Optimal Re-alignment Strategy for MAX IV Upgrade

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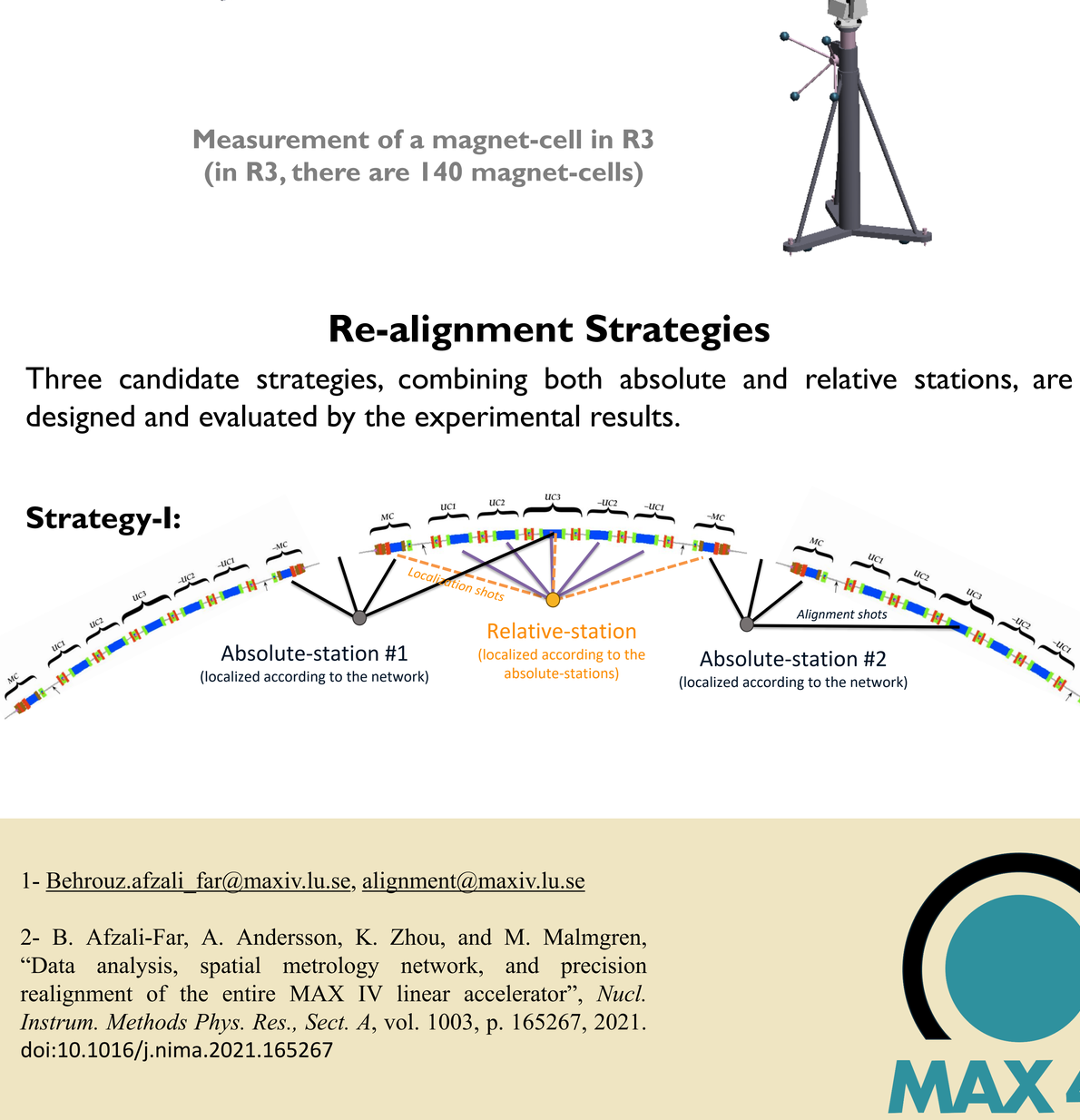
Abstract

In preparation for the upcoming upgrade of the MAX IV Laboratory 3 GeV storage ring, tighter alignment tolerances are required for the magnet-cells to achieve the lower target beam emittance. We evaluate alignment strategies that ensure both relative cell-to-cell smoothness and absolute alignment with reference to the control network. Three candidate strategies are designed and evaluated using tailored survey measurements conducted on a single achromat. In addition to the survey results for each strategy, practical considerations such as achromat symmetry and alignment time efficiency are taken into account to determine the optimal strategy to meet the upgrade specifications.

Method

For any alignment task in the 3 GeV storage ring (R3) at MAX IV Laboratory, laser trackers need to be localized. The localization can be done **absolutely** to the control network or **relatively** to the neighboring magnet cells. Note that for the absolute localization, at MAX IV, we use constrained networks to remove the low-spatial-frequency error[2].

Similarly, the **absolute uncertainty** is defined as the alignment uncertainty of a magnet-cell to the control network, whereas **relative uncertainty** represents the cell-to-cell uncertainty. To quantify the absolute and relative uncertainties directly from measurements, we have conducted a series of measurements on Achromat03 of R3, with the layout shown below. The measurements consist of 3 sets (9 stations), including 6 absolute and 3 relative stations.

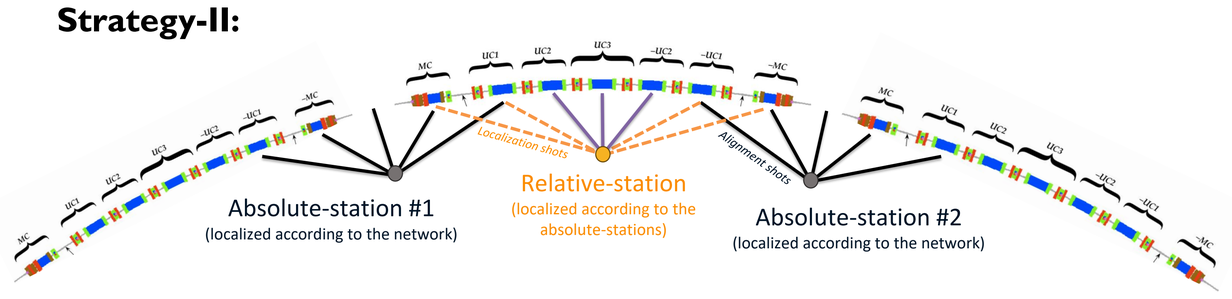


Re-alignment Strategies

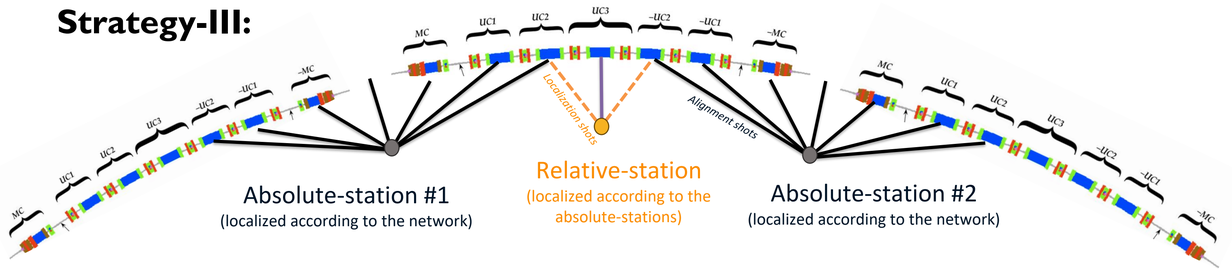
Three candidate strategies, combining both absolute and relative stations, are designed and evaluated by the experimental results.

Strategy-I:

Strategy-II:



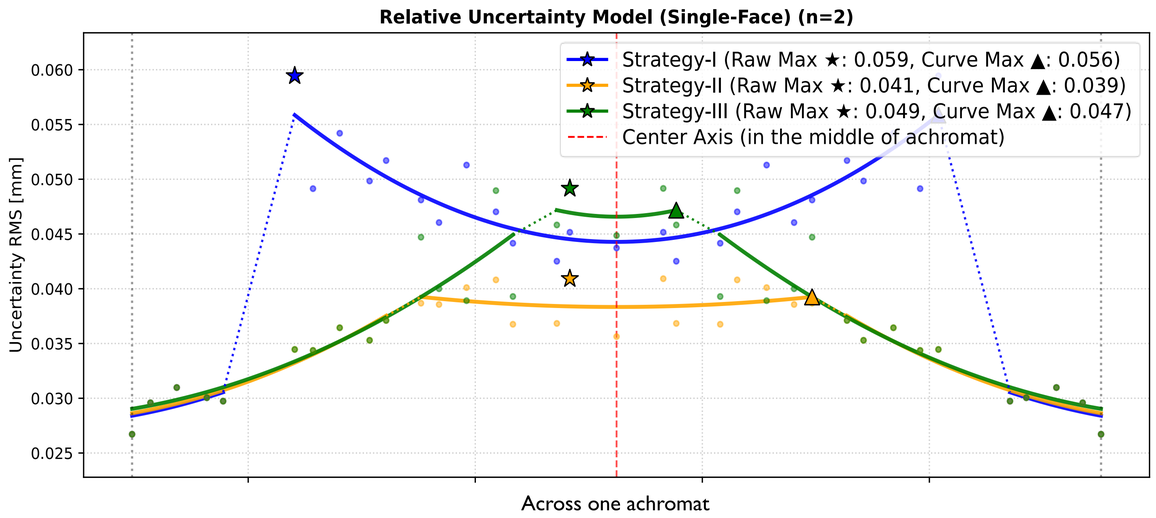
Strategy-III:



Measurement results

The results are obtained in four categories, based on absolute/relative uncertainty as well as single/double face measurements.

In practice, alignment is done using single-face observations of laser trackers. Furthermore, if the cell-to-cell relative uncertainty is of interest, the relative single-face model drives the decision on obtaining the optimal strategy (this relative single-face model is presented below).



The curves are segmented. The first part is the uncertainty by the absolute stations, and the second part is the uncertainty by the relative stations.

It should be noted that the relative uncertainty results already include an additional manual alignment uncertainty of 0.017 mm (1σ).

Furthermore, we have matched the obtained results with a previously obtained (conservative) uncertainty model, which leads to a 1.2 factor of safety.

Strategy-II yields the lowest maximum values, showing a peak uncertainty of approximately 0.04 mm. After applying a safety factor, aligning the entire achromat within a relative uncertainty of 0.05 mm (1σ) is assumed to be feasible.

Conclusions

- This is a **hybrid** approach: absolute stations ensure alignment to the control network, while relative stations ensure smoothness.
- On average, re-alignment of the entire R3 requires only **two stations per achromat** (one absolute and one relative station)—40 stations in total.
- Alignment is practically done single-face, and if the **cell-to-cell uncertainty** is of interest, the relative model (single-face) is a key factor. This is where **Strategy-II** performs **considerably better** than the other two strategies.
- The cell-to-cell relative uncertainty from this hybrid approach will be **independent of the network deformation**.
- Therefore, these initial results show that **Strategy-II is likely to be optimal**, as it yields the lowest uncertainty; additionally, it offers **symmetry** and alignment **time efficiency**. The investigation is ongoing.

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2- B. Afzali-Far, A. Andersson, K. Zhou, and M. Malmgren, "Data analysis, spatial metrology network, and precision realignment of the entire MAX IV linear accelerator", *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 1003, p. 165267, 2021. doi:10.1016/j.nima.2021.165267

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