Beam Delivery R&D
Evaluation and establishing tolerances
*internal review*

Andrei Seryi

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Tolerances in beam delivery
Procedure. First steps

- **First: evaluate effect of**
  - Transverse offset, longitudinal displacement, rotation around x, y or s axis, field errors
    - On the beam in terms of
      - IP offset, angular offset, dispersion, angular dispersion, waist shift, coupling
- **Then, for a given beam, evaluate effect on luminosity and find tolerances for**
  - Transverse offset, longitudinal displacement, rotation around x, y or s axis, field errors. Criteria (e.g.) 2% luminosity loss

The method was developed by O.Napoly et al. and incorporated into FFADA set of programs [O.Napoly, S.Fartoukh, A.Sery]
To simplify presentation, further examples of tolerances are given for this part of BD.
Tolerance evaluation...

- First: evaluate effect of
  - Transverse offset, longitudinal displacement, rotation around x, y or s axis, field errors
- On the beam in terms of
  - IP offset, angular offset, dispersion, angular dispersion, waist shift, coupling

These numbers depend only on optics, not on the beam

Calculated with FFADA

Example:
effect of offset on
IP beam offset

Example:
effect of offset on
IP dispersion
Tolerance evaluation…

- Then, for a given beam, evaluate effect on luminosity and find tolerances for
  - Transverse offset, longitudinal displacement, rotation around x, y or s axis, field errors. Criteria (e.g.) 2% luminosity loss.

Note the difference between jitter tolerance (black bar) and stability tolerance (when offset error at IP is corrected)
Another example: filed errors

Tolerances for field errors ($\delta k_{BQ}/k_{BQ}$) in bends and quadrupoles

- $Criterium: Max(|\delta \sigma_x/\sigma_x|,|\delta \sigma_y/\sigma_y|) \leq 2\%$
- $Criterium: \text{ Offset and angular offset correction and } |\delta L_c/L_c| \leq 2\%$
- $Criterium: \text{ Offset correction(not angular offset correction) and } |\delta L_c/L_c| \leq 2\%$
- $Criterium: \text{ No correction and } |\delta L_c/L_c| \leq 2\%$

Note: bend B3 is split.
Actual tolerance for bend field is $\sim 1E-5$
What are tolerances on FD internal modes?

Effect of transverse internal modes in final quads on the beam offset at the IP is averaged out for short $\lambda$

However, there are other effects which determine the tolerances on amplitude of transverse internal mode:

- **Mechanics of construction, etc.**
  - High order modes may be coupled to lower mode motion via many effects: asymmetry of construction, not perfect elasticity, etc.

Working guess: higher order modes may have at most factor of several (2-3?) less severe tolerance than the common motion mode.
After evaluating individual tolerances…

- Evaluate tolerances globally for a particular ground motion
  - Fast motion – jitter
  - Slow motion – stability
- Temperature stability ???
  - Needs to be understood

- Requirements to girders
- IR region stability, evaluation of requirements to active systems

Methods of evaluation have been developed, specific work is being done
Fast motion in beam delivery

- **Fast motion produces beam offset at the IP**

**Rough scale of jitter tolerances:**

- **Final quads:** tolerance $\sim 0.5 - 1$ nm
  - rely on active methods (not because ground is not stable, but because detector may be not stable)
- **Some quads in beam delivery:** toler.$\sim$ a few beamsize $\sim 5 - 20$ nm
  - rely on natural quietness, maybe some minor active methods

- Beam-based feedback acts below $\sim \frac{F_{\text{rep}}}{20} \sim 6$ Hz
Correlation measurements give information about relative motion and allow to build 2D spectrum $P(\omega,k)$, which is used to evaluate FF performance more accurately.

Modeling $p(\omega)$ and $p(\omega,L)/2$ spectra for “SLAC 2AM” model:

- Fast wave-like motion
- Diffusive ATL motion
- Systematic motion
**Fast motion & Final Focus**

**global evaluation of tolerances**

### Rms IP offset for different ground motion models.

**ff01**

- **HERA**
  - shallow tunnel in highly urbanized area, very noisy, bad correlation (too pessimistic)

- **SLAC**
  - shallow tunnel in moderately urbanized area, not too noisy, moderate correlation

- **LEP**
  - deep tunnel without in-tunnel sources, noise is close to natural (too optimistic)

Feedback with \( f_0 = 6 \text{Hz}, 16 \text{m between Final Quad supports} \). **Solid lines - no FD stabilization, dashed - relative motion of FD is excluded by active system.**

### Spectral response function

- **Characteristic of Feedback**
  - \( F(\omega) \approx 1 \)
  - \( \sim (F/F_0)^2 \)

### Performance of inter-bunch feedback

- **rms IP beam offset** \( \approx \int \int P(\omega, k) \cdot G(k) \cdot F(\omega) \cdot dk \cdot d\omega \)

- **2D spectrum of ground motion**

- **Spectral response function**

Acceptable without any active stabilization. **But - Underestimate** effect since detector adds noise and FD supports are not ideal.

**HERA model** - shallow tunnel in highly urbanized area, very noisy, bad correlation (too pessimistic)

**SLAC model** - shallow tunnel in moderately urbanized area, not too noisy, moderate correlation

**LEP model** - deep tunnel without in-tunnel sources, noise is close to natural (too optimistic)
Stability tolerances

- Effect of slow ground motion can be evaluated

- Other effects, such as temperature stability, etc., needs to be understood

Beam size growth vs time in ff57. **No beamsize feedback.**

Ground motion model with $A = 5 \cdot 10^{-7} \frac{\mu m^2}{m \cdot s}$
**Vibrations @ IR**

**Example: SLAC Large Detector (SLD)**

- SLD pit floor noise is affected by building ventilation, compressors…
- Noise on the **SC triplet** ~10 X
  - Mostly driven by **on-SLD mounted** racks, pumps, etc.

**Need better engineering for NLC detector**

**Need active systems**

**To accurately evaluate necessary performance of active systems, a modeling method has been developed, specific work is being done**
Requirements for girders

- Girder problem arise from two factors:
  - Need adjustment for magnets
  - Human height is ~ 2m

- NLC girders need to be more perfect than example shown here
- Accurate evaluation of requirements is under way

Vibrations of 54Q10 quad on FN20 girder of SLC FF

Given factor of ~ 3 – 5 relieve in tolerance with respect to FD, this girder is OK for beams with $\sigma^* \sim 15 – 25$ nm
Improving ground motion modeling for cultural noise, girders and active systems

- **Cultural noise** can sharply depend on location, as in IR region, but $P(\omega,k)$ spectrum cannot.

  **Solution:**
  Use $P(\omega,k)$ and also additional spectrum $p(\omega,s)$ which explicitly depends on position. For correlation information also need mutual spectra $p_{12}(\omega,s_1,s_2)$.

- **Damping/amplification** (by girder or active system) can be taken into account in the following way:

  \[
  \langle \Delta X^2 \rangle = \iint P(\omega,k) 2[1 - \cos(\omega T)] \cdot 2[1 - \cos(k L)] \frac{d\omega}{2\pi} \frac{dk}{2\pi}.
  \]

  Example, if girders amplify by $R_k(\omega) = r_k(\omega) e^{i\phi_k(\omega)}$ then
  \[
  \left[ r_1^2 + r_2^2 - 2r_1r_2 \cos(kL + \phi_1 - \phi_2) \right]
  \]
  replaced by
Tolerances.
What needs to be done

- Continue optimize FF to improve tolerances
- Understand non-ground motion stability and jitter tolerances
- Make modeling and establish requirements for girders
- Create IR noise model and establish requirements for active system
- Document and distribute relevant information to appropriate people

Even though it will be uncertain …