Plan to Correct the Debuncher Energy Mismatch

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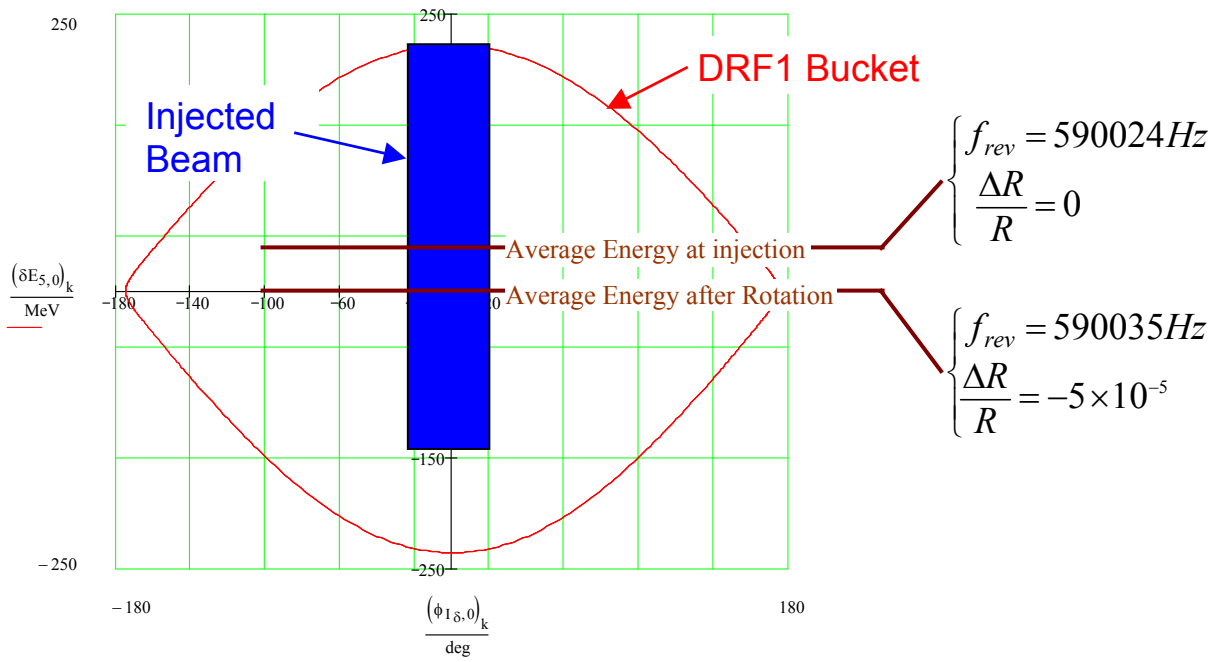
Present Situation



Beam is injected into the Debuncher 27 MeV above the center of the DRF1 bucket. The injected beam fills the momentum aperture of the Debuncher. Bunch rotation decelerates the beam causing a radial position error. The post-rotation energy is, however, the proper energy for extraction to the Accumulator.

The Plan

The goal of this plan is to change bend fields in AP2 and the Debuncher and the RF frequency so that the energy is lowered by 27 MeV and $\Delta R/R$ is kept at zero. The RF frequency that accomplishes this is 90×590004.5 Hz. The new Debuncher bend field (as read on D:BFIELD) will be 16,881.9 Gauss. The derivation of these numbers is included in the Appendix.

These changes are inserted while the Antiproton Source is in stacking mode. The detailed procedure is as follows:

1. <u>Set and Document initial conditions</u>:
   - Bring up P60 ACC50 sub page 40. Adjust Debuncher and Accumulator bend buses as necessary:

- Adjust D:IB so that D:BFIELD reads 16,933.5 Gauss
- Adjust A:IB so that A:NMR50 reads 16,720.4 Gauss

- Perform a target tune, tune up Debuncher injection (P152), and tune up bunch rotation (optimize D:R1LLPS and D:R1LLMT).
- Record stacking rate, production efficiency, stack size, and cycle time. Use a long cycle time for this measurement. T_{cycle} = 10 sec should be long enough for all conceivable stack sizes.
- Document the post bunch rotation longitudinal distribution. Load P41 file 3 to SA1. Save the SA1 trace to a file using P42.
- Use P148 (VSA D/A FFT) to measure the revolution frequency of beam on the injection orbit of the Accumulator. Record this number. Save the FFT display.
- Measure and record Debuncher tunes (correct if necessary). Use P41 files 59 and 60. The canonical tunes are: Horizontal – 9.770, Vertical – 9.765.
- Turn off bunch rotation and all Debuncher stochastic cooling. Measure the momentum distribution of beam injected into the Debuncher. This distribution should appear similar to Figure 1 below.
  - Record the –10 dB edge frequencies
  - Record the frequency of the coherent spike
  - Immediately restore DRF1 so that it can start tuning in.

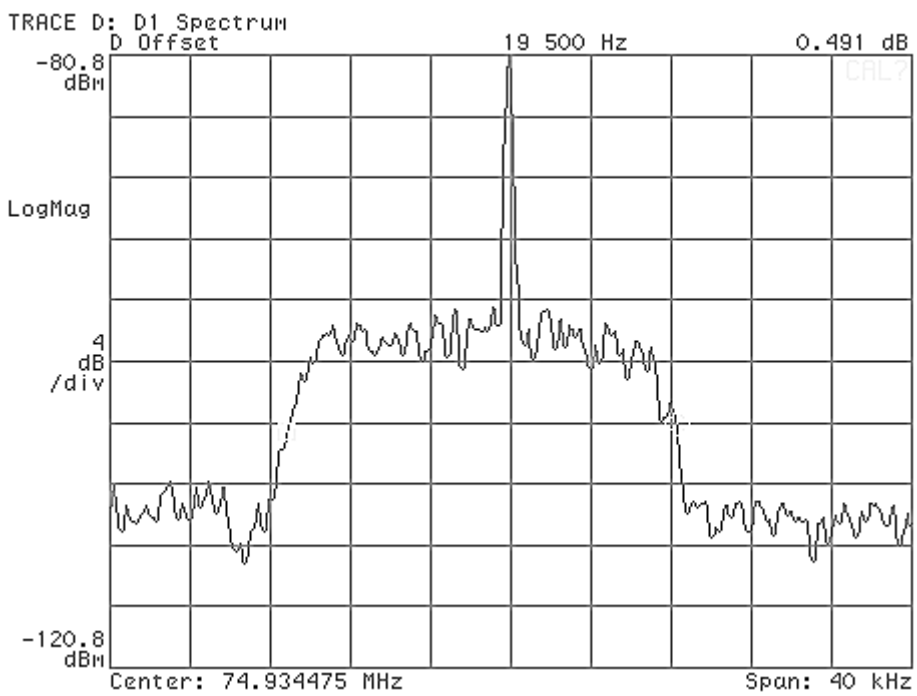


Figure 1. Debuncher longitudinal schottky display of the 127th harmonic of the initial revolution frequency distribution of beam injected into the Debuncher.

2. <u>Set new RF frequency and phase</u>. Parameters for this step are on P8 DRF_1 sub page 29
   - Set D:PJWR53 to 90×590004.5 Hz – 53 MHz = 100405.00 Hz
   - The present value of D:PJWR53 is 103070.42 Hz. The 90th harmonic of the frequency change is 2665.42 Hz. The time from an event $79 until beam arrival in the Debuncher is 295 μsec. The required phase change is:

360°× (2665.42 Hz) × (295 μsec) = 283°. Set D:PJPHAS to D:PJPHAS + 283° (modulo 360°). This should be a number near 260°.

3. Set AP2 and Debuncher bend fields:
   - This step assumes that D:H717 is set at 878.8 Amps and all the D:H717n shunts are set to zero. Lower D:H717 by 2.69 Amps (i.e. set D:H717 to 876.11 Amps). Set D:H7172, D:H7173, D:H7176, and D:H7177 to 0.21 Amps.
   - Lower D:IB until D:BFIELD = 16,881.9 Gauss. This will require a change of approximately 4.9 Amps.
   - Increase D:QT205, D:QT405, and D:QT606 by the amount that D:IB was decreased.
   - Cycle the Debuncher buses.
   - Adjust D:IB so that D:BFIELD = 16,881.9 Gauss.

4. Correct stochastic cooling delays:

   The revolution period of the beam is longer by $\frac{1}{590004.5Hz} - \frac{1}{590035Hz} = 88\,\text{psec}$.
   - Increase all Debuncher cooling notch filter delays by 88 psec.
     Notch filter trombone devices are: D:H1TMF, D:H2TMF, D:V1TMF, D:V2TMF, D:P1TMF, D:P2TMF, D:P3TMF, D:P4TMF.
   - Increase all Debuncher cooling trunk trombones by ⅓ of this (29 psec).
   - Trunk trombone devices are: D:H1TM1, D:H2TM1, D:H3TM1, D:H4TM1, D:V1TM1, D:V2TM1, D:V3TM1, D:V4TM1, D:P1TM1, D:P2TM1, D:P3TM1, D:P4TM1.
   - Check the phasing of all Debuncher cooling systems (requires ~2 hours) at the earliest opportunity.

5. Measure results:
   - Re-establish stacking.
   - Perform a target tune if necessary. Tune up Debuncher injection (P152).
   - Perform the Debuncher momentum cooling notch filter alignment procedure.
   - Use P148 (VSA D/A FFT) to measure the revolution frequency of beam on the injection orbit of the Accumulator. Adjust D:IB so that beam arriving on the Accumulator injection orbit is at the frequency measured in step 1 above. If this is not a small change (<0.5 Amps) our calculations are all wrong and it's time to put everything back. Note the change in D:IB setting from this step.
   - Change D:QT205, D:QT405, and D:QT606 by -ΔD:IB in the previous step.
   - Note the value of D:BFIELD. *This is our new nominal Debuncher bend field.*
   - Turn off bunch rotation and all Debuncher stochastic cooling. Measure the momentum distribution of beam injected into the Debuncher. This distribution should appear similar to Figure 1 above.
     - Record the –10 dB edge frequencies
     - Record the frequency of the coherent spike
     - The average frequency and the frequency of the coherent spike should be very close to the 127th harmonic of 590004.5 Hz.
     - Immediately restore DRF1 so that it can start tuning in.
   - Document the post bunch rotation longitudinal distribution. Load P41 file 3 to SA1. Save the SA1 trace to a file using P42.

- ❑ Attempt to turn up the gain of the Debuncher momentum cooling.
- ❑ Measure and record Debuncher tunes (correct if necessary). Use P41 files 59 and 60.
- ❑ Record stacking rate, production efficiency, stack size, and cycle time. Again, use a long cycle time for this measurement – 10 sec should be long enough for all conceivable stack sizes.
- ❑ Perform the Paul Derwent momentum cooling characterization.

6. <u>Reverse Proton orbit measurement</u>. At the next opportunity for reverse proton studies do the following:
   - ❑ Bunch beam with DRF3 and move it to f_{rev} = 590004.5 Hz. Scrape the momentum tails. Measure and save the closed orbit.
   - ❑ Compare this measurement with the most recently saved measurement at f_{rev} = 590024 Hz (i.e. taken before the above changes were made). If we were successful, there should be very little *dp/p* in the difference orbit.

Appendix

Calculation of RF Frequency and Debuncher & AP2 Bend Field Changes

MathCad Worksheet

AP2-Debuncher Energy

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02/16/2004

Units & Constants

$e_c \equiv 1.60217733 \cdot 10^{-19} \cdot \text{cou}$

$c \equiv 299792458 \cdot \frac{m}{sec}$

$\text{mrad} \equiv 10^{-3} \cdot \text{rad}$

$eV \equiv e_c \cdot \text{vol}$

$MeV \equiv 10^6 \cdot eV$

$kG \equiv 10^3 \cdot \text{gauss}$

$keV := 10^3 \cdot eV$

$GeV \equiv 10^9 \cdot eV$

$m_p \equiv 938.27231 \cdot \frac{MeV}{c^2}$

Proton mass

Parameters

$p_{Acc} \equiv 8886.26 \cdot \frac{MeV}{c}$

Accumulator Extraction orbit momentum

$\Delta E_{Deb} := 27 \cdot MeV$

Energy offset of beam relative to central energy of DRF1 bucket

$f_{rev} := 590024.2 \cdot Hz$

Central frequency of Debuncher momentum aperture

$\eta := 0.006$

$B_{Deb} := 16933.50 \cdot \text{gauss}$

Nominal D:BFIELD

$$E_{Acc} := \sqrt{\left(p_{Acc} \cdot c\right)^2 + \left(m_p \cdot c^2\right)^2}$$

$E_b := E_{Acc} + \Delta E_{Deb}$

$E_b = 8962.66\,MeV$

$p_b := \frac{1}{c}\sqrt{E_b^{\,2} - \left(m_p \cdot c^2\right)^2}$

$p_b = 8913.41\,\frac{MeV}{c}$

$\beta_b := \frac{p_b \cdot c}{E_b}$

$\gamma := \frac{E_b}{m_p \cdot c^2}$

$\delta_p := \frac{1}{\beta_b^{\,2}} \cdot \frac{\Delta E_{Deb}}{E_b}$

$\delta_p = 0.305\,\%$

$\gamma_t := \left(\eta + \frac{1}{\gamma^2}\right)^{-\frac{1}{2}}$

$\Delta p_{Deb} := p_b \cdot \delta_p$

$\Delta p_{Deb} = 27.149\,\frac{MeV}{c}$

$\gamma_t = 7.679$

$\Delta f_{rev} := -f_{rev} \cdot \eta \cdot \delta_p$

$\Delta f_{rev} = -10.8\,Hz$

Now:

1) Central energy of the Debuncher = E_b
2) Central f_{rev} of the Debuncher = f_{rev}
3) DRF1 decelerates beam by ΔE_{Deb}
4) Rotated beam is off-center in the momentum aperture

Want:

1) Change DRF1 frequency so that rotation is centered in the bucket
   (DRF1 will no longer change the average energy of the beam to first order)
2) Change central Debuncher energy to $E_b - \Delta E_{Deb}$
3) Require $\Delta R/R = 0$ for $E = E_b - \Delta E_{Deb}$

Radial position constraint:

$$\frac{dp}{p} = \gamma_t^2 \frac{dR}{R} + \frac{dB}{B} \qquad \frac{dB}{B} = \gamma^2 \frac{df}{f} + \left(\gamma^2 - \gamma_t^2\right)\frac{dR}{R}$$

Present $\Delta R/R$ of beam at f_{rev} = 590024 Hz:

$\delta_R := 0$

Calculate ΔB

$\Delta B := B_{Deb} \cdot \left[\left(-\delta_p\right) - \gamma_t^2 \cdot \delta_R\right]$

$\Delta B = -51.58\,\text{gauss}$ $\qquad$ $B_{Deb} + \Delta B = 16881.92\,\text{gauss}$

Calculate Δf_{rev} to change energy by $-\Delta E_{Deb}$ and maintain $\Delta R/R = 0$

$$\frac{dp}{p} = \gamma^2 \frac{df}{f} + \gamma^2 \frac{dR}{R}$$

$\Delta f := f_{rev} \cdot \left[\frac{-\delta_p}{\gamma^2} - \left(-\delta_R\right)\right]$

$\Delta f = -19.7\,\text{Hz}$ $\qquad$ $f_{rev} + \Delta f = 590004.5\,\text{Hz}$

Check:

$$\frac{dB}{B} = \gamma_t^2 \frac{df}{f} + \frac{\gamma^2 - \gamma_t^2}{\gamma^2} \frac{dp}{p}$$

$$\Delta E := E_b \cdot \frac{\beta_b^2 \cdot \gamma^2}{\gamma^2 - \gamma_t^2} \cdot \left(\frac{\Delta B}{B_{Deb}} - \gamma_t^2 \cdot \frac{\Delta f}{f_{rev}} \right)$$

$\Delta E = -27.0000\,\mathrm{MeV}$ Should get $\Delta E = -\Delta E_{Deb}$

$$\delta B := \gamma_t^2 \cdot \frac{\Delta f}{f_{rev}} + \frac{\gamma^2 - \gamma_t^2}{\gamma^2} \cdot (-\delta_p)$$

$\delta B \cdot B_{Deb} = -51.58\,\mathrm{gauss}$ Should be the same as ΔB above

Calculate required change in AP2 line bends

$BL_{IB2} := 34.642 \cdot kG \cdot m$ Integrated field for IB2, IB3, IB6, and IB7

$BL_{IB4} := 24.634 \cdot kG \cdot m$ Integrated field for IB4 and IB5

$BL_{IBV1} := 18.304 \cdot kG \cdot m$ Integrated field for IBV1 (V730)

$$\frac{dp}{p} = \frac{dB}{B}$$

$\Delta BL_{IB2} := -\delta_p \cdot BL_{IB2}$ $\Delta BL_{IB2} = -0.106\,kG \cdot m$

$\Delta BL_{IB4} := -\delta_p \cdot BL_{IB4}$ $\Delta BL_{IB4} = -0.075\,kG \cdot m$

$\Delta BL_{IBV1} := -\delta_p \cdot BL_{IBV1}$ $\Delta BL_{IBV1} = -0.056\,kG \cdot m$