AN ELECTROMAGNETIC VARIABLY POLARIZING QUASI-PERIODIC UNDULATOR*

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Abstract

An electromagnetic variably polarizing quasi-periodic undulator was installed in the Advanced Photon Source (APS) storage ring in April 2012 and has been successfully commissioned with stored beam. This device is identified as the Intermediate Energy X-ray (IEX) undulator. The IEX undulator takes its name from the IEX beamline where it is installed. The IEX undulator is able to produce a variety of polarizations: linear vertical, linear horizontal, and right- or left-handed elliptical or circular. Ten pairs of poles, distributed quasi-periodically along the undulator length, are powered separately, allowing the field strength of the quasi-periodic poles to be adjusted. This adjustability allows the user to seek a balance between the suppression of the higher harmonics and the loss of flux in the fundamental that best suits the measurement being made. The IEX undulator has a 12.5-cm period and can achieve photon energies as low as 250 eV in horizontal polarization and 440 eV in vertical polarization. A description of the IEX undulator will be presented.

INTRODUCTION

The IEX beamline team, consisting of APS staff members along with researchers from the Universities of Illinois at Chicago and at Urbana-Champaign, is commissioning a new dual beamline with one leg dedicated to angle-resolved photoemission spectroscopy (ARPES) measurements and the other dedicated to resonant soft x-ray scattering (RSXS) [1]. The undulator needs to provide photons ranging from 250 to 2500 eV, with horizontal and vertical linear, and left- and right-circular and elliptical polarizations. (Vertical linear polarization only goes as low as 440 eV.) The presence of high harmonics in the spectrum degrades the signal-to-noise ratio in both techniques, so a quasiperiodic undulator is sought for its ability to shift the high harmonics in energy so they are eliminated by the beamline optics.

Several possible variably polarizing undulator designs were considered, including an Apple II (all permanent magnet), an electromagnetic/permanent magnet, and an all-electromagnetic design similar to the circularly polarizing undulator (CPU) [2] presently installed at the APS. The all-electromagnetic design was chosen, largely because of its ability to vary the magnetic strength reduction in the quasiperiodic poles so trade-offs could be made between additional high-harmonic reductions at the expense of a loss in photon beam intensity. Magnetic field simulation and optimization [3] were done, and prototypes were built and tested before building the full-length device. The full-length device was successfully commissioned at the APS in 2012 [4].

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PARAMETERS

Table 1 lists selected parameters for the IEX undulator.

Table 1: IEX Undulator Selected Parameters

Title	Description	Value	Unit
General	Period	12.5	cm
	Gap	10.5	mm
	Periods per device (including end poles)	38	periods
Horizontal Linear Polarization	Minimum photon energy	240	eV
	Measured maximum vertical effective field	4614	Gauss
Vertical Linear Polarization	Minimum photon energy	440	eV
	Measured maximum horizontal effective field	3312	Gauss
Circular Polarization	Minimum photon energy	234	eV
	horizontal and vertical effective field	3312	Gauss

DESIGN AND ASSEMBLY

Figure 1 shows the IEX undulator at the magnetic measurement bench. The device is 958 mm wide × 2118 mm tall × 5044 mm long (37.7” × 83.4” × 198.6”) and weighs 6350 kg (14,000 lbs). Casters attached to the base allow it to be manually rolled across a flat concrete floor by six people. The undulator is installed onto floor bases that are grouted to the floor. The undulator gap is fixed at 10.5 mm. The jaw assembly is mounted to high-precision linear roller bearings and can manually be moved

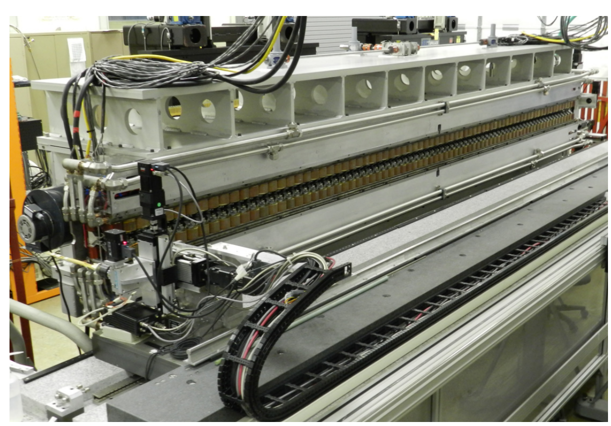

Figure 1: The IEX undulator at the magnet measurement bench.

horizontally in and out of operating position, allowing for well-controlled alignment of the fixed gap around the vacuum chamber during installation. There are fine adjustments for longitudinal, vertical, and horizontal positions as well as roll, pitch, and yaw. The undulator is designed with a calculated mechanical fundamental natural frequency of 34 Hz.

Figure 2 shows the coil and pole arrangement for a single jaw. There are a total of 304 B_x (horizontal field) poles and 152 B_y (vertical field) poles. The coils are vacuum impregnated with epoxy [5].

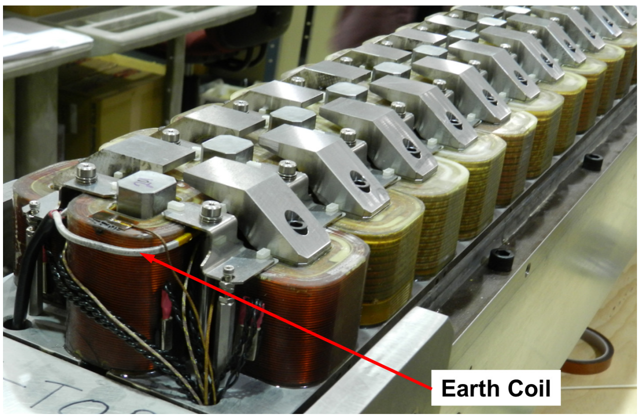

Figure 2: Top jaw coil and pole configuration. The centered vertical field poles alternate with pairs of horizontal poles along the undulator axis. The bottom jaw configuration mirrors this arrangement.

CORRECTOR COILS

End Coils

To minimize the first and second field integrals through the ends of the undulator, fewer turns are used in the endmost coils at both ends. The strength of the last pole is ¼ and the next-to-last pole is ¾ of full field. This leaves room around the end poles to add corrector windings. Six corrector coils are supplied on both the upstream and downstream ends of the undulator to provide a means for electron beam steering and multipole control. Figure 3 shows the configuration of the upstream corrector coils. The coils are labeled top (T), bottom (B), and quadrants Q1, Q2, Q3, and Q4. To minimize the imbalance between the 25% and 75% end poles that causes flux leakage into the full-field poles, a flux bridge is added on each end.

Each corrector coil has its own power supply. Figure 4 shows the coil field directions needed to obtain the various multipole moments. Table 2 lists the maximum achievable integrated multipole corrections, where the limit is imposed by the power supply and by the coil becoming hot. These corrections are more than was needed to meet specifications so the coil currents were limited to 20% of the maximum.

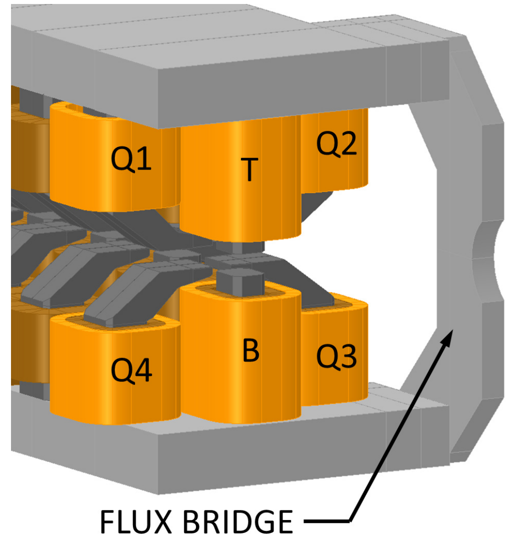

Figure 3: Configuration of the upstream corrector coils.

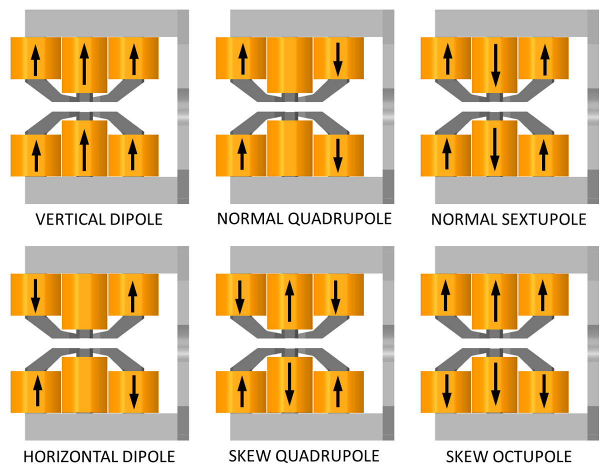

Figure 4: Coil field directions for the various multipole moments.

Table 2: IEX Undulator Maximum Achievable Integrated Multipole Corrections from the Corrector Coils

Multipole	Value	Unit
DS Horizontal Dipole	9021	G-cm
DS Vertical Dipole	13153	G-cm
DS Skew Quadrupole	4251	G
DS Normal Quadrupole	15158	G
DS Normal Sextupole	10236	G/cm
DS Skew Octupole	346	G/cm^2
US Horizontal Dipole	8043	G-cm
US Vertical Dipole	13054	G-cm
US Skew Quadrupole	4569	G
US Normal Quadrupole	15144	G
US Normal Sextupole	10140	G/cm
US Skew Octupole	375	G/cm^2

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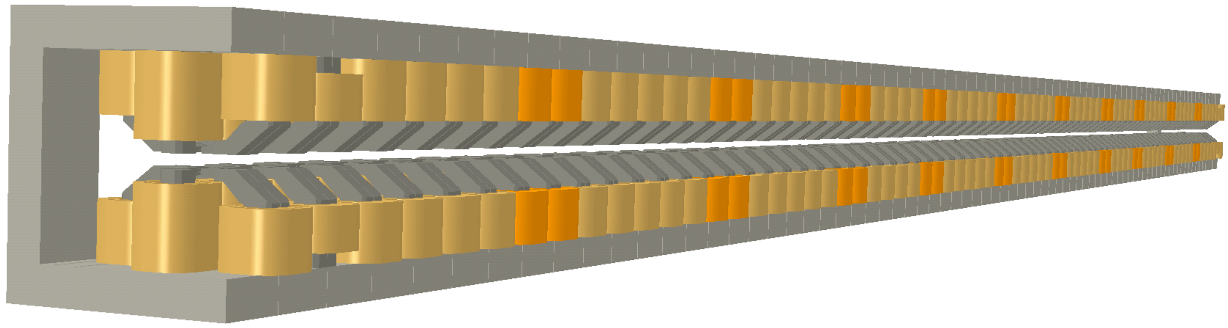

Figure 5: IEX undulator quasi-periodic pole positions.

Skew Sextupole Correction

An integrated skew sextupole component that was out of specification was discovered during magnetic simulations. No combination of end correctors provides a correction that is mainly skew sextupole, but the horizontal dipole corrector also produces a small skew sextupole component. The relative amounts of horizontal dipole and skew sextupole were adjusted by shortening the tips of the downstream horizontal dipole end poles, then increasing the current in those coils. A series of simulations was used to minimize the skew sextupole component.

Earth Coil

An earth coil is provided to compensate for the earth's magnetic field. The earth coil consists of a one-turn coil around the B_y poles on both the top and bottom jaws. The top jaw portion of the earth coil can be seen in Figure 2. The earth coil can supply an integrated B_y field up to 3900 G-cm. This is more than enough to correct the earth's field along with the approximately four-fold enhancement by the steel poles.

THERMAL

The coils are indirectly water cooled. Water lines directly cool the cores. The poles are bolted to the cores, and the coils are epoxied to the poles to ensure good thermal contact. At full power the device operates at 12,000 W; 9,500 W is removed by water cooling. The remaining 2,500 W is removed by air cooling. Blowers and a baffle draw air over the coils and exhaust the warm air (2,500 W) directly into the storage ring tunnel air handling exhaust. This immediately removes the heat from the tunnel so it will not interfere with storage ring tunnel temperature control. The heat loads given above were empirically obtained by building and testing a four-period test model.

QUASI-PERIODICITY

Quasi-periodicity suppresses the higher-order radiation harmonics [6]. The IEX undulator is supplied with quasi-periodic capabilities in both horizontal and vertical polarizations. For a 38-period undulator there are 76 pole sets (two pole sets per period). Coils are numbered 1 to 76. The quasi-periodic coils for the IEX undulator are 7, 8, 14, 15, 20, 21, 27, 28, 34, 35, 40, 41, 47, 48, 54, 55, 61, 62, 67, and 68. Figure 5 shows the configuration of the quasi-periodic coils. The B_x quasi-periodic coils are connected in series and have their own power supply. The remaining B_x coils are connected in series and have their own separate power supply. Similar connections are done for the B_y coils. The quasi-periodic coils can be operated at a reduced current (~85%) that will shift the higher spectral harmonics to a lower energy.

POWER SUPPLIES

Seventeen power supplies are required to operate the IEX undulator: B_x and B_y main power supplies, B_x and B_y quasi-periodic power supplies, twelve end-coil power supplies, and one Earth-coil power supply. Each power supply is bi-polar to allow for degaussing.

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