BEAM BASED ALIGNMENT

Beam time request on Beam-based alignment

July 2, 2018 | Tim Wagner, on behalf of the JEDI Collaboration | Institut für Kernphysik, Forschungszentrum Jülich
OUTLINE

- Introduction
  - Why is beam-based alignment needed?
  - How does it work?

- Progress so far
  - What has been measured until now?
  - What are the results?

- Plan for the requested beam time
  - How to perform the measurement?
  - Why is one week needed?
WHY IS BEAM-BASED ALIGNMENT NEEDED?

- For an EDM measurement the orbit has to be as good as possible
- Orbit RMS should be lower than 100 µm → Orbit Control
- Orbit Control corrects the beam to the BPM zero position
- Goal is to go central through all magnets (i.e. quadrupoles)
- Thus BPM to quadrupole offset has to be known → Beam Based Alignment
HOW DOES BEAM-BASED ALIGNMENT WORK?

- Use beam to optimize the beam position
- Vary quadrupole strength
- Observe orbit change
- Try to minimize the orbit change
HOW DOES BEAM-BASED ALIGNMENT WORK?

- How does the orbit change when varying the quadrupole strength?

\[ \Delta x(s) = \frac{\Delta k \cdot x(s_0) l}{B \rho} \cdot \frac{1}{1 - k \frac{l \beta(s_0)}{2B \rho \tan \pi \nu}} \cdot \frac{\sqrt{\beta(s)} \sqrt{\beta(s_0)}}{2 \sin \pi \nu} \cos[\phi(s) - \phi(s_0) - \pi \nu] \]

- Not possible to calculate \( x(s_0) \) due to lack of precise knowledge of all other parameters
HOW DOES BEAM-BASED ALIGNMENT WORK?

- Use the following merit function

\[ f = \frac{1}{N_{\text{BPM}}} \sum_{i=1}^{N_{\text{BPM}}} (x_i(+\Delta k) - x_i(-\Delta k))^2 \]

\[ f \propto (\Delta x)^2 \propto (x(s_0))^2 \]

- By finding the minimum the optimal beam position can be found
- Quadrupoles are powered in families of four
- On the poles of quadrupole QT12 the additional back-leg windings of the steerer BLW04 were recabled to work as a quadrupole
BEAM-BASED ALIGNMENT MEASUREMENT

Quadrupole behavior

Tunes

Change of quadrupole strength
BEAM-BASED ALIGNMENT MEASUREMENT

Location of QT12

COSY sketch with position of quadrupole QT12 indicated
Quadrupoles are powered in families of four.
On the poles of quadrupole QT12 the additional coils of the steerer BLW04 were recabled to work as a quadrupole.
Effectively the strength of quadrupole QT12 can be varied.
Local bumps applied at the position of the quadrupole.
Measured effect on orbit upon varying the quadrupole strength.
RESULTS

- Two measurements done with quadrupole QT12 (Nov 2017 & May 2018)
- First proof of principle measurement in Nov 2017
- Repetition of measurement in May 2018 for verification of result and test of faster measurement procedure
- Increase in measurement speed by a factor of 6 (20 points in 7 h vs. 50 points in 3 h)
- Optimal horizontal position of $-1.14(2)$ mm and vertical position of $2.08(3)$ mm
Plan for the requested beam time

- Measure Quadrupole to BPM offset for all 12 quadrupoles with back-leg windings
- To prevent loss of steerers it is necessary to do it one by one
**MEASUREMENT STRATEGY**

- Total quadrupoles to be measured: 12
- Recabling can only be done during the day by dedicated personal
- The recabling (red) takes approx. 2 hours
- The setup (yellow) after recabling was done is estimated with 1 hour
- The measurement (green) takes approx. 3 hours for 50 points
- Sunday as a backup timeslot (blue)

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We request one week of beam time (plus one week MD) with protons or deuterons at 970 MeV $c^{-1}$.

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FORMULA FOR ORBIT CHANGE

\[ \Delta x(s) = \frac{\Delta k \cdot x(s_0) l}{B\rho} \cdot \frac{1}{1 - k \cdot \frac{l \beta(s_0)}{2B\rho \tan \pi \nu}} \cdot \frac{\sqrt{\beta(s)} \sqrt{\beta(s_0)}}{2 \sin \pi \nu} \cos[\phi(s) - \phi(s_0) - \pi \nu] \]

- \( \Delta x \) = orbit change
- \( s \) = measurement position
- \( s_0 \) = position of quadrupole
- \( \Delta k \) = change of quadrupole strength
- \( x(s_0) \) = position of beam inside the quadrupole
- \( \beta \) = beta function
- \( \nu \) = tune
- \( \phi \) = betatron phase
- \( k \) = quadrupole strength
- \( l \) = length of quadrupole
- \( B\rho \) = magnetic rigidity of the beam
Start with effect of a dipole kick $\theta$ on the orbit.

$$\Delta x(s) = \theta \times \frac{\sqrt{\beta(s)} \sqrt{\beta(s_0)}}{2 \sin \pi \nu} \cos[\phi(s) - \phi(s_0) - \pi \nu]$$

$$\theta = \frac{\Delta B l}{B \rho}$$

To first order a beam offset inside a quadrupole sees a change in quadrupole strength as a dipole kick.

The change of the tune, beta function and betatron phase are effects of second order and can be neglected.
DERIVATION OF FORMULA FOR ORBIT CHANGE

- Quadrupole magnetic field is $B = kx$, thus

$$\Delta B = (k + \Delta k)(x + \Delta x) - kx = \Delta kx + \Delta xk + \mathcal{O}(\Delta k \Delta x)$$

- Combine the equations with $s_0 = s$ to get

$$\Delta x = \frac{(\Delta kx + \Delta xk)l}{B \rho} \frac{\beta}{2 \sin \pi \nu \cos \pi \nu}$$

- and solve for $\Delta x$.

$$\Delta x = \Delta kx \frac{\frac{\beta l}{2 B \rho \tan \pi \nu}}{1 - \frac{\beta l}{2 B \rho \tan \pi \nu}}$$
With that calculate $\Delta B$

$$\Delta B = \Delta k x \frac{1}{1 - k \frac{\beta l}{2 B \rho \tan \pi \nu}}$$

and insert that into the equation for $\theta$ and $\Delta x(s)$.

$$\Delta x(s) = \frac{\Delta k \cdot x(s_0) l}{B \rho} \cdot \frac{1}{1 - k \frac{l_\beta(s_0)}{2 B \rho \tan \pi \nu}} \cdot \frac{\sqrt{\beta(s)} \sqrt{\beta(s_0)}}{2 \sin \pi \nu} \cos[\phi(s) - \phi(s_0) - \pi \nu]$$