MAGNETIC MEASUREMENTS AND TUNING OF UNDULATORS FOR THE APS FEL PROJECT

I.B. Vasserman, R.J. Dejus, P.K. Den Hartog, M. Erdmann, E. Gluskin, E. R. Moog, and E. M. Trakhtenberg, Advanced Photon Source, Argonne National Laboratory, Argonne IL 60439

Abstract

Two insertion device magnetic structures have been prepared for the Advanced Photon Source (APS) FEL project [1]. The magnetic structures are standard APS undulators, 2.4 m long with a 3.3-cm period. Measurements and tuning of the undulators have been completed at a magnetic gap of about 9.3 mm, where K is 3.1. Special measurement and tuning techniques were used to satisfy the tight trajectory straightness requirement that the second field integral be less than 3.3 kG-cm^2. The magnetic field strengths of the undulators must be well matched; this leads to the requirement that the magnetic gap must be controlled to better than 10 microns. Proper phasing between the undulators is ensured by adjusting the length of the drift space between the undulators. The drift space length that is needed is strongly affected by the end fields of the magnetic structures. The results of measurements of the magnetic field and calculations of the drift length are provided.

1. HORIZONTAL FIELD MEASUREMENTS

The tight requirements for vertical trajectory straightness of FEL insertion devices means that not only field integrals, but the magnetic field map as well, must be measured to high precision. The measurements of the horizontal field in the presence of a strong vertical field (up to 1 T) is difficult due to the planar Hall probe effect [2], but precise alignment of the probe can eliminate this effect for one particular pair of poles. The task becomes even more complicated for an undulator with a large number of poles that are not aligned with perfect accuracy. Due to specific tolerances of each particular magnetic structure, it is by no means clear that it is possible to align the probe to measure the horizontal field precisely enough along the entire device. To prepare for the FEL project at the APS a test was performed to check the reliability of horizontal field measurements [3]. Two types of probes were tested. These were a custom-designed two-axis Sentron analog Hall transducer [4] and a two-axis Bell probe. A stretched-wire rotating coil and an 81-mm-long moving coil were used to make the reference measurements. Insertion device Undulator A #3 was used for these measurements with a gap of 11 mm and a peak field of about 0.85 T. As the result of this test, a Sentron probe was chosen for horizontal field measurements. The main advantage of this probe is its small sensitivity to angular orientation. This feature makes it possible to obtain the proper field map of a device with many periods and imperfect alignment of the poles in the longitudinal direction, Z. It is possible to use a moving coil to obtain the field map averaged over the length of the coil.

Although this approach is not sufficiently accurate to obtain the harmonic spectrum, it is good enough for the trajectory straightness determination. The disadvantage of the moving coil is a zero drift in the integrator that leads to the need for a large data set and extensive data reduction to obtain reliable results. Consequently, it is better to use the moving coil for reference measurements and to apply the Hall probe for tuning purposes. The tests show that the Sentron probe provides reliable results after proper alignment. The measurement results are shown in Fig. 1 for one of the devices used in the FEL beam line. It is worth noting that a very precise alignment in the vertical Y direction is required for this specific Hall probe and for the undulator itself.

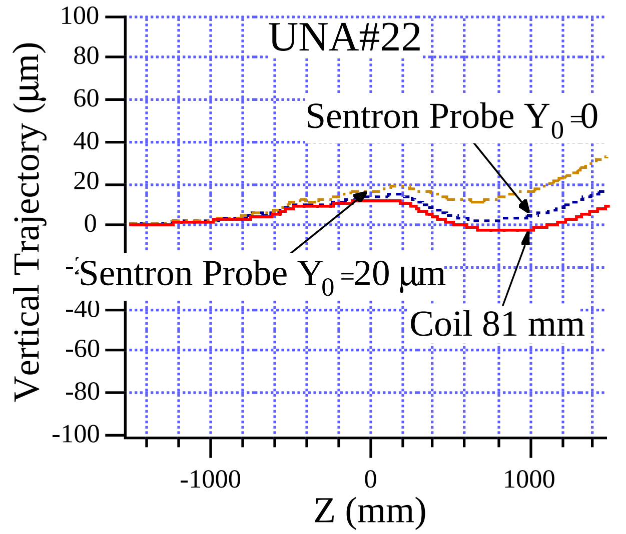

Fig. 1 Hall probe measurements with different Y offsets. A moving coil reference measurement is included for comparison. The particle energy is assumed to be 220 MeV.

2. RESULTS OF TUNING

The permanent support system for the FEL devices is an H-style fixed-gap structure, which allows only minor gap variations of 9.3 ± 0.2 mm. To facilitate shimming, the initial tuning for the FEL project was performed using a C-frame variable gap mechanism that allowed full side access for magnetic measurements. After performing the

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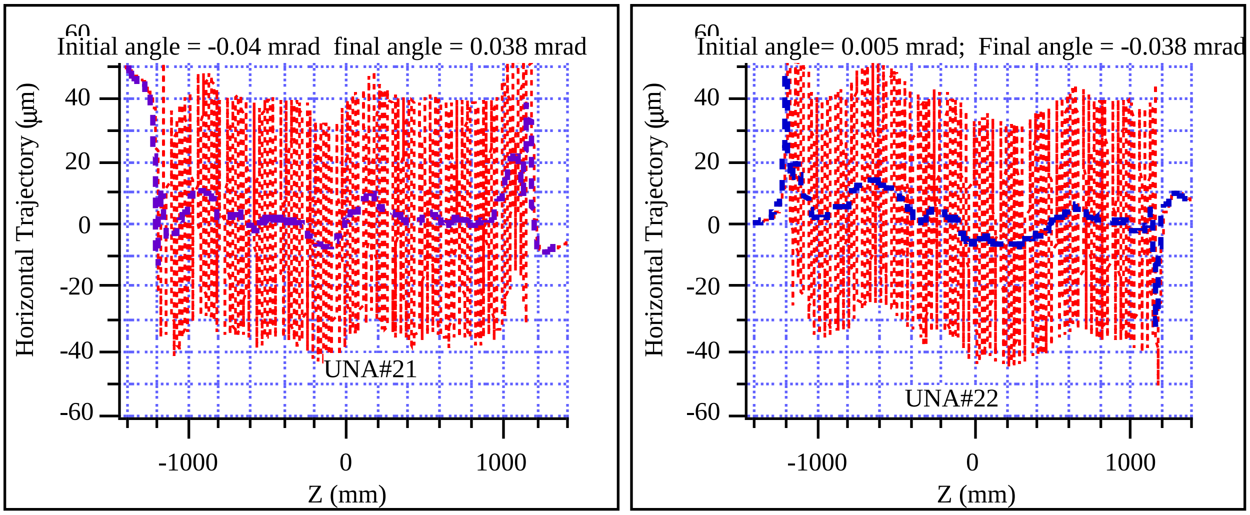

Fig. 2 Horizontal trajectory of the first two FEL devices. The dark line is the wiggle-averaged trajectory.

tuning on the C-frame and moving the devices to the fixed-gap support, changes in the field integrals and the sag profile were measured because of differences between the magnetic structure supporting points. Consequently, it was found necessary to perform a full set of measurements on the fixed-gap support in order to set the proper value of the wiggler strength parameter K, to tune the trajectories and to find the break length necessary for proper phasing of the devices. To accomplish this, a feature was designed to allow access to the gap of device for the magnetic sensors all along the device length, and a set of measurements was performed with the Hall probe and moving coils using this feature. Measurements of the gap at several locations along the device were performed with an accuracy better than 5 µm to provide a reference so the gap profile could be reproduced after moving the device to its location on the beam line. The break length required for proper phasing was calculated from measured data using the upgraded MA code [5]. The device was divided into 3 parts: a central part, and upstream and downstream terminations. Polynomial fitting was performed to smooth the changes associated with local distortion of phases. The break length is strongly affected by the specific sag configuration of the device and varies by a few millimeters from device to device (see Table 1).

TABLE 1

	UNA #21	UNA #22
DS end (cm)	19.68	20.44
US end (cm)	20.02	20.12

It is possible to change the required break length to some extent by phase shimming. The results of final tuning are shown in Figs. 2 and 3 for horizontal and vertical trajectories, respectively. The requirement of 3.3 kG-cm^2 corresponds to 45 µm of trajectory displacement for a particle energy of 220 MeV. The maximum distortions for the first two devices are smaller than ±15 µm.

3. DISCUSSION

We would like to discuss some specific requirements associated with this project. Planar devices at small energy provide quite strong natural focusing in the vertical direction due to edge focusing from the magnets with parallel edges. The focusing of a device is given by [6]:

$$\frac{1}{f_y} = \frac{K^2}{2\gamma^2} k_p{}^2 L_w$$

where the relativistic γ is the ratio between the particle's total energy and its rest energy, $k_p=2\pi/\lambda_W$, f_y is the focusing length of the device, L_W is the total length of the device, and λ_W is the period length of the wiggler or undulator.

This focusing makes the vertical alignment of the device critical: in our case the device must be aligned with an accuracy of 50 µm. It also means that measurement of the magnetic center of the device is necessary in order to find the difference between the magnetic and the geometric center, if any. Such measurements were performed using the well-known fact that the vertical magnetic field has its minimum at the median plane of the pair of poles that is the source of the magnetic field in hybrid structure devices. Scanning of the field in the vertical direction using the Hall probe allows one to obtain the location of the magnetic center with a precision better than ±10 µm. The set of measurements performed on the FEL devices showed that the magnetic and geometric centers coincide more closely than the position accuracy required [1]. While there are local distortions associated with shimming at a particular pole or with the strength of the adjacent permanent magnets (see Fig.4), the averaged behavior of the magnetic center follows the geometric center quite well. This means that for our particular case the geometry of the device can be used as the reference for alignment.

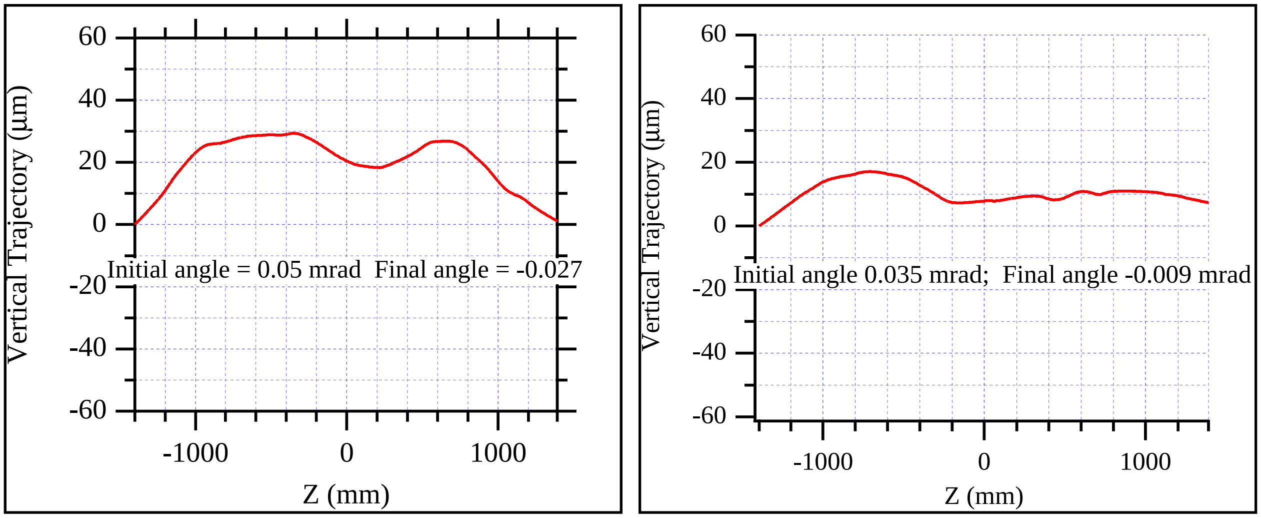

Fig. 3 Vertical trajectory of the first two FEL devices

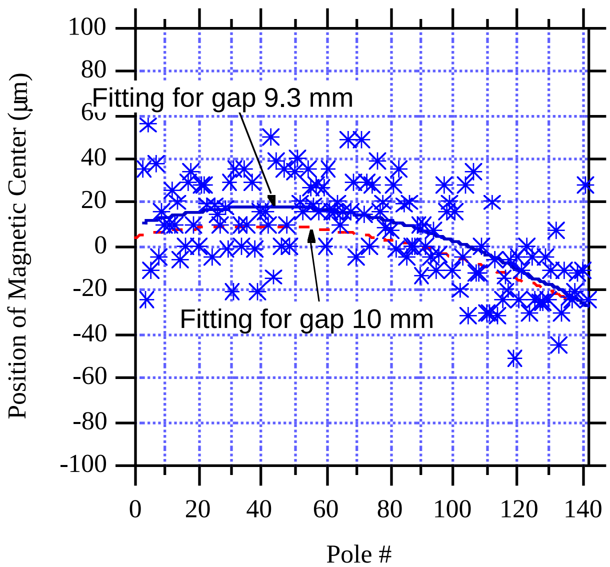

Fig. 4. Position of magnetic centers for UNA#21. The solid line shows the fit to the data; the corresponding fit for a gap of 10.0 mm is shown for reference. The overall 40 µm slope is due to the geometrical misalignment of the sensor and device.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

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