energies, however below transition this became progressively more difficult (reason unknown). At 3594 Mev/c the tunes appear to be almost completely coupled. The 2 skew quads, SQ100, and SQ607, have polarity switches on them which can be changed during deceleration, but we were unable to find a polarity combination which eliminated coupling at low energies.

IV. Conclusions

The deceleration ramps generated during the 12/90 - 1/91 studies period should be adequate for the coming E760 run, and represent a small improvement over the previous set of ramps in orbit uniformity. A fairly complete library of measurements for these ramps is contained in the "E760 Ramps Notebook" generally kept at AP10.

Developing new ramps in the future would be greatly facilitated by an improved orbit correction Application Program. The orbit corrections were by far the most time-consuming part of this effort.

P81 BEAM DECELERATION IN THE ACCUMULATOR (II) ♦COPIES♦

*LX♦ X-A/D X=TIME Y=L:TESCAR, :QB15F ,T QA45 ,T QA45F
 Eng-U I= 0 I= 0 , -50 , -50 , -50
 One+ AUTO F= 400 F= 1 , 50 , 50 , 50

momentum = 5174 mev time = 0secs

READ FROM SCREEN		WRITE TO SCREEN		-<-1>+ A:		-< 0>+ A:		RETURN
seconds	mom(Mev)	seconds	mom(Mev)	seconds	mom(Mev)	seconds	mom(Mev)	
1 0	5174 P	17 22	4754	33 54	4114	49 86	3474	
2 1	5164	18 24	4714	34 56	4074	50 88	3434	
3 2	5154	19 26	4674	35 58	4034 P	51 90	3394	
4 3	5134 P	20 28	4634	36 60	3994	52 92	3354	
5 4	5114	21 30	4594	37 62	3954	53 94	3314	
6 5	5094	22 32	4554	38 64	3914	54 96	3274	
7 6	5074	23 34	4514	39 66	3874	55 98	3234	
8 7	5054	24 36	4474	40 68	3834	56 100	3194	
9 8	5034	25 38	4434 P	41 70	3794	57 102	3154	
10 9	5014	26 40	4394	42 72	3754	58 104	3114	
11 10	4994	27 42	4354	43 74	3714	59 106	3074	
12 12	4954	28 44	4314	44 76	3674	60 108	3034	
13 14	4914	29 46	4274	45 78	3634	61 110	2994	
14 16	4874	30 48	4234	46 80	3594 P	62 112	2954	
15 18	4834 P	31 50	4194	47 82	3554	63 114	2914	
16 20	4794	32 52	4154	48 84	3514	64 116	2874	

BELOW TRANSITION

P81 BEAM DECELERATION IN THE ACCUMULATOR (II) ♦COPIES♦

*LX♦ X-A/D X=TIME Y=L:TESCAR, :QB15F ,T QA45 ,T QA45F
 Eng-U I= 0 I= 0 , -50 , -50 , -50
 One+ AUTO F= 400 F= 1 , 50 , 50 , 50

momentum = 8834 mev time = 0secs

READ FROM SCREEN		WRITE TO SCREEN		-<-1>+ A:		-< 0>+ A:		RETURN
seconds	mom(Mev)	seconds	mom(Mev)	seconds	mom(Mev)	seconds	mom(Mev)	
1 0	8834 P	17 32	8194	33 76	7314	49 139	6054	
2 2	8794 P	18 34	8154	34 79	7254 P	50 143	5974	
3 4	8754	19 36	8114	35 83	7174	51 147	5894	
4 6	8714	20 38	8074 P	36 87	7094	52 151	5814 P	
5 8	8674 P	21 40	8034	37 91	7014	53 155	5734	
6 10	8634	22 43	7974	38 95	6934	54 159	5654	
7 12	8594	23 46	7914	39 99	6854	55 163	5574	
8 14	8554 P	24 49	7854	40 103	6774 P	56 167	5494	
9 16	8514	25 52	7794	41 107	6694	57 171	5414	
10 18	8474	26 55	7734 P	42 111	6614	58 175	5334 P	
11 20	8434	27 58	7674	43 115	6534	59 179	5254	
12 22	8394	28 61	7614	44 119	6454	60 183	5174 P	
13 24	8354 P	29 64	7554	45 123	6374	61 187	5094	
14 26	8314	30 67	7494	46 127	6294 P	62 191	5014	
15 28	8274	31 70	7434	47 131	6214	63 195	4934	
16 30	8234	32 73	7374	48 135	6134	64 199	4854	

ABOVE TRANSITION

FIG. 1: Deceleration ramp tables showing momentum vs. time; "primary" ramp points are denoted by "P"

ACCUMULATOR CLOSED ORBIT (HORIZONTAL)

A:RILLFS 52.624 A:R3HLFB .2495869
A:IBEAM .0032
RECORD 169 CO Date/Time: 1/11/91 0202:38 NEW E760 REF FILE- HORIZ. ONLY:
AVG OVER 20 FRAMES (20 20 20 20 20 20)
Deltap/p = 0

BEAM POSITIONS (mm)

A1Q1 -1.59	A2Q14 -3.81	A3Q1 2.06	A4Q14 1	A5Q1 -4.26	A6Q14 -6.22
A1Q3 3.4	A2Q11 3.81	A3Q3 1.06	A4Q11 6.22	A5Q3 -1.26	A6Q11 6.22
A1Q4 7.23	A2Q10 5.02	A3Q4 5.74	A4Q10 -4.62	A5Q4 1.73	A6Q10 -8.24
A1Q6 -4.93	A2Q8 7.73	A3Q6 8.77	A4Q8 -9.65	A5Q6 7.76	A6Q8 -2.93
A1Q8 7.73	A2Q6 -4.6	A3Q8 1.4	A4Q6 .4	A5Q8 8.77	A6Q6 -1.59
A1Q10 -2.21	A2Q4 11.72	A3Q10 -3.41	A4Q4 -1.26	A5Q10 -8.24	A6Q4 -3.26
A1Q11 -5.02	A2Q3 2.06	A3Q11 7.43	A4Q3 2.06	A5Q11 1.4	A6Q3 -1.59
A1Q14 3.41	A2Q1 4.4	A3Q14 7.03	A4Q1 -1.26	A5Q14 -5.02	A6Q1 -1.26

ACCUMULATOR CLOSED ORBIT (VERTICAL)

A:RILLFS 52.82441 A:R3HLFB 96.69649
A:IBEAM 2.812
RECORD 168 CO Date/Time: 12/14/90 2026:21 NEW E760 REF FILE FOR ORBIT CORR
AVG OVER 40 FRAMES (20 20 20 20 20 20)

BEAM POSITIONS (mm)

A1Q1 5.94	NO PU NO MUX	A3Q1 2.59	NO PU NO MUX	A5Q1 -.06	NO PU NO MUX
A1Q2 1.93	A2Q14 .65	A3Q2 2.26	A4Q14 -.6	A5Q2 -2.06	A6Q14 -1.78
A1Q5 -1.5	A2Q13 1.72	A3Q5 6.27	A4Q13 1.9	A5Q5 -4.06	A6Q13 -1.86
A1Q7 -.06	A2Q9 .26	A3Q7 -4.73	A4Q9 -1.73	A5Q7 -3.73	A6Q9 2.26
A1Q9 -1.73	A2Q7 -2.73	A3Q9 1.59	A4Q7 7.28	A5Q9 1.26	A6Q7 -6.07
A1Q13 -.6	A2Q5 .59	A3Q13 -.24	A4Q5 -1.4	A5Q13 .47	A6Q5 3.59
A1Q14 .65	A2Q2 1.26	A3Q14 .29	A4Q2 1.26	A5Q14 .65	A6Q2 -1.06
NO PU NO MUX	A2Q1 3.93	NO PU NO MUX	A4Q1 1.93	NO PU NO MUX	A6Q1 2.26

FIG. 2: The horizontal and vertical reference orbits used in making orbit corrections

ACCUMULATOR CLOSED ORBIT (HORIZONTAL)

A:RILLFS 52.792 A:R3HLFB 258.8615
A:IBEAM 4.57

CO Date/Time: 12/18/90 0653:52
AVG OVER 20 FRAMES (20 20 20 20 20 20) FILE 168 HAS BEEN SUBTRACTED
Deltap/p = 0

BEAM POSITIONS (mm)

A1Q1	-1	A2Q14	1.21	A3Q1	.67	A4Q14	-2.4	A5Q1	-2.01	A6Q14	1.21
A1Q3	0	A2Q11	2.41	A3Q3	1	A4Q11	-2.41	A5Q3	-2.33	A6Q11	1.21
A1Q4	-.5	A2Q10	2.41	A3Q4	-.33	A4Q10	-1.2	A5Q4	-1.32	A6Q10	0
A1Q6	-1.34	A2Q8	-1.5	A3Q6	-3.67	A4Q8	1.69	A5Q6	1.33	A6Q8	-2
A1Q8	2.47	A2Q6	3.99	A3Q8	-4.65	A4Q6	1.99	A5Q8	4.07	A6Q6	2.33
A1Q10	-1.21	A2Q4	3.53	A3Q10	1.21	A4Q4	.33	A5Q10	-2.41	A6Q4	-2.67
A1Q11	-2.41	A2Q3	-.33	A3Q11	1.21	A4Q3	-.66	A5Q11	-2.41	A6Q3	-3.99
A1Q14	-2.41	A2Q1	0	A3Q14	1.21	A4Q1	-1	A5Q14	-1.2	A6Q1	-3.34

ACCUMULATOR CLOSED ORBIT (VERTICAL)

A:RILLFS 52.792 A:R3HLFB 258.8615
A:IBEAM 4.57

CO Date/Time: 12/18/90 0653:52
AVG OVER 20 FRAMES (20 20 20 20 20 20) FILE 168 HAS BEEN SUBTRACTED

BEAM POSITIONS (mm)

A1Q1	-.34	NO PU NO MUX	A3Q1	.34	NO PU NO MUX	A5Q1	-1	NO PU NO MUX	
A1Q2	-.34	A2Q14	-.71	A3Q2	0	A4Q14	.71	A6Q14	-.18
A1Q5	-.48	A2Q13	-.9	A3Q5	-1.34	A4Q13	.72	A5Q5	.66
A1Q7	1.65	A2Q9	0	A3Q7	1.33	A4Q9	-1.33	A5Q7	0
A1Q9	.33	A2Q7	1	A3Q9	-1.33	A4Q7	.68	A5Q9	-.67
A1Q13	.36	A2Q5	-.33	A3Q13	.89	A4Q5	-1	A5Q13	.18
A1Q14	0	A2Q2	.67	A3Q14	.36	A4Q2	.33	A5Q14	0
NO PU NO MUX		A2Q1	.67	NO PU NO MUX		A4Q1	0	NO PU NO MUX	
								A6Q1	0

FIG. 3: A typical difference orbit; beam momentum = 6214 Mev/c

FIG. 4: Bend bus current as a function of beam momentum; shunt current as a function of momentum

FIG. 5: Horizontal and vertical apertures as a function of momentum, as compared to previous deceleration ramps

P79 TUNES, GAMMAT, COUPLING SET D/A A/D Eng-U ♦COPIES♦
-<FTP>+ *LX♦ X-A/D X=TIME Y=L:CGAUSS,L T2CHIP,B ELCWSP,B WLCWSP
COMMAND ---- Eng-U I= 0 I= 140 , 0 , 90 , 90
-< 1>+ One+ AUTO F= 1200 F=-140 , 80 , 130 , 130
params MULTS apert cool'n radmon gasdet stackn paux.. bumps

MULT:4 HOR TUNE QT .00446
-A:LQ*-.021 ACCUMULATOR LARGE QUA 0 * 0 Amp *T.
-A:QT*.225 ACCUMULATOR QUAD TRIM 0 * .0003 Amp *T.
-A:QDF*-.051 ACCUMULATOR QUAD DF B 0 *- .0007 Amp *T.
-A:QSD*2 QDF DEFOCUSIN SHUNT 0 * .065 AMP

MULT:4 VER TUNE QT -.03448
-A:QT*-.03 ACCUMULATOR QUAD TRIM 0 * .0003 Amp *T.
-A:QDF*.041 ACCUMULATOR QUAD DF B 0 *- .0007 Amp *T.
-A:QSF1*.623 QDF FOCUSIN SHUNT # 1 0 * 0 AMP
-A:LQ*.008 ACCUMULATOR LARGE QUA 0 * 0 Amp *T.

-A:SQ607*.1 SKEW QUAD 100AMP 35.69 * 20 -95AMP *TL
-A:SQ607R SQ607 POLARITY REVERSAL 0 VOLT +
-A:SQ100*.1 SKEW QUAD 200AMP 3.064 * 20 -95AMP *TL
-A:SQ100R SQ100 POLARITY REVERSAL 0 VOLT +

-A:LQ*.01 ACCUMULATOR LARGE QUA 0 * 0 Amp *T.
-A:QT*.01 ACCUMULATOR QUAD TRIM 0 * .0001 Amp *T.

P79 CHROMATICITY MULTS SET D/A A/D Eng-U ♦COPIES♦
-<FTP>+ *LX♦ X-D/A X=B:HL21 Y=B:HL21 ,M ABTHR , ,
COMMAND ---- Eng-U I=-10 I=-10 , -2 , -10 , -10
-< 3>+ r_14 Auto F= 10 F= 10 , 10 , 10 , 10
params MULTS apert cool'n radmon gasdet stackn paux.. bumps

MULT:2 HORIZ CHROM
-A:SEX10*1.16 Q10 SEX 600A/100V SEX 392.4 * 20 -95AMP *TL
-A:SEX12*2.28 Q12 SEX 600A/100V SEX 422.5 * 20 -95AMP *TL

MULT:2 VERT CHROM
-A:SEX10*1.16 Q10 SEX 600A/100V SEX 392.4 * 20 -95AMP *TL
-A:SEX12*3.29 Q12 SEX 600A/100V SEX 422.5 * 20 -95AMP *TL

FIG. 6: Tune mults and chromaticity mults

FIG. 7: Transition gamma as a function of beam energy; also shown are the dispersions at the straight sections