MAGNETIC PERFORMANCE OF INSERTION DEVICES AT THE ADVANCED PHOTON SOURCE

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Abstract

The insertion devices (IDs) at the Advanced Photon Source have been magnetically tuned to minimize the integrals of the field through the devices and to minimize the variation of those integrals with gap, with a goal of not perturbing the stored particle beam. Measurements of the particle beam motion as the ID gap was changed found that the closed-orbit distortion was better than the requirement and agreed well with predictions based on magnetic measurement results. Another goal of the magnetic tuning is to ensure high brilliance in the low-order harmonics by keeping the rms phase error small.

1 INSERTION DEVICES AT THE APS

The Advanced Photon Source (APS) has 23 insertion devices (IDs), of which 18 are installed on the storage ring. Thirteen of the installed devices are 33-mm-period undulators. Other installed undulators have periods of 27 mm, 55 mm, and 18 mm; an 85-mm-period wiggler and an elliptical wiggler with a 160 mm period complete the list of installed devices. The elliptical wiggler was built jointly by the Budker Institute of Nuclear Physics (Novosibirsk, Russia) and APS; all the rest of the IDs were built and tuned to demanding specifications by STI Optronics (Bellevue, WA). The IDs have undergone further refinement of their magnetic field at APS since their delivery. The straight sections where the IDs are installed are long enough to accommodate two standard-length (2.4-meter) IDs, but only the sector that is occupied by the 55 mm and a 33 mm undulator has more than one ID installed at present.

An early conceptual version of the 33-mm-period undulators was intended to have a minimum gap of 11.5 mm. The tuning curve for this undulator, however, predicted a decrease in brilliance of about a factor of 3 when moving at constant photon energy from the third harmonic at closed gap to the first harmonic at a more open gap. The users preferred not to have such a large discontinuity in brilliance as the photon energy was scanned. In order to eliminate this jump, two things were done: the undulator magnetic design was changed to increase the magnetic field so the third harmonic would extend to lower energy, and tighter tolerances were placed on the straightness of the vacuum chamber so that the undulator would be able to go to smaller gap. The undulators currently installed can all go to a minimum gap of 10.5 mm.

2 MEASUREMENTS OF THE FIRST AND SECOND FIELD INTEGRALS

It is important that the integrals of the field through the ID not change by much as the ID gap is changed, so that the net effect of a gap change on the particle-beam closed orbit is small. The first and second field integrals of both the horizontal and vertical components of the magnetic field must be small enough to meet the APS requirement that the particle beam be stable to within 10% of its emittance. If compensation by local storage-ring steering correctors is relied upon, this translates into first field integral changes of no more than 100 G-cm and second field integral changes of no more than 100000 G-cm^2 [1]. Without compensation, the requirement is a vertical first field integral change less than 26.5 G-cm, a horizontal first field integral change less than 11.2 G-cm, a vertical second field integral change less than 37400 G-cm^2, and a horizontal second field integral change less than 11200 G-cm^2.

Measurements of the first and second integrals of the vertical and horizontal components of the magnetic field through each ID were made as a function of gap; one goal of the magnetic field refining was to minimize the changes in these integrals. The development of magnetic tuning techniques is an ongoing process at APS. New techniques are applied to IDs that are subsequently tuned or retuned. The total range spanned by the field integrals as the gap is changed is shown in Fig. 1 for the APS IDs as they are presently configured.

Changes in the field integrals as measured in the magnetic measurement facility may differ from the changes when the ID is installed in the storage ring, however, due to different environmental magnetic fields [2]. The vanadium permendur poles in these hybrid IDs can serve as field shunts, either removing horizontal components of the environmental field at small gap or focusing a vertical environmental field across the gap at small gap.

Measurements of changes in the first and second field integrals, and of changes in the tune, were also made using the particle beam in the storage ring. These measurements are complicated by other sources of orbit and tune motion, particularly because the gap change is relatively slow (approx. 1 min.) and the undulator-induced orbit and tune changes are quite small. To deal with this, we measure the difference in orbit and tune between two states of an undulator: "large" gap, typically 45 mm, and "small" gap, typically 11 mm. We take, typically, 10 measurements per state, alternating randomly between

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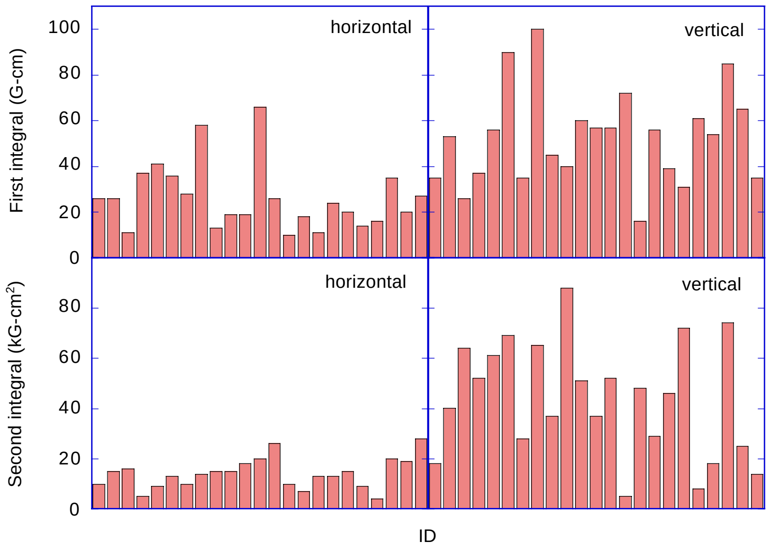

Figure: 1 First and second integrals of the vertical and horizontal components of the magnetic field through each of the IDs, as measured in the APS magnetic measurement facility.

states to reduce the effect of drifts. These two gaps were chosen because the extrema in field integrals as measured in the lab often occur at these gaps. Each measurement consists of acquiring the orbit (heavily averaged to reduce electronic noise and fast beam motion) and the spectrum around the vertical tune line (which is easier to measure precisely than the horizontal tune).

The orbit difference is determined after processing the orbits for each state to remove spikes that sometimes occur due to malfunctioning beam position monitors [3]. The undulator error field is modeled in the accelerator simulation program ELEGANT using two angle kicks per plane of beam motion, one at each end of the ID. The first integral is related to the sum of the kicks for a single plane, while the second integral is related to the value of the upstream kick. This provides exact modeling of the first and second integrals by giving the simulation control of the change in slope and angle due to passage through the device. Fig. 2 shows a typical result for displacement in the vertical plane, along with the fit from the simulation.

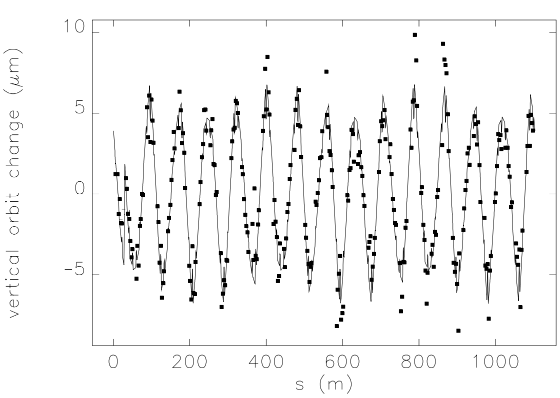

Figure: 2 Difference in vertical orbit for two different ID gaps, as a function of position around the ring. The points are the measured displacement values, and the line is the fit from the simulation. The ID is located at about 25 m.

While orbit displacement data can be measured easily and accurately, the small tune changes that result from changing an ID gap are not readily measured. We have found that in general the vertical tune change is less than 0.001, which is close to the limit of our ability to measure.

Measurements of the changes in the first and second integrals made using this beam-based technique agree with the results of magnetic measurements of the IDs that were carried out before the ID was installed on the storage ring.

3 PHASE ERRORS

Phase errors are another measure of the quality of an undulator magnetic field. A small rms phase error is needed in order to produce high-brilliance peaks in the undulator spectrum, although the effect of a large rms phase error is greater for high harmonics than for low ones. The IDs undergo tuning to decrease the phase errors, and, as with the field integrals, progressively better results are being achieved. The phase errors for all the 3.3 cm undulators are shown in Fig. 3. The phase is tuned primarily by placing shims on top of the magnets on the undulators. The magnets are recessed slightly (<0.5 mm) as compared to the poles in these hybrid IDs, so there is space to place shims without affecting the minimum gap. It has proved very useful in the tuning of these devices to have shims that are near-pure, i.e., that affect only the phase or only the trajectory. A standard trajectory shim would be one that covers half of the magnet in the beam direction and the whole magnet in the transverse direction. (Four of these would commonly be used together: one on each side of each of the two poles that face one another across the gap.) This shim serves to weaken the kick given by the pole and thereby changes the angle of a

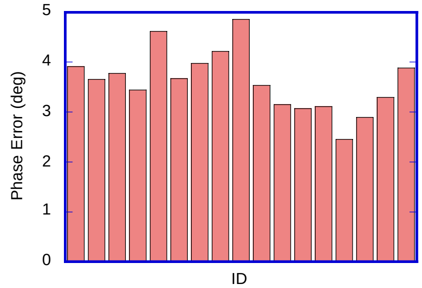

Figure: 3 Rms phase errors of all the APS 33 mm undulators, at a gap of 11.5 mm.

particle's trajectory through the ID. This shim, however, also has a strong direct effect on the phase, as can be seen by placing two such shims adjacent to one another with the opposite correction. The net effect on the phase will be large, particularly for IDs that have small magnet recesses, whereas there will be no net effect on the trajectory angle. If the length of the shim in the beam direction is made shorter, however, the direct effect on the phase will be much smaller compared to the effect on the trajectory [4]. For many of the undulators, it was found that there was no need to separately adjust the phase. Once the trajectory was corrected using the non-phase-altering trajectory shims, the rms phase error was already adequately small (less than 4 degrees).

Calculations have been made to predict the effect of the remaining phase errors on the spectral quality of the emitted photon beam, and to determine what the effect would be of making further improvements in the phase. The on-axis brilliance was calculated for the undulator with the smallest rms phase error (2.5 degrees) and for an undulator with a large rms phase error (4.6 degrees). The calculations are for an undulator gap of 11.5 mm and include representative values for the APS beam emittance and energy spread, and a coupling of 4.4%. The ratios of the intensities for the first, third, and fifth harmonics are 1, 0.98, and 0.90, respectively. The effect on higher harmonics is more pronounced, as can be seen in Fig. 4. The present phase errors meet the original design intention for the standard 33-mm-period undulator because they were intended to be used in the 1st, 3rd, and occasionally 5th harmonics. Should a user want to use higher harmonics, however, an undulator with a smaller rms phase error would be advantageous.

4 SUMMARY

The IDs at the APS more than meet the requirements for magnetic field quality, so that users are now allowed to change their gaps freely. The requirements will become more demanding in the future as the quality of the stored beam is improved or as users do more work at higher energy. We are developing techniques and applying them to IDs to further refine the magnetic field quality. The long-term magnetic performance of the IDs may be affected by radiation damage, though no effect has been seen yet. This is under experimental investigation [5].

5 ACKNOWLEDGEMENTS

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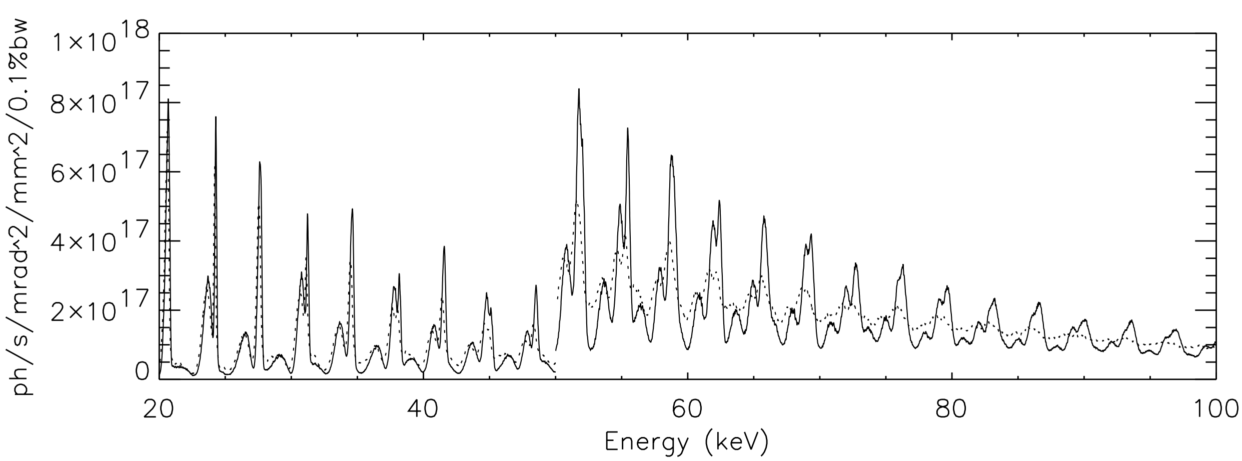

Figure: 4 Calculated on-axis brilliance, beginning at the 6th harmonic. The solid line is for the 33-mm-period undulator with the smallest rms phase error (2.5 degrees), and the dotted line is for an undulator with an rms phase error of 4.6 degrees, at 11.5 mm gap. *The brilliance above 50 keV has been multiplied by a factor of 4 for clarity*. While this difference in rms phase error has no effect at lower energies, it would affect the brilliance at higher energy.