Validation of micro-triangulation with direct wire measurements in the LHC tunnel

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Introduction

Objective
Measure offsets between fiducial points and wire(s).

Method
Automatic micro-triangulation with direct wire observations.

Principle
Measure horizontal and vertical angles to targets and wire(s).

Problem
Observations to non-corresponding points on the wire.

Solution
Wire modeled as straight line, parabola, catenary.

Surveying network

Configuration
• 12 theodolite positions
• 2 series of measurement per position
• 13 magnet fiducial points
• 10 points on the tunnel wall
• 1 stretched wire

Least-squares adjustment
• 3312 observations
• 1233 unknown parameters
• Minimum constraints solution
• Robust fit with iteratively reweighted observations
• Scale adopted by Laser Tracker measurements

Results

95% confidence ellipses for the fiducials point and their projections on the wire

95% confidence intervals for the offsets between fiducials and wire

Comparison with scartometry measurements on 26/02/2018.

1\textsuperscript{st} day (27/02/2018)
• precision (1\(\sigma\)): 170 \(\mu\)m

2\textsuperscript{nd} day (28/02/2018)
• precision (1\(\sigma\)): 60 \(\mu\)m

Micro-triangulation measurement in the LHC tunnel

Vertical component of the deviation between the observation and the estimated wire

• 1\textsuperscript{st} case: One straight line fit. We observe the catenary shape (\(\approx 2\) cm for 80 m wire).

• 2\textsuperscript{nd} case: One catenary fit. We observe two groups of deviations (consistent with the day of measurement).

• 3\textsuperscript{rd} case: Two catenaries fit. Standard deviation of the vertical deviations equals 0.16 mm (wire diameter equals 0.4 mm).

Wire model

Leica Nova TS60:
• Robotic theodolite
• High accuracy: 0.5 arcsec / 2.4 \(\mu\)m

QDaedalus:
• Developed at ETH Zurich
• Reversible replacement: eye-piece \(\leftrightarrow\) CCD

Ceramic spheres:
• \(\Omega 38\) mm (1.5 inch)
• Grade 40 (sphericity 1 \(\mu\)m)

Vectran wire:
• Multi thread
• \(\Omega 0.4\) mm

Conclusion

• Successful validation of the method in the LHC tunnel.

• Micro-triangulation can be used for to measure stretched-wire offsets.

• Precision at the level of a few tens of micrometres, depending on the conditions.

• The method is more time efficient in static configurations, but works well otherwise.

• Suitable for complex configurations with many wires.

➢ Advantages: accurate, automatic, contactless, remote-controlled, portable

➢ Limitation: Lack of scale

Future work:
➢ Hardware upgrade (e.g., new CCD camera, coaxial light).
➢ Software tools development (towards automation).
➢ Include more systematic effect in the model (e.g., curvature, refraction).
➢ Evaluation in more cases (e.g., multiple wires, vertical offset estimation).