Beams-doc-1451-v2

BPM Calibration Discussion

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- Part 1:
  - First shown on Nov. 22, 2004.
- Part 2:
  - First shown on Nov. 15, 2004.
    (Yes, the dates are backwards)

Part 1: Scales of Interest

- Analog effects from pickups to digitizer:
  - Differential attenuation: 0.1 db = 150 μm.
  - Differential phase shift: $1^\circ = 10$ μm.
- Digitizer:
  - In closed orbit mode. An offset of a full bit 40 μm for a single bunch and about 1 μm for 36 bunches.
  - Both are small compared to the relevant resolution.
- Time Stability
  - Long term stable.
  - "Medium" term stable.
    - Requires time dependent calibration.
  - Random or quasi-random on a time scale of 500 Hz.
- Some may depend on mode of operation.
- Goal:
  - Discover the limiting effects so we do not have to waste time on effects which are not limiting.

Classes of Effects

1. Effects of beam species being measured.
   (a) Intensity.
   (b) Position in coordinate being measured.
   (c) Position in other coordinate.
   (d) Angle of beam through the pickups.
   (e) Lebedev head-tail effect.
2. Effects of the other beam species.
   - Will discuss another day.
3. Instrumental effects:
   (a) Mechanical offset of the electrical center of pickups from the magnetic center of the quads.
   (b) Feed-thrus from pickups to tunnel.
   (c) Cables from tunnel to house.
   (d) Filter board
   (e) Digitzer.
   (f) Phase of the 7/5 at the start of the measurement.

1. Instrumental effects:
   (a) Mechanical offset of the electrical center of pickups from the magnetic center of the quads.
      - Table of corrections exists.
      - Uncertainty on correction is: ???? μm.
   (b) Feed-thrus from pickups to tunnel.
      - I don't have any information about differential attentuaion and phase shift in these. Is there any info?
   (c) Cables from tunnel to house.
      - I have an excel spreadsheet from Marv Olson with both differential attenuation and phase shifts.
      - Uncertainty on this information: ???? μm.
   (d) Filter board
      - Spec for analog filters:
         - $< 1^\circ$ of differential phase shift.
         - ??? db of differential attenuation.
      - Other effects?
   (e) Digitzer.
      - Small compared to the resolution but may be relevant if we average many measurements.
   (f) Phase of the 7/5 at the start of the measurement.
      - We saw before that adding low pass filters made this small enough to be not limiting. Need to recheck.

Old Electrical Offsets

- Information from a discussion with Marv Olson.
- In the tunnel disconnect cables from BPM and inject balanced signal into the two cables.
- Signal types: Single bunch and 20 consecutive buckets.
- Read position using old BPM electronics.
- Use this position the measured offset.
- Compare with offsets inferred from differential attenutation and phase shift measured in the cables:
  - In most cases the offset is dominated by the electronics, not the cables.
  - There are a few cable pairs for which the cable properties are important.

Part 2

References on Calibration

- Beams-doc-1161, Derivation of main equations.
- Beams-doc-1205, What was done before shutown.
  - With some small changes recommend we start the same way after the shutdown.
- Beams-doc-1149, Quadratic term.

Raw vs Corrected Measurements

$$
\begin{aligned}
A'_P &= A_P \\
B'_P &= B_P \\
A'_A &= A_A - aA_P - bB_P \\
B'_A &= B_A - cB_P - dA_P
\end{aligned}
$$

- All quantities above are complex.
- Unprimed are raw measurements.
- Primed are corrected measurements.
- Notation anticipates that, in the future, the raw and corrected Proton measurements may be distinguished.
- Determination of (a, b, c, d) described later.

Intensity Will be Reported in Echotek Units

$$I_P = |A'_P| + |B'_P|$$
$$I_A = |A'_A| + |B'_A|$$

- Following discussions with Mike and others it was decided that the front ends will report the intensity in raw Echotek units, *without* a correction for beam energy or any other factors.
- This comes closest to current practice.
- One can imagine many improvements to this but they are all off the table for the scope of this project.
- Proposal to define tresholds for valid data:

$$|A'_P| + |B'_P| \geq t_P \qquad\qquad |A'_A| + |B'_A| \geq t_A$$

- where $t_P = 100$ and $t_A = 100$. (previously:$t_A = 50$).

Computation of Proton Position

- Using the notation of Beams-doc-1161.

$$\begin{aligned} P_{posraw} &= g\frac{|B'_{HP}| - |A'_{HP}|}{|B'_{HP}| + |A'_{HP}|} + E_{offset} \\ P_{Intensity} &= |A'_{HP}| + |B'_{HP}| - kP^2_{posraw} \\ P_{final} &= g\frac{|B'_{HP}| - |A'_{HP}|}{P_{Intensity}} + E_{offset} + Q_{offset} \end{aligned}$$

P_{posraw}	Raw position
$P_{Intensity}$	Corrected intensity
P_{posraw}	Corrected position
g	Scale factor dictated by spacing between BPM plates. Propose: g=26 mm for all BPMs.
E_{offset}	Electrical offset: measured displacement between physical center and electrical center of BPM. See next page.
Q_{offset}	Offset of center of BPM relative to center of quadrupole correction element. Propose: use values from before. (Can be zero on day 1.)
k	Quadratic correction parameter See next page.

- E_{offset} and k affected by:
  1. Properties of the pickups.
  2. Differential attenuation and phase shifts in the cables, connectors, going to the houses.
  3. Differential attenuation and phase shifts analog filters and attenuators ...
  4. Differences among digitizers.
- In the old system
  - E_{offset} corrected only for properties of the BPM electronics (analagous to 3); other effects were ignored.
  - I don't think that there was an analog of k.
- Beams-doc-1149 discusses how to find k but only if we can safely ignore, or correct for, the effects of 1 and 2.
- For startup: propose to set both E_{offset} and k to zero.
- What we could do if we wanted to:
  - Attack 1 and 2 it by sending signals from the house, through the BPM and back up.
  - Attack 3 and 4 by bench tests (for board swap). Is it big enough to worry about?
- Not yet a fully formed plan.

Computation of Positions at Startup

- Calculation for anti-protons is similar to that discussed for protons.
- Final results for startup:

$$\begin{aligned} D_P &= g\frac{|B'_P| - |A'_P|}{|B'_P| + |A'_P|} + Q_{offset} \\ D_A &= g\frac{|B'_A| - |A'_A|}{|B'_A| + |A'_A|} + Q_{offset} \end{aligned}$$

- D is displacement (position) in mm.
- $g = 26$ mm
- Q_{offset} is the same for protons and Pbar; it is a property of the physical construction of the plates.

Things to Come

- Computation of correction coefficients to subtract proton contamination from pbar cables.
- When is it useful to do grid studies?
- When should we do a store with reversed helix?
- When should we do a pbar only store?
- What to do about position bias as a function of intensity (Beams-doc-1406)?
- What to do about occasional bad outliers, Beams-doc-1301?
- What to do about difference in measured position in short gate vs closed orbit mode? Beams-doc-1197. Difference for protons is about 50 μm. Difference for pbars is about 600 μm.