Experience With Algorithm-guided Tuning of APS-U Undulators*

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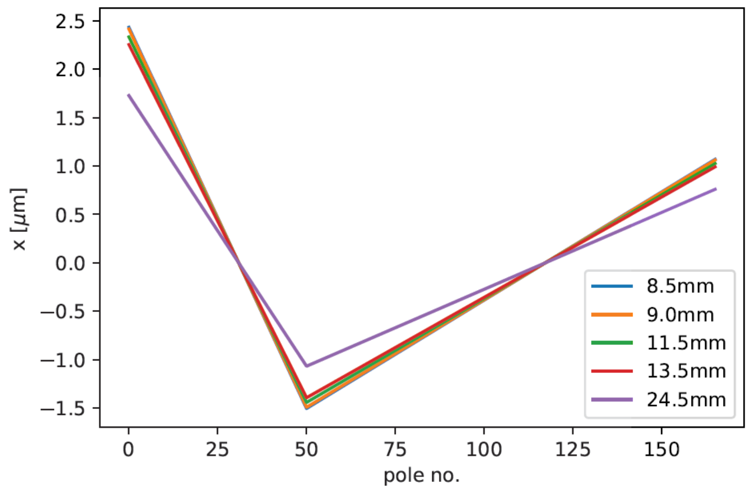
Introduction

- The Advanced Photon Source (APS) is undergoing a major upgrade to its storage ring. The APS Upgrade (APS-U) project plans to build over 40 new hybrid permanent magnet undulators (HPMUs) and rebuild over 20 existing HPMUs.
- To meet the APS-U undulator requirements, the quality of the undulator magnetic field needs to be fine-tuned to the specifications. The traditional methods that depend on the tuning specialist's experience are not desirable for tuning large quantities of undulators. We developed algorithms that automate the tuning of HPMUs.
- For tuning of the undulator trajectory and phase, the algorithms optimize the tuning parameters with differential evolution-based global optimization. The algorithms have been successfully applied to 24 APS-U HPMUs. The results and experiences of the tuning are reported in detail.

Trajectory Signature

- Trajectory of an undulator at a gap is period-averaged first, and only the trajectory at pole-center is considered.



- The above picture shows the trajectory signatures of a shim that is installed on pole no. 50.
- The trajectory signatures are obtained from measurements.
- Only the trajectory straightness matters, therefore the linear components have been removed.
- Trajectory signature with linear component removed is denoted as

$$S'(j,k,g;i)$$

j: the index of the type of the shim; k: the pole index where the shim is installed; g: the gap opening; i: the pole index.

Prediction Function

- **Predicted trajectory = initial trajectory + signatures**

$$X_p(\{j,k\}_m, g; i) = X_0(g; i) + \sum_{t=1}^{m} S'(j_t, k_t, g; i)$$

Objective Function

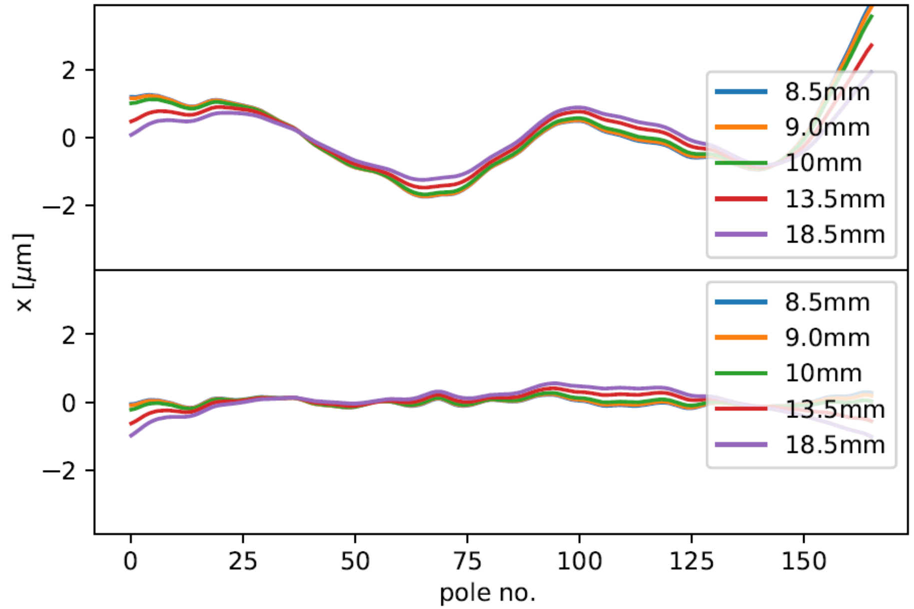
- We want the trajectories at all gaps to be straight; an objective function is constructed

$$F_{err}(\{j,k\}_m) \equiv \sum_{g=1}^{n_{gaps}} w(g) \cdot rms(X_p(\{j,k\}_m, g; i))$$

Solver

- Differential evolution algorithm is used to determine the tuning parameters $\{j,k\}_m$ that minimize the above objective function.
- The user must tell the solver the number of shims m and the weight of each gap.
- Normally the minimum gap has the largest trajectory error, hence heavier weights are assigned to smaller gaps.

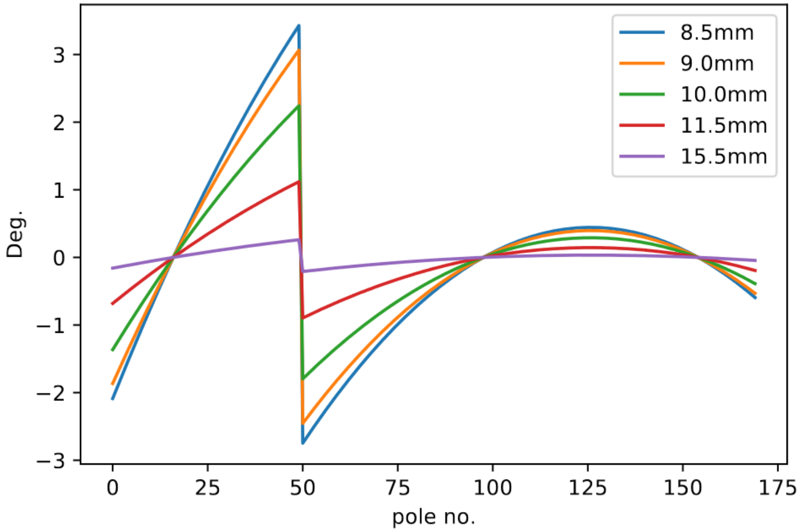
Trajectory Tuning Example



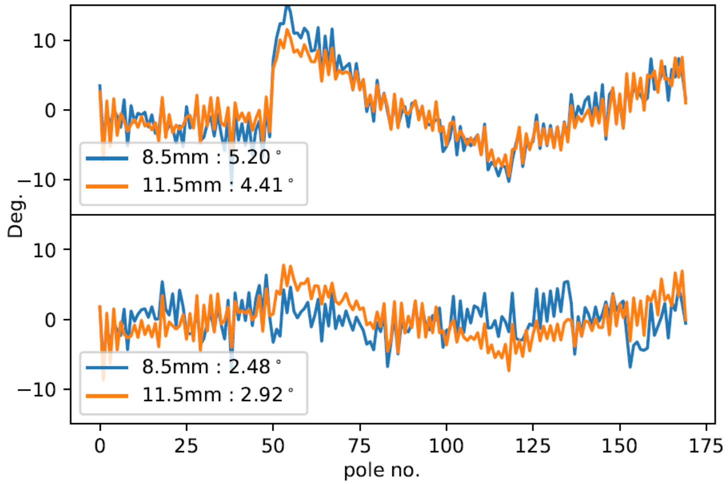
Period-averaged trajectories at different gaps of a 27-mm-period device before (top panel) and after (bottom panel) being corrected by side shims. These were achieved in one round of tuning by installing side shims on six poles with the parameters from the algorithm. The electron energy is 6 GeV.

Adoption for Phase Tuning

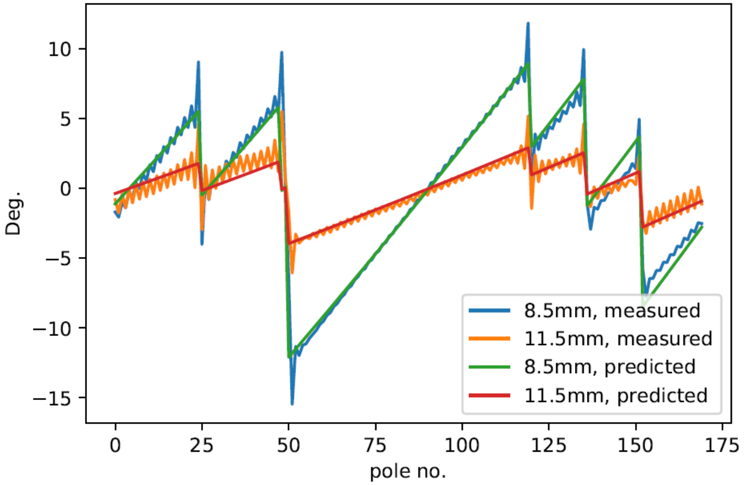
- Surface shim-based phase error tuning shares the same algorithm with the trajectory tuning.
- Phase error at each pole center is to be tuned, the RMS phase error is the tuning objective.
- Because the parabolic component in phase error could be removed by taper mechanism in HPMUs, the phase signature does not contain a parabolic component. An example is shown in the figure below.



Phase Tuning Example



Phase error of a 23-mm-period undulator before (top panel) and after (bottom panel) being corrected by surface shims.



Comparison of predicted phase changes and real phase changes in the above example. Phase shims at five locations were used.