# MAGNETIC TUNING OF THE APS WIGGLER AS A STUDY FOR TUNING THE NSLS-II DAMPING WIGGLER*

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*Abstract*

A wide variety of tuning techniques has been developed and employed at APS in the course of tuning insertion devices for use on the APS storage ring, the APS free-electron laser, and in the developing and assisting with the Linac Coherent Light Source (LCLS) undulator tuning. The tuning requirements for the National Synchrotron Light Source II (NSLS-II) damping wigglers are very demanding and include limits on the off-midplane field integrals that are new in the repertoire of undulator magnetic tuning. The goal of this study was to assess the applicability of existing tuning techniques to meeting the off-midplane requirements of NSLS-II. Tests were run using an available APS 8.5-cm-period wiggler. In addition to existing techniques, a special new shim design was tested. This report summarizes the results of these tests and shows that the wiggler can be tuned to the required specifications on the midplane over the requested ±15 mm in the horizontal direction. In the vertical direction, however, the specifications could only be met within ±0.5 mm. This falls short of the ±15 mm by ± 3 mm good-field region that is sought by NSLS-II.

## INTRODUCTION

In the 2010 year, the APS Magnet Devices group and the NSLS-II design and construction team were considering a collaborative effort for the development of damping wigglers (DWs) for the NSLS-II storage ring. The DWs are required in order to achieve the 1-nm emittance design goal set for the NSLS-II. In principle this collaborative effort could result in a very straightforward task, since the APS has quite significant experience in the design and construction of state-of-the-art insertion devices (IDs), including wigglers. But the NSLS-II team came forward with the specifications on the magnetic performance of DWs that APS had never met before for any of its IDs. Particularly, it set very stringent limits on the off-mid-plane magnetic performance of the DWs.

In order to investigate the applicability of the magnetic tuning techniques used at the APS for the task of meeting NSLS-II specifications, the APS team conducted experimental tests utilizing the APS wiggler [1] and all existing and newly developed tools for magnetic tuning. This report summarizes the results of these tests.

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## SPECIFICATIONS FOR NSLS-II DWS

The list of magnetic specifications for NSLS-II damping wigglers is presented in Table 1. The main distinctive difference between these specifications and those of the APS wiggler is the requirement on specific values for 1st and 2nd field integrals within the 30×6 $mm^2$ vertical cross section of the DW midplane. Typically, for APS IDs (and similar for LCLS IDs) a similar requirement is only "one-dimensional," i.e., midplane (y=0) field integrals within -5 mm < x < +5 mm should not exceed a specified value [1].

To date, the APS has not had direct experience in designing and tuning IDs according to the NSLS-II specifications. Therefore, in order to learn such a process, as well as to assess the applicability of existing tuning techniques to the new task, it was proposed to use the APS wiggler as a prototype for the development.

Table 1: NSLS-II DW 1st and 2nd Integral Requirements; gap = 12.5 mm, y is vertical, x is horizontal coordinate

| | |
|---|---|
| $J_{1y}=\int_{-\infty}^{\infty} B_y(x,y,z)dz$ | < 50 G.cm<br>(\|x\|<15 mm,<br>y=0 mm),<br>< 100 G.cm<br>(\|x\| < 15 mm,<br>y=3 mm) |
| $J_{1x}=\int_{-\infty}^{\infty} B_x(x,y,z)dz$ | < 30G.cm<br>(\|x\| < 15 mm,<br>y=0 mm),<br>< 60 G.cm<br>(\|x\| < 15 mm,<br>y=3 mm) |
| $J_{2y}=\int\int_{-\infty-\infty}^{\infty\, z} B_y(x,y,z')dz'dz$ | < 10,000G.$cm^2$<br>(\|x\| < 15mm,<br>y=0 mm),<br>< 20,000G.$cm^2$<br>(\|x\| < 15 mm,<br>y=3 mm) |
| $J_{2x}=\int\int_{-\infty-\infty}^{\infty\, z} B_x(x,y,z')dz'dz$ | < 5000 G.$cm^2$<br>(\|x\| < 15 mm,<br>y=0 mm),<br>< 10,000G.$cm^2$<br>(\|x\| < 15 mm,<br>y=3 mm) |
| $J_{2x}=\int\int_{-\infty-\infty}^{\infty\, z} B_x(x,y,z')dz'dz$ | \|x\| < 60 μm,<br>\|y\| <5 μm<br>\|y′\| < 10 μrad |


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## APS WIGGLER

The APS wiggler is one of the special APS IDs that has been used for quite some time at different APS beamlines. Although some parameters of the APS wiggler are different from those of the NSLS-II DWs, nevertheless the important numbers, such as the peak field and width of the poles, are close enough to ensure the conclusive results of applicability tests (see Table 2). The APS wiggler was originally tuned by its manufacturer, STI Optronics. Before any additional tuning was done for this development, the wiggler was characterized at the APS magnet measurement facility, and it was verified that the wiggler met the APS specifications requirements for both field integrals and integrated multipole components (see Table 3).

Table 2: Standard NSLS-II DW Magnet Array Parameters vs. APS Wiggler A

| Item | NSLS-II Parameters | APS Parameters |
|---|---|---|
| Magnetic Length | > 3.4 m | 2.4 m |
| Period Length | 90 mm | 85 mm |
| Minimum Pole Width | 80 mm | 50 mm |
| Magnetic Gap | > 12.5 mm | 11.5 mm |
| Nominal Peak Field | 1.8 T | 1.4 T |
| Integral of $B_y^2$ on-axis for one period in longitudinal direction | > 95% of 0.1458 $T^2$.m | No requirements |

Table 3: Specifications for Integrated Multipole Components of the APS ID (x=0 mm, y=0 mm)

| | |
|---|---|
| Normal quadrupole ($b_1$) | 50 G |
| Skew quadrupole ($a_1$) | 50 G |
| Normal sextupole ($b_2$) | 200 G/cm |
| Skew sextupole ($a_2$) | 100 G/cm |
| Normal octupole ($b_3$) | 300 G/cm$^2$ |
| Skew octupole ($a_3$) | 50 G/cm$^2$ |

Here, the integrated multipole fields are defined as:

$$\int_{-\infty}^{\infty} dz(B_y + iB_x) \equiv \sum_{n=0}^{\infty} (b_n + ia_n)(x+iy)^n \ .$$

## MAGNETIC MEASUREMENT AND TUNING TECHNIQUES

The APS has used its magnet measurement facility [2] to measure and tune the APS wiggler to study the feasibility of achieving the NSLS-II specifications requirements for DWs. The well-established magnetic measurements technique based on the use of a rectangular-shaped, long, stretched loop/coil has been applied; and, for the magnetic tuning, the ID shimming technique has been exploited.

The long (about 4 m) stretched coil is made of 0.1-mm-thick BeCu wire and has a width of 4.2 mm. Two modes of the coil operation were used:

1. *Translation mode*—the coil was moved parallel to itself with the coil's plane positioned vertically for measurements of horizontal field integrals or horizontally for measurements of vertical field integrals. These measurements provide only relative values of measured field integrals.

2. *Rotating mode*—the coil was rotated by 360°. These measurements provide absolute values of field integrals.

The majority of measurements were performed at a wiggler gap of 11.5 mm. But in several cases the measurements were taken with the gap opened to 15 mm in order to accommodate the vertical motion of the coil.

Two sets of measurements and tuning of the APS wiggler were performed. The first set consisted of measurements performed at the small gap, but tuning, i.e., magnetic shims placement, was done while the magnetic gap was wide open. The second set of measurements and tuning was performed at closed gap since it was anticipated that the NSLS-II DWs would be fixed-gap devices. In order to perform magnetic tuning with the wiggler's gap closed down to 11.5 mm, a specially designed shim holder was utilized (see Fig. 1). The holder provided precise and firm positioning of spot-welded shims in the narrow fixed gap of the wiggler.

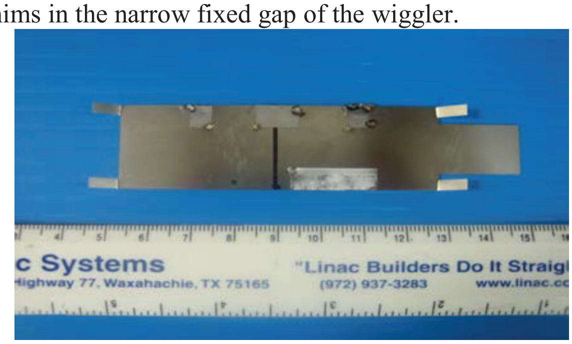


Figure 1: Picture of the shim holder with magnetic shims on it.

## RESULTS OF TUNING AND MEASUREMENTS

The results of the first set of measurements are presented in Figs. 2, 3, and 4. Figure 2 shows that the specification requirement for the 1st horizontal field integral was met only for Y< ±0.5 mm. Also it has to be pointed out that, at that stage of the magnetic tuning, one of the multipole components was not within the specified range even for Y=0, as shown in Fig. 4 (integrated skew octupole).

The results of the second set of measurements are presented in Figs. 5 and 6. Again, specification requirements for the 1st horizontal field integral were barely met for Y< ±0.5 mm only. At the same time, more accurate tuning of integrated skew multipoles at Y=0 was accomplished, and the results presented in Fig. 6 show that all specifications for skew multipoles at Y=0 were met. Nevertheless, it did not lead to any improvement in the Y dependence of the 1st horizontal field integral. At this point, the APS does not have the capabilities or tools to achieve the required field integral values in the range of Y above 1 mm.

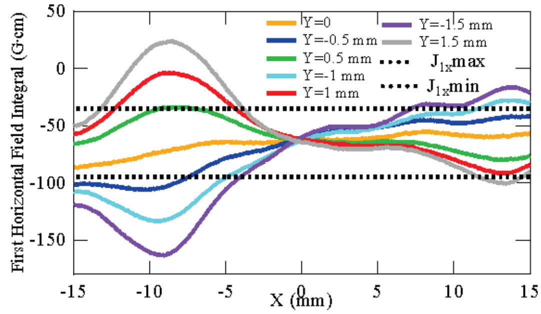


Figure 2: Translation mode measurement results.

First field integral at X=0 ($a_0$) was obtained from rotating coil measurements. The specification of the NSLS-II DW for the 1st horizontal integral $\Delta J_{1x} < 60$ G-cm is satisfied for the range ±0.5 mm in Y.

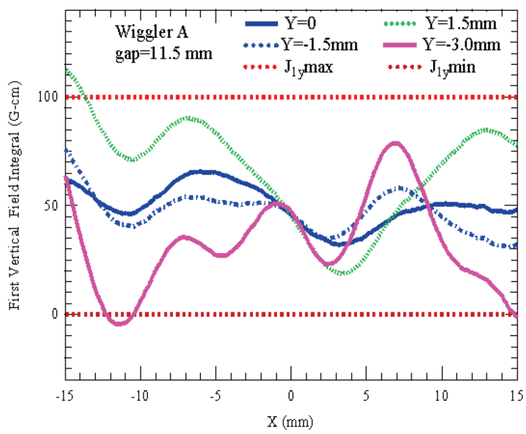


Figure 3: Translation mode measurement results.

The specification of NSLS-II DW for the first vertical field integral $\Delta J_{1y} < 100$ G.cm is satisfied in the range -3 mm < Y < 1.5 mm.

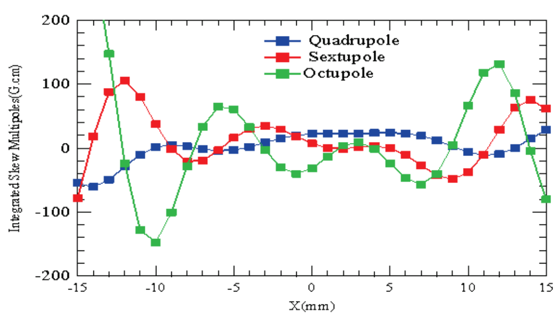


Figure 4: The tuning results of the skew multipole components of the device for the first set of measurements. The skew octupole component $a_3$ is out of the specification requirement of NSLS-II DW.

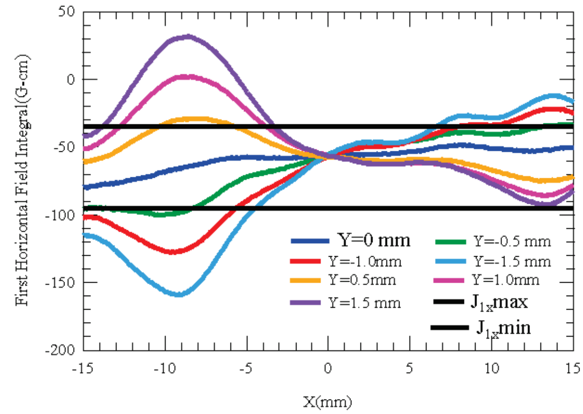


Figure 5: Results of the second set of measurements: fixed gap ID, translation mode.

The specification of NSLS-II DW for the first horizontal field integral $\Delta J_{1x} < 60$ G.cm is satisfied in the range Y ≤ ±0.5 mm. The absolute values of the first integral are obtained from rotating coil measurements.

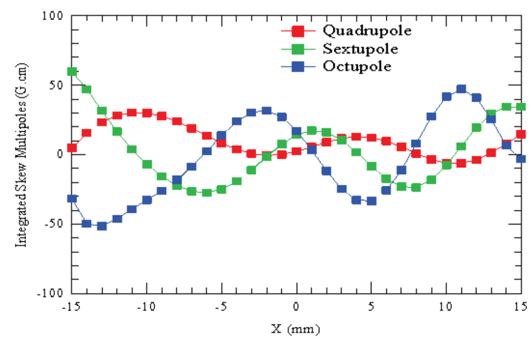


Figure 6: Skew multipole components for fixed-gap device after tuning at Y=0. All of them meet the specifications requirements of the NSLS-II DW.

## CONCLUSION

The APS wiggler has been used to do the feasibility study of magnetically tuning the device according to NSLS-II DW specifications. With existing tools and methods at the APS, the wiggler could be tuned to the required specifications only within the 30×1 mm$^2$ cross section at the midplane, which is several times smaller than the specifications require. Existing tuning techniques at the APS do not provide the tools to tune the device multipole components at Y≠0.

## REFERENCES


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[2] J. Xu and I. Vasserman, "A new magnetic field integral measurement system," ANL/APS/TB-49, January 2005.





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