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MAGNETIC SHIMS STUDIES FOR APS-U HYBRID PERMANENT MAGNET UNDULATORS*

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Abstract

For the newly designed and fabricated APS Upgrade (APS-U) hybrid permanent magnet undulators (HPMUs), the development of magnetic shims has been critical to successfully tuning the undulators to meet the tight APS-U physics requirements [1]. Different types of side and surface shims have been developed and applied for this purpose.

The side shims are primarily used for trajectory tuning, and the surface shims are for phase and multipole tuning as well as trajectory tuning. Current design, applications, and measurement of the shims for the newly designed and fabricated APS28 (28 mm period) undulators are presented in this paper.

INTRODUCTION

The APS chose many years ago to use hybrid undulator magnet designs to generate x-rays, which is also the case for the new undulators but with improved mechanical structures. However, the new undulators as well as the old undulators that will be reused, require magnetic tuning to meet the strict APS-U physics requirements [1]. The development of new shims was critical to the successful and efficient magnetic tuning of all the planned new APS28 undulators. The key factors to consider are the gap-dependent magnetic shim signatures, ease and repeatability of installation, and stability under strong magnetic forces. Figure 1 shows the first APS 28-mm-period undulator installed on the 3-meter-long measurement bench in the magnetic measurement laboratory.

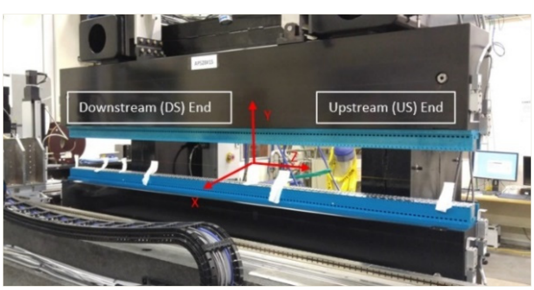

Figure 1: The first APS28 undulator on the measurement bench with the measurement coordinate system overlayed.

The undulator trajectory and phase analysis are based on on-axis magnetic field measurements with Hall probes, and the multipole analysis is based on long-coil measurements. There are 168 and 148 poles on each jaw for the 2.4-m-long and 2.1-m-long APS28 undulators, respectively.

SIDE SHIMS

In a hybrid undulator a pole is sandwiched between two magnets except at the ends, which terminate with poles. The side shims are placed on one or both sides of a pole to alter/tune the magnetic field in the vicinity of the pole. They are normally used in pairs, with one shim installed on the top jaw and one installed on the bottom jaw at the same pole location. Side shims are preferred over surface shims because they do not reside near the beam axis in case a shim would come loose. However, side shims have limitations: due to their predominant normal dipole characteristics, they can be used primarily for trajectory tuning.

Configurations

For the newly designed undulator, the elemental side shim is made from a 0.5-mm-thick sheet metal of low carbon 1010 steel. A piece of side shim of a certain thickness consists of a number of stacked 0.5-mm-thick elemental shims sandwiched between two aluminium holders, as shown in Fig. 2.

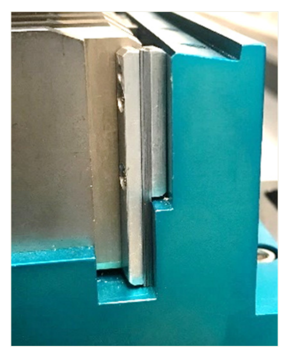

Figure 2: Photograph of a 1.5-mm-thick side shim (three 0.5-mm elemental shims stacked) placed against the teal-colored keeper. To the left of the shim is the pole and behind it is the first magnet. The shim was placed at the end pole for illustration only.

Magnetic Signatures

For magnetic signature measurements several pairs of side shims (more pairs for thin shims) are placed at poles of the same polarity in the core of undulator to obtain better averaged signatures. Figure 3 shows the measured normalized gap-dependent signatures for the APS28#1S undulator. All signatures were normalized to their values at a 10-mm gap.

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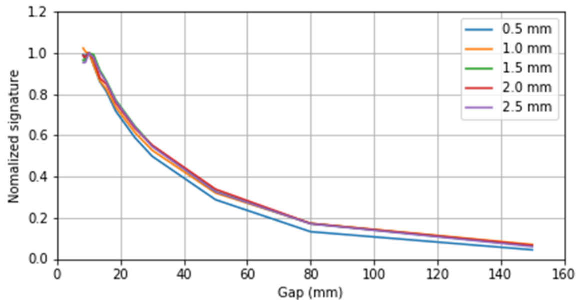

Figure 3: Measured gap-dependent signatures of side shims of different thicknesses (APS28#1S). Values normalized at the 10-mm gap.

The gap-dependent profiles are very similar for different shim thicknesses. The shim signature values used for the normalization is given in Fig. 4.

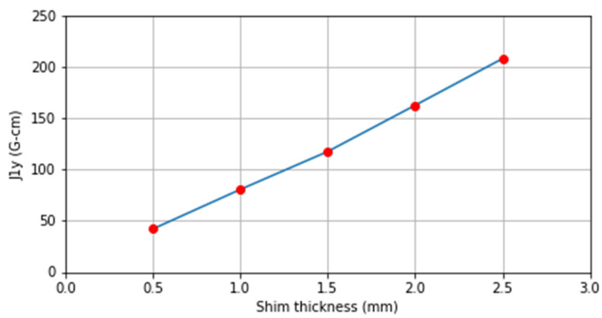

Figure 4: Side shim signatures for different shim thicknesses at a 10-mm gap for the APS28#1S undulator.

The trajectory tuning performed is demonstrated for the APS28#12S undulator. Figure 5 shows initial trajectories at three different gaps before tuning.

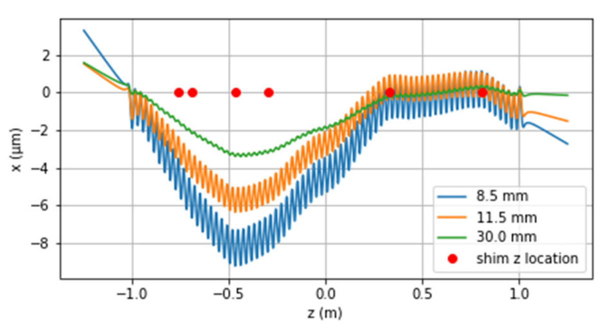

Figure 5: Trajectories of the APS28#12S undulator at 8.5-, 11.5-, and 30-mm gaps *before* trajectory tuning (6 GeV). The side shim tuning locations are indicated by the red dots.

The side shim locations and corresponding strengths (thicknesses) as determined from multi-gap trajectory/phase tuning optimization simulations are listed in Table 1 [2].

Table 1: Side Shim Locations and Strengths (Pole Numbers Counted from the z- End)

Pole#	Thickness (mm)
20	0.5
25	1.5
41	3.5
53	1.5
98	2.0
132	1.0

Side shims were applied according to simulations (from Table 1), and the results after tuning with straightened trajectories are shown in Fig. 6.

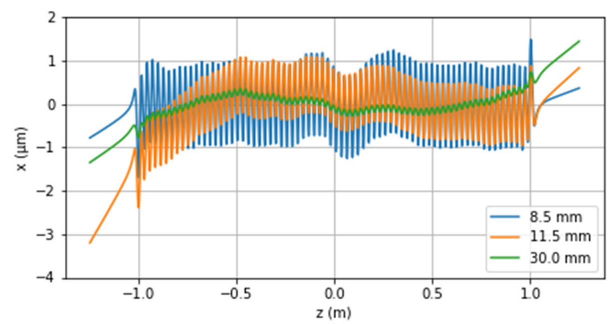

Figure 6: Trajectories of the APS28#12S undulator at 8.5-, 11.5-, and 30-mm gaps *after* trajectory tuning (6 GeV).

SURFACE SHIMS

A magnet recess with respect to the poles was designed for accommodating surface shims for the APS undulators. Surface shims of different thicknesses and lengths (in the x-direction) are designed to provide different tuning strengths and gap-dependent profiles. The surface shim widths (in the z-direction) are normally designed to be around half of the magnet thickness except for phase shims, which cover the whole magnet. The surface phase shims are placed on top of magnets between two poles of opposite polarity, which leads to phase changes. For clarity, the surface phase shims will be referred as “phase shims” to distinguish them from other “surface shims” in this paper.

In addition to thickness and length, surface shims are also arranged in certain configurations to tune both normal and skew dipoles as well as multipoles.

Configurations

For the APS28 undulators the magnet recess is 0.5 mm. The surface shims are 0.1 mm, 0.2 mm, and 0.4 mm thick. For each shim thickness four different shim lengths (in the x-direction) are designed: 5 mm, 10 mm, 15 mm, and 20 mm. The shim width (in the z-direction) is 4.7 mm (the magnet thickness is 9.2 mm).

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Magnetic Signatures

Surface shims Surface shims are often used in pairs (top and bottom jaws) or in a group of four pieces for multipole tuning. For the multipole signatures the surface shims are computed with Opera 3D [3]. However, verification of simulated signatures against measurements were performed for certain configurations. Figure 7 shows an example of such studies.

Figure 7: Photograph of twelve 0.2-mm-thick × 5-mm-long surface shims placed on the bottom jaw with a 10-mm x-shift from the beam axis for the APS28#7 undulator.

The signature of multipole shims is expressed per 4 pieces of the same-sized surface shims. The integrated multipoles are measured with the long-coil system. Figures 8 and 9 show verification measurements of the normal and skew multipoles, respectively. Clearly, the Opera-simulated signatures of the multipoles agree well with the measurements.

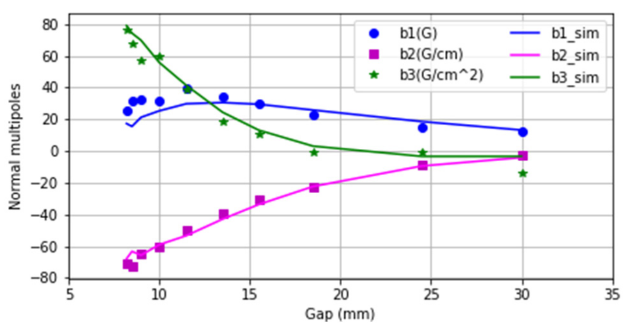

Figure 8: Comparison of normal quadrupoles (b1), sextupoles (b2), and octupoles (b3) from measurements and simulations.

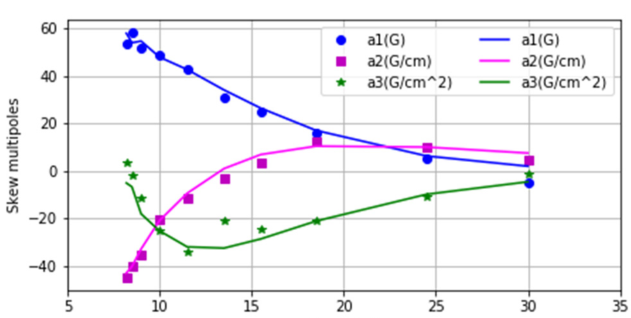

Figure 9: Comparison of skew quadrupoles (a1), sextupoles (a2), and octupoles (a3) from measurements and simulations.

Phase shims The signature of a pair of phase shims can be derived from the phase changes caused by them. Figure 10 shows the signature of a pair of 0.2-mm-thick phase shims for the APS28#8 undulator.

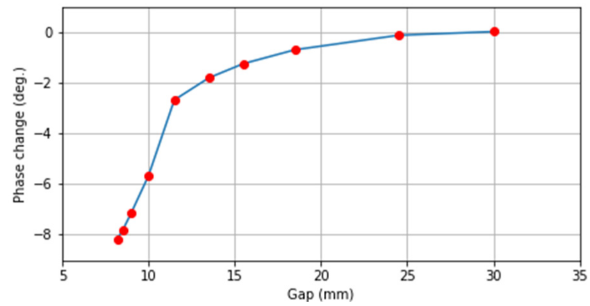

Figure 10: Gap-dependent signature of a pair of 0.2-mm-thick phase shims for the APS28#8 undulator.

For phase tuning, the shim locations and strengths are determined from simulations [3]. Figure 11 shows phase errors at a 8.5-mm gap before and after phase shimming for APS28#7.

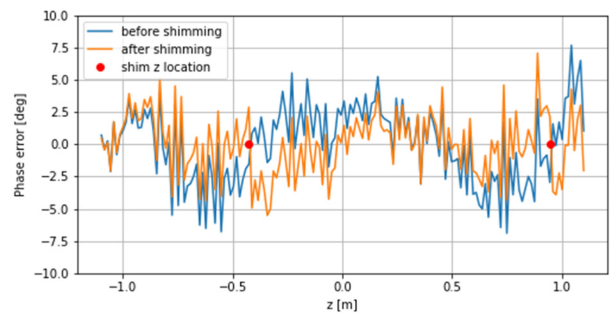

Figure 11: Phase errors before and after phase shims applied to APS28#7 at a 8.5-mm gap. Pairs of 0.2-mm-thick phase shims (red dots) were placed at magnet numbers 54 and 152. The RMS phase errors were improved from 2.94° to 2.41°.

CONCLUSION

After several design iterations and tests, the current design of side shims and surface shims have been proven successful. With the new phase tuning method [2] and an algorithm-guided tuning methodology [4], all 13 newly fabricated APS28 undulators have been tuned well within the APS-U specifications [5]. Additionally, the design has also been successfully extended to the shorter undulator period lengths of 25 mm and 21 mm for the APS-U with successful tuning of the 2 undulators, one for each period length [6].

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