Pbar Note 611

Fermilab Antiproton Source

Calculation of Accumulator Deceleration Ramps

Guidelines for the Calculation of the Accumulator Magnet Bus Ramps for Fermilab Experiment E835

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April 15, 1999

Overview

This report lists the steps that are required to calculate deceleration ramps for all relevant Accumulator devices. The ramps used for the 1996-97 fixed target run (experiment E835) are saved in files associated with ACNET console application PA1627 (PAUX RAMP DEVELOP). These ramps cannot be re-used because the Accumulator γ_t upgrade has significantly changed the lattice since the last time the ramps were used. Consequently, new deceleration ramps must be calculated and commissioned before the next fixed target run.

The deceleration ramp for a particular device is a table that gives the sequence of set values sent to the device as the ramp is executed. The 1997 ramps consist of ramp tables for 100 devices. Appendix 1 gives a list of the devices ramped. Most of these devices will still require ramps for the next fixed target run. Future decelerations will also require ramps for the quadrupole magnet shunts that were installed as part of the γ_t upgrade. Additionally, ramps must be constructed for the two skew-sextupole magnets that will be installed during the summer of 1999.

The Beam Momentum and Bend Field Ramps

The deceleration ramp index (i.e. the quantity that labels the rows of each ramp table) is a pseudo ACNET device called X:POFTT. The value of POFTT is approximately the beam momentum. The actual value of the beam momentum at each point in the ramp is determined by the bend bus (A:IB) ramp. The bend bus ramp determines the rate at which deceleration proceeds. A:IB is chosen to decrease linearly with beam momentum[1]. The above transition A:IB ramp for the 1997 fixed target run is shown in Figure 1.

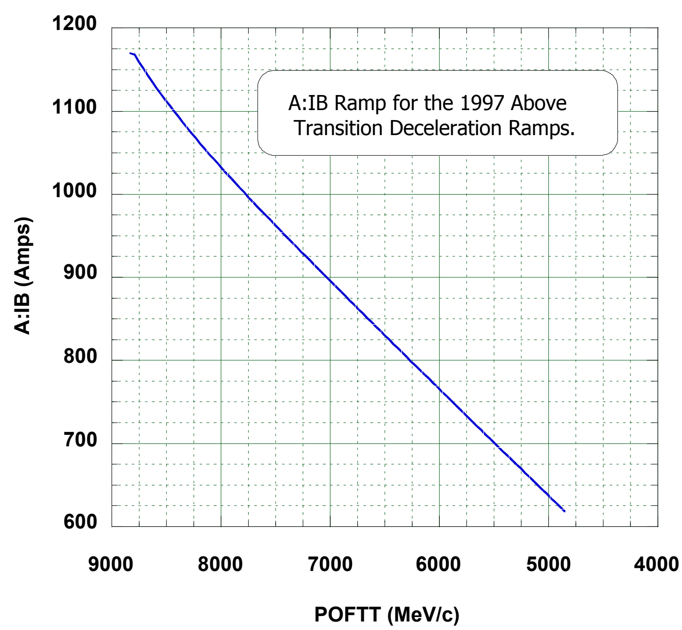

Figure 1. The above transition portion of the A:IB ramp used for the 1997 fixed target run.

[1] A:IB does not change from the first ramp point to the second. The first step of the ramp is to move the beam with RF from the core orbit to the central orbit. Subsequent deceleration proceeds on the central orbit.

The bend field as a function of momentum, $B(p)$, is:

$$B(p) = \frac{p}{e\rho} \tag{1}$$

where, ρ is the radius of curvature through the main bending dipoles. Computation of the A:IB ramp requires knowledge of the magnet excitation transfer functions for the main bending dipoles in the Accumulator. For a dipole that bends the beam through an angle Θ, the bend bus current, $I_B(p)$, is determined by solving equation (2) below. If dipole shunt corrections are ignored, $I_B(p)$ is the A:IB ramp.

$$\begin{aligned} \Theta &= \frac{1}{B\rho}\int_0^{L_{eff}} Bdl \\ &= \frac{e}{p}\sum_{n=0}^{4} a_n [I_B(p)]^n \end{aligned} \tag{2}$$

L_{eff} is the effective length of the magnet. The coefficients a_n are the excitation parameters for that dipole. The Accumulator contains five types of main bending dipole. Table I gives the bend angle (Θ) for each type.

Table I

Magnet Type	**Θ (degrees)**	**Location (s = sector number)**
SDA	15 °	AsB8
SDB	10 °	AsB7
SDC	5 °	A3B3, A4B3, A5B3, A6B3
LDA	15 °	AsB9, AsB10
MDC	5 °	A1B3, A2B3

MTF (Fermilab Magnet Test Facility) recently measured an Accumulator SDB dipole. Figure 2 shows the excitation curve for this magnet. Equation (2) can now be solved for $I_B(p)$, at $p = POFTT$ for each row in the ramp tables, using the a_n's given in Figure 2.

A few words about POFTT

While it is desirable to make X:POFTT as close to the actual beam momentum as possible, it is probably best to think of it only as the ramp table index and not as the beam momentum. The function of POFTT is solely to label the rows of the ramp table. Here are a few useful facts regarding POFTT:

1. The starting point for all decelerations is at 8 GeV with beam on the core orbit. This is the top of the ramp (i.e. the first table value) and corresponds to POFTT = 8833.888 MeV/c. The actual momentum of beam on the core orbit is 8769 MeV/c. The first step of the ramp (from table point 1 to table point 2) moves the beam with RF to the central orbit. A:IB is not changed during this step. Moving the beam from the core to the central orbit actually accelerates the beam by approximately 60 MeV/c. However, rather than following the beam momentum, POFTT, acting as a proper ramp index, decreases.

2. The rate at which POFTT changes with time is controlled by a time ramp. The entries in the time ramp are the number of 60 Hz ticks between successive table values of POFTT.
3. POFTT is frequently given as an integer. In addition, the console applications that manage deceleration often require POFTT input values be entered as 4-digit integers. One integer unit of POFTT is 1/209.7088 MeV/c. The relationship between the integer POFTT (denoted by N_{POFTT}) and the floating point POFTT is:

$$POFTT = \frac{[N_{POFTT} \times 209.7088 + 0.5]}{209.7088}$$

where [...] indicates truncation.

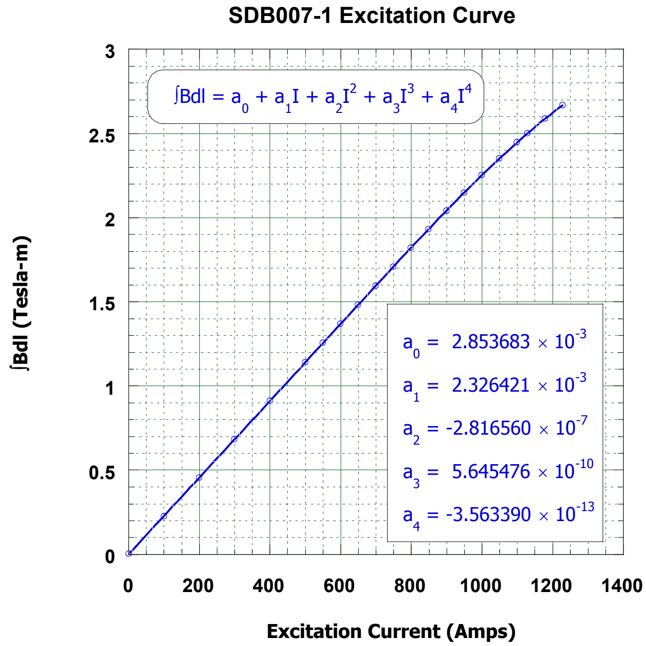

Figure 2. The excitation curve from the May 1996 measurements of SDB007-1.

The γ_t Ramp

The 8 GeV Accumulator lattice upgrade design value of γ_t is 6.58357. This corresponds to a center of mass energy at transition of 3654 MeV (p_{beam} = 6105.5 MeV/c). Preserving this value of γ_t on the ramp places all of the charmonium states below the open charm threshold (except the ψ') below transition. Rather than face the operational difficulties and the machine limitations associated with a transition crossing on almost every deceleration, it has been decided to change γ_t on the ramp so that all of the energies of interest lie above transition. The following considerations determine the γ_t ramp:

1. A small component of the uncertainty in the beam energy measurement is the effect of lattice differences between the reference energy and every other point where the energy is measured. Operating with the same Accumulator lattice at all energies where accurate beam energy measurement is required eliminates this uncertainty. This requires that γ_t reach its final (minimum) value before momentum ramp reaches the ψ' energy ($p_{beam}(\psi') \cong 6232$ MeV/c). Thus one constraint on the γ_t ramp is that **the minimum value of γ_t must be reached before p_{beam} = 6250 MeV/c.**

2. The lowest energy of interest in the upcoming E835 run is that of the χ_0 resonance ($M(\chi_0) \cong 3415$ MeV/c^2, $p_{beam}(\psi') \cong 5192$ MeV/c). The χ_0 is wide ($\Gamma \cong 13.5$ MeV/c^2), therefore, we require that the χ_0 resonance be at least $5 \times \Gamma$ above transition. This imposes the constraint that **the minimum value of γ_t must be below a value given by: $\gamma_t = 5.31$.**

3. The stochastic cooling must work properly at all energies where E835 data taking is anticipated. Therefore, we require a "reasonable value" for the bad (pickup to kicker) mixing factor associated with the transverse stochastic cooling[2]. The mixing factor, *M*, is given by:

$$M = \frac{f_{rev} \ln 2}{W|\eta|\left(\frac{\Delta p}{p}\right)} \tag{3}$$

where *W* is the cooling microwave bandwidth (4 GHz) and Δp is the beam momentum spread. η is given by:

$$\eta = \frac{1}{\gamma_t^2} - \frac{1}{\gamma^2} \tag{4}$$

From equation (4) it is apparent that η gets small near transition. Equation (3) shows that a decreasing value of η increases *M* and therefore increases the bad mixing. There are two remedies available: (i) lower γ_t, and/or (ii) increase Δp. **For a beam rms momentum spread of $\sigma_p = 2.0$ MeV/c ($\sigma_{Ecm} \cong 550$ MeV), the value of value of γ_t must be less than approximately 4.8 for the bad mixing to be no worst than it is at 8 GeV.**

4. We also require the value of η to be large enough to avoid the onset of longitudinal instability. Longitudinal stability requires the longitudinal impedance (*Z/n*) of the Accumulator to be less than the impedance threshold (*Z/n*) given by the Keil-Schnell stability criterion. The Keil-Schnell requirement is:

$$\left(\frac{Z}{n}\right)_{thresh} < F\,\frac{2\pi|\eta|\beta E_{beam}}{eI_{beam}}\left(\frac{\sigma_p}{p_{beam}}\right)^2 \tag{5}$$

where *F* is a beam shape form factor and is of order unity. The largest impedance in the Accumulator are the ARF3 cavities, which contribute approximately 1500 Ω per cavity at n = 2. Therefore, in view of equation (5), we require the quantity $\eta\sigma_p^2/I_{beam}$ to be large enough to make the threshold (*Z/n*) greater than about 750 Ω[3]. **At the χ_0, longitudinal stability of the beam requires that γ_t be less than approximately 4.8.**

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[2] The momentum cooling imposes a less serious constraint since pickups and kickers are farther apart

[3] I am assuming here that we will operate with one of the ARF3 cavities shorted.

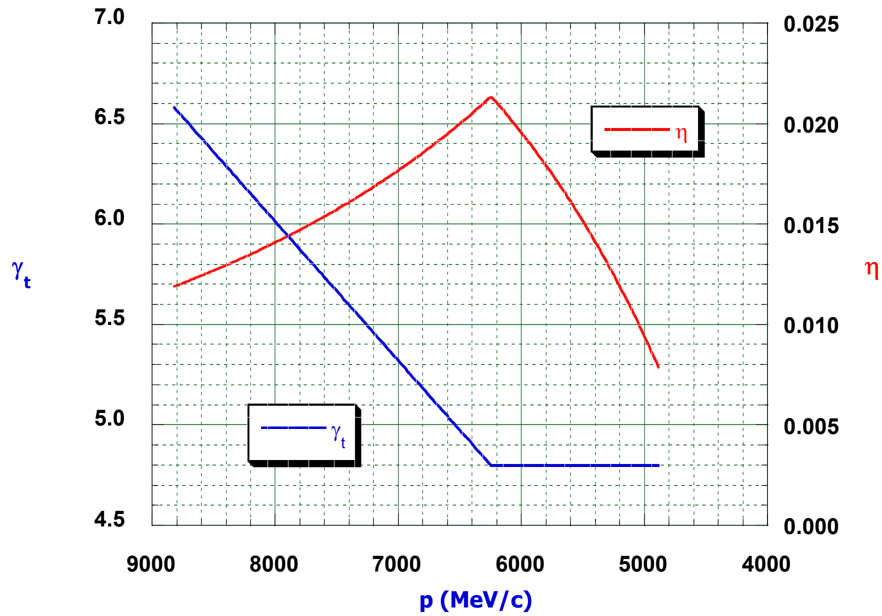

Figure 3. γ_t ramp of equation (6) and the resulting η ramp.

Considerations 3 and 4 above indicate that the minimum γ_t on the ramp should not be greater than about 4.8. Moreover, a smaller γ_t at the low energy end of the ramp is better for both cooling and longitudinal stability. A γ_t ramp that satisfies all of these constraints is specified in equation (6) below:

$$\gamma_t(p) = \begin{cases} \gamma_t(top) - \dfrac{\gamma_t(top) - \gamma_t(\min)}{p_{top} - p_{phys}}(p_{top} - p) & p_{top} > p > p_{phys} \\ \gamma_t(\min) & p < p_{phys} \end{cases} \qquad (6)$$

where $\gamma_t(top)$ is the Accumulator lattice upgrade design γ_t (6.58357), $\gamma_t(min)$ is the value of γ_t for that part of the ramp where E835 takes physics data ($\gamma_t(min)$ = 4.80), p_{top} is the beam momentum at injection energy (8827.385 MeV/c), and p_{phys} is the beam momentum that marks the beginning of the energies of interest to experiment E835 (p_{phys} = 6250 MeV/c). Figure 3 shows the γ_t ramp of equation (6) as well as the resulting η ramp. The mixing and (Z/n) threshold for the γ_t ramp is shown in Figure 4.

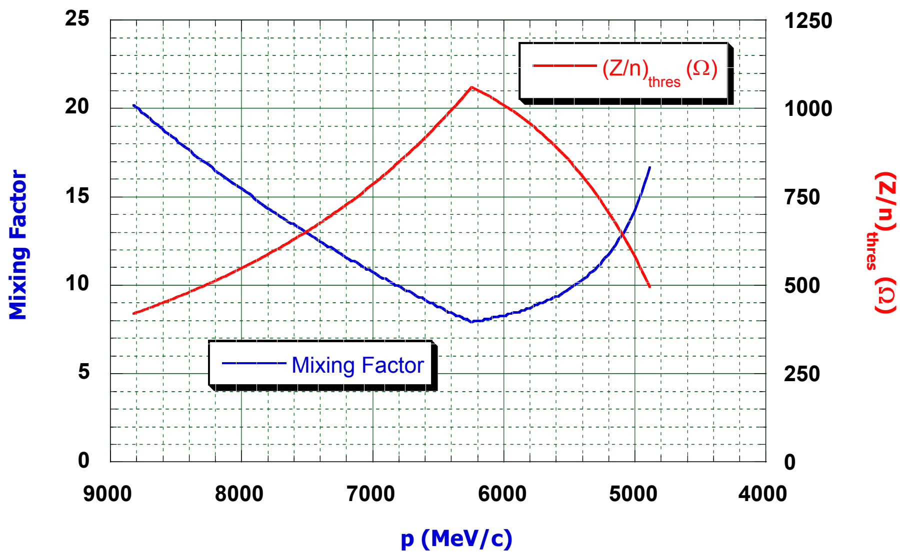

Figure 4. Variation of the cooling Mixing Factor and the threshold impedance for longitudinal instability on the γ_t ramp of equation (6) for I_{beam} = 80 mA beam and σ_p = 2.0 MeV/c.

Other Considerations

Several other issues constrain the Accumulator lattice at any point in the deceleration ramps. There are also a number of deceleration issues not related to the lattice. This section contains a list of some of these considerations.

1. Tunes and chromaticity – the operating point must be far from sum resonance lines in the tune plane. We should maintain the same tunes throughout the ramp to minimize the area traversed by the beam in the tune plane during a deceleration. Longitudinal stability calls for a positive chromaticity while minimizing the area occupied in the tune plane calls for a small chromaticity. Therefore, the chromaticity in both plans should be small and positive – but not zero.
2. For that portion of the ramp where E835 data taking is likely to take place the betatron phase advance from pickup to kicker for the transverse cooling systems should be within 20° of an odd multiple of 90°.
3. For proper operation of the momentum cooling, the dispersion at A30 and A50 should be as close to zero as possible (not more than about 1 cm).
4. Aperture considerations require the beta functions in both planes at the center of the zero dispersion straight sections to be small (< 8 m). However, to avoid degrading the sensitivity of the various pickups at A10, the beta functions should be kept greater than about 5 m – at least in the data taking part of the ramps. Elsewhere, in the lattice, the beta functions should be as small as possible.
5. Pay attention to Damper pickup to kicker phase advances. ????(They are hosed at 8 GeV – so it's hard to imaging making them worse).
6. Constant bucket area ramp for ARF3 voltage.
7. Upgrade deceleration console software to include ramp tables for the lattice upgrade quad shunts and the new skew sextupoles.

8. Verify that both ARF3 cavities are Robinson stable (i.e. $2f_{rev}$ > frequency of peak cavity response).
9. Precision measurements of η require an accurate calibration of ARF3 cavity voltage versus the fanbacks at AP10.

Appendix A 1997 Fixed Target Run Ramped Devices

Device Index	PAUX Device	ACNET Device	Description
0	X:POFTR	X:POFTT	Ramp index (~ Beam momentum)
1	X:IBR	A:IB	Bend Bus
2	X:LQR	A:LQ	Large Quad Bus
3	X:QDFR	A:QDF	Focusing/Defocusing Bus
4	X:QSF1R	A:QSF1	Focusing Shunt on Focusing/Defocusing Bus
5	X:SQ100R	A:SQ100	Skew Quad
6	X:SQ607R	A:SQ607	Skew Quad
7	X:SEX3R	A:SEX3	Sextupole
8	X:SEX7R	A:SEX7	Sextupole
9	X:SEX9R	A:SEX9	Sextupole
10	X:SEX10R	A:SEX10	Sextupole
11	X:SEX12R	A:SEX12	Sextupole
12	X:OCT10R	A:OCT10	Octupole
13	X:OCT12R	A:OCT12	Octupole
14	X:NMRD0R	A:NMRD0	NMR Probe parameter
15	X:BS110R	A:BS110	Dipole Shunt
16	X:BS109R	A:BS109	Dipole Shunt
17	X:BS108R	A:BS108	Dipole Shunt
18	X:BS107R	A:BS107	Dipole Shunt
19	X:BS103R	A:BS103	Dipole Shunt
20	X:BS210R	A:BS210	Dipole Shunt
21	X:BS209R	A:BS209	Dipole Shunt
22	X:BS208R	A:BS208	Dipole Shunt
23	X:BS207R	A:BS207	Dipole Shunt
24	X:BS203R	A:BS203	Dipole Shunt
25	X:BS310R	A:BS310	Dipole Shunt
26	X:BS309R	A:BS309	Dipole Shunt
27	X:BS308R	A:BS308	Dipole Shunt
28	X:BS307R	A:BS307	Dipole Shunt
29	X:BS303R	A:BS303	Dipole Shunt
30	X:BS410R	A:BS410	Dipole Shunt
31	X:BS409R	A:BS409	Dipole Shunt
32	X:BS408R	A:BS408	Dipole Shunt
33	X:BS407R	A:BS407	Dipole Shunt
34	X:BS403R	A:BS403	Dipole Shunt
35	X:BS510R	A:BS510	Dipole Shunt
36	X:BS509R	A:BS509	Dipole Shunt
37	X:BS508R	A:BS508	Dipole Shunt
38	X:BS507R	A:BS507	Dipole Shunt
39	X:BS503R	A:BS503	Dipole Shunt

Device Index	PAUX Device	ACNET Device	Description
40	X:BS610R	A:BS610	Dipole Shunt
41	X:BS609R	A:BS609	Dipole Shunt
42	X:BS608R	A:BS608	Dipole Shunt
43	X:BS607R	A:BS607	Dipole Shunt
44	X:BS603R	A:BS603	Dipole Shunt
45	X:H100R	A:H100	Horizontal Dipole Trim
46	X:H105R	A:H105	Horizontal Dipole Trim
47	X:H205R	A:H205	Horizontal Dipole Trim
48	X:H305R	A:H305	Horizontal Dipole Trim
49	X:H405R	A:H405	Horizontal Dipole Trim
50	X:H505R	A:H505	Horizontal Dipole Trim
51	X:H605R	A:H605	Horizontal Dipole Trim
52	X:V102R	A:V102	Vertical Dipole Trim
53	X:V104R	A:V104	Vertical Dipole Trim
54	X:V106R	A:V106	Vertical Dipole Trim
55	X:V109R	A:V109	Vertical Dipole Trim
56	X:V202R	A:V202	Vertical Dipole Trim
57	X:V204R	A:V204	Vertical Dipole Trim
58	X:V206R	A:V206	Vertical Dipole Trim
59	X:V209R	A:V209	Vertical Dipole Trim
60	X:V302R	A:V302	Vertical Dipole Trim
61	X:V304R	A:V304	Vertical Dipole Trim
62	X:V306R	A:V306	Vertical Dipole Trim
63	X:V309R	A:V309	Vertical Dipole Trim
64	X:V402R	A:V402	Vertical Dipole Trim
65	X:V404R	A:V404	Vertical Dipole Trim
66	X:V406R	A:V406	Vertical Dipole Trim
67	X:V409R	A:V409	Vertical Dipole Trim
68	X:V502R	A:V502	Vertical Dipole Trim
69	X:V504R	A:V504	Vertical Dipole Trim
70	X:V506R	A:V506	Vertical Dipole Trim
71	X:V509R	A:V509	Vertical Dipole Trim
72	X:V602R	A:V602	Vertical Dipole Trim
73	X:V604R	A:V604	Vertical Dipole Trim
74	X:V606R	A:V606	Vertical Dipole Trim
75	X:V609R	A:V609	Vertical Dipole Trim
76	X:QTR	A:QT	Quad triplet bus
77	X:QSDR	A:QSD	Defocusing Shunt on Focusing/Defocusing Bus
78	X:NMRD1R	A:NMRD1	NMR Probe parameter
79	X:1LLFSR	A:R1LLFS	Sciteq Frequency (ARF3)
80	X:H201R	A:H201	Horizontal Dipole Trim

Device Index	PAUX Device	ACNET Device	Description
81	X:H204R	A:H204	Horizontal Dipole Trim
82	X:DVND1R	A:DPVND1	Vertical Damper notch delay
83	X:DHND1R	A:DPHND1	Horizontal Damper notch delay
84	X:DVSD1R	A:DPVSD1	Vertical Damper system delay
85	X:DHSD1R	A:DPHSD1	Horizontal Damper system delay
86	X:3LLAMR	A:R3LLAM	ARF3 Amplitude DAC
87	X:Q100RR	A:SQ100R	Skew Quad Polarity reversing switch
88	X:Q607RR	A:SQ607R	Skew Quad Polarity reversing switch
89	X:EMITHR	A:EMITHS	Horiz. 79 MHz Emittance Monitor synthesizer freq.
90	X:EMITVR	A:EMITVS	Vert. 79 MHz Emittance Monitor synthesizer freq.
91	X:EMT5HR	A:EMT5HS	Horiz. 500 MHz Emittance Monitor synthesizer freq.
92	X:EMT5VR	A:EMT5VS	Horiz. 500 MHz Emittance Monitor synthesizer freq.
93	X:862DPR	A:862DIP	E862 Dipoles
94	X:862SLR	A:862SOL	E862 Solenoid
95	X:S8621R	A:BS8621	E862 Dipole Shunt
96	X:S8622R	A:BS8622	E862 Dipole Shunt
97	X:PT101R	X:PT101T	2-4 GHz Dp cooling trombone correction
98	X:HT101R	X:HT101T	Horizontal cooling trombone correction
99	X:VT101R	X:VT101T	Vertical cooling trombone correction
100	X:MT101R	X:MT101T	4-8 GHz Dp cooling trombone correction