Barker Jana
Ferney-Voltaire, 1st November 2022
Petra IV

- Petra III upgrade → Petra IV
- Circumference 2304 m
- TDR expected in late 2023
- 6 GeV. Emittance < 20/4 pm-rad hor/vert
- Uses mostly existing tunnels, new experimental hall
- Divided into cells with 4 girders each
- Girder – the smallest handled structure in tunnel
Introduction

Motivation

- Requested magnet-to-magnet accuracy of 30 µm
- Girder-to-girder accuracy “relaxed” at 50 µm
- No available space for assembly, alignment, and storage near tunnel → GAB → girder transportation by truck
- Magnets are epoxied
- Tight alignment budget → transport deformations < 5 µm
- Petra III test process insufficient → new procedure
- Petra IV girders are not yet produced → Petra III QTLU girder used
Measurement Procedure

Measurement Setup

- Idea from KinAiry
- Custom mirror setup
- Lines of sight exclusively measured by interferometer
- Leica AT960 interferometer: 0.4 µm + 0.15 ppm
- 30 lines of sight measured from 2 LT stations
- Rectilinear LoS sensitivity in translation
- Diagonal LoS sensitivity in rotations
- Every fiducial measured at least once by IF and once by standard geodetic measurements
- Two different silver protected mirror sizes
Measurement Procedure

Measurement Tooling

- Various custom-made SMR holders, mirror adapters and frames were made
- R+K (80/20) reinforced frames had great repeatability
Measurement Procedure

Measurements

- Measurements take place in climate controlled cabin
- Some lines are measured in darkness
- Mirrors aligned using bulls eye target
- LT stands stayed throughout
- Each epoch measurements scenario:
  - Beam Right Station: LoS, fids, network
  - Beam Left Station: network, fids, LoS
  - Same LT, (engraved) SMRs
- Frames are always removed
Transport Deformation Test

Crane Transportation

- Girder doesn't leave the climatic cabin
- Still needs acclimatization time since the ceiling hatch must be open for crane access
- Crane crews instructed to handle the girder extra carefully
Test Preparation

Trailer Testing

- Covered long trailer
- Uncovered long trailer
- Uncovered short trailer
Transport Deformation Test

Truck Transportation

• After trucking, the girder is acclimatized overnight before measuring.
• Standard route, other routes...
Analysis

Theory

• Processing interferometric (d_i) and geodetic measurements (Hz, Z, d)

• Using Gauss-Markov model:

\[
L = \varphi(X)
\]

• Magnet body rigidity is assumed and introduced into the model by using constraints:

\[
C = \left[ \sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2} \right] + \vec{c} = 0
\]

• Resulting in functional model:

\[
\begin{bmatrix}
\varphi(X) \\
C
\end{bmatrix} = \begin{bmatrix} L \\ 0 \end{bmatrix}
\]

• 4 virtual points per magnet realized by constraints

• Scale fixed by distance observations → 6 DoF not defined.

→ N has rank n-6

→ N is singular

→ Pseudo-inverse with smallest trace \(N^+\) is used.

• Model is distorted by the constraints

• Next model implementation will combine two epochs into a single model.

• The following model will be implemented

\[
0 = \varphi(X, L)
\]

\[
X = [X_{e1} - X_{e2}]
\]

\[
L = \begin{bmatrix} L_{e1} \\ L_{e2} \end{bmatrix}
\]
Analysis

Software

• Python implementation of the Gauss–Markov model
• Reads in input from SA
• Typo and gross error checking
• Two-face measurement checks plus standard deviation assignment
• Additional one-face measurement processing
• Originally done with 4 DoF but AT960 is not gravity compensated → 6 DoF model
• Weight matrix starts with manufacturer’s st.devs and with individual epoch factors which are manually optimized based on results.
• One-epoch analysis possible, main mode is pre-and post-transport epoch analysis.

• Program allows for measurement exclusion
• Results show deformation and statistical significance calculated from the covariance matrices of both epochs.
Results

Theory

- Analysis code doesn’t determine the virtual point accuracy
- Empirically determined method accuracy: 5 µm
- Average magnet fiducial move: 8.9 µm, median: 7.1 µm
- Few deformations of the magnet points were statistically significant
- Epoxying magnets to the girder demonstrated suitable for high accuracy requirements
- Girder rigid body hypothesis disproven

<table>
<thead>
<tr>
<th>Epoch</th>
<th>Date measured</th>
<th>Type of movement</th>
<th>Max. move, Virtual point [µm]</th>
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<tr>
<td>-1</td>
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<td>-</td>
<td>-</td>
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<td>-</td>
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<td>Crane test</td>
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<td>29.9.2021</td>
<td>Truck (std route)</td>
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<td>3</td>
<td>21.2.2022</td>
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<td>4</td>
<td>22.2.2022</td>
<td>No move</td>
<td>4.1</td>
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<tr>
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<td>No move</td>
<td>3.5</td>
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<td>Crane</td>
<td>3.3</td>
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<td>8.2</td>
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<td>Crane</td>
<td>6.0</td>
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<tr>
<td>3-16</td>
<td>-</td>
<td>February – April movement</td>
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Conclusion: magnetic axis will not significantly move by the transport and installation proposed for PETRA IV.
Thank you very much for your attention

Contact

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