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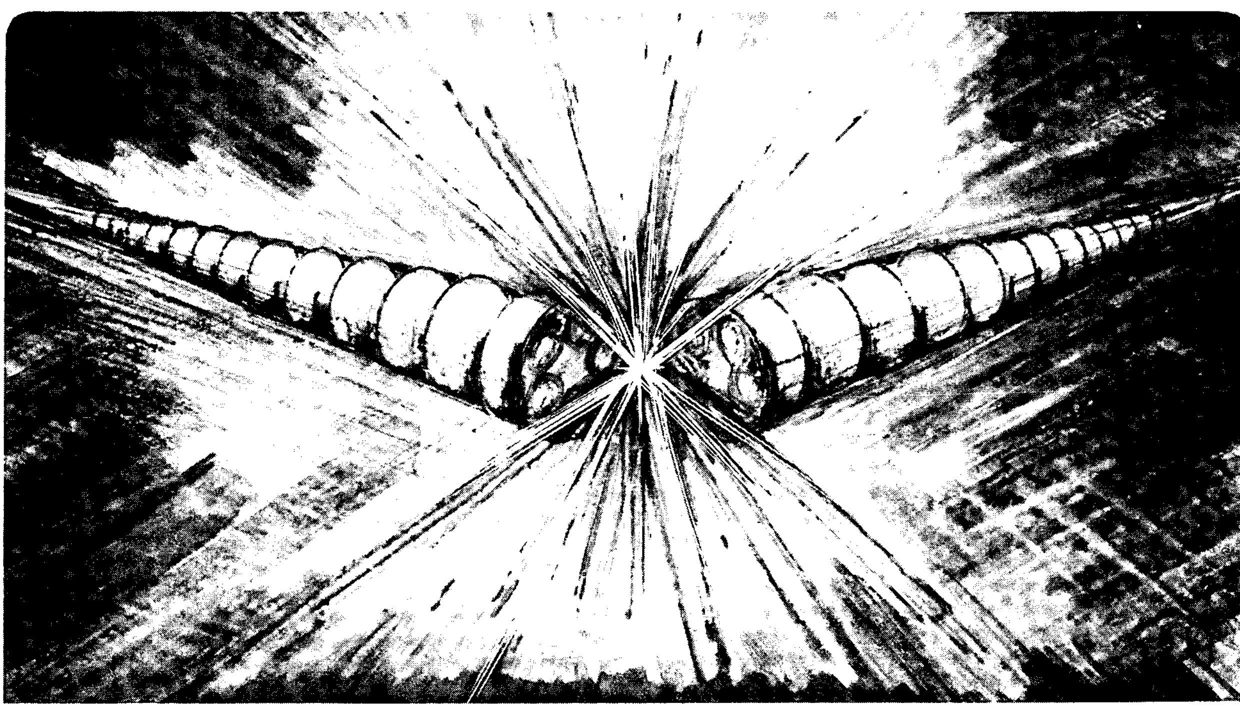

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UNDULATORS AT THE ALS*

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Undulators at the Advanced Light Source.

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Abstract

At Lawrence Berkeley Laboratory's (LBL) Advanced Light Source (ALS), three 4.6 m long undulators have been completed, tested and installed. A fourth is under construction. The completed undulators include two 5.0 cm period length, 89 period devices (U5.0s) which achieve a 0.85 T effective field at a 14 mm minimum gap and a 8.0 cm period length, 55 period device (U8.0) that reaches a 1.2 T effective field at a 14 mm minimum gap. The undulator under construction is a 10.0 cm period length, 43 period device (U10.0) that is designed to achieve 0.98 T at a 23 mm gap. Undulator magnetic gap variation (rms) is within 25 microns over the periodic structure length. Reproducibility of the adjustable magnetic gap has been measured to be within +/- 5 microns. Gap adjusting range is from 14 mm to 210 mm, which can be scanned in one minute. The 5.1 m long vacuum chambers are flat in the vertical direction to within 0.74 mm and straight in the horizontal direction to within 0.08 mm over the 4.6 m magnetic structure sections. Vacuum chamber base pressures after UHV beam conditioning are in the mid 10^{-11} Torr range and storage ring operating pressures with full current are in the low 10^{-10} Torr range. Measurements show that the uncorrelated magnetic field errors are 0.23%, and 0.20% for the two U5.0s and the U8.0 respectively and that the field integrals are small over the 1 cm by 6 cm beam aperture. Device description, fabrication, and measurements are presented.

INTRODUCTION

At Lawrence Berkeley Laboratory;s (LBL) Advanced Light Source (ALS), three 4.6 m long hybrid type undulators, two U5.0s and a U8.0 have been completed, tested and installed. A fourth hybrid type undulator, also 4.6 m, a U10.0 is under construction. Principal parameters for these devices are tabulated in Table I.

Undulator specifications and design have been reported elsewhere.[1-4] A completed U5.0 undulator is shown in Fig.1.

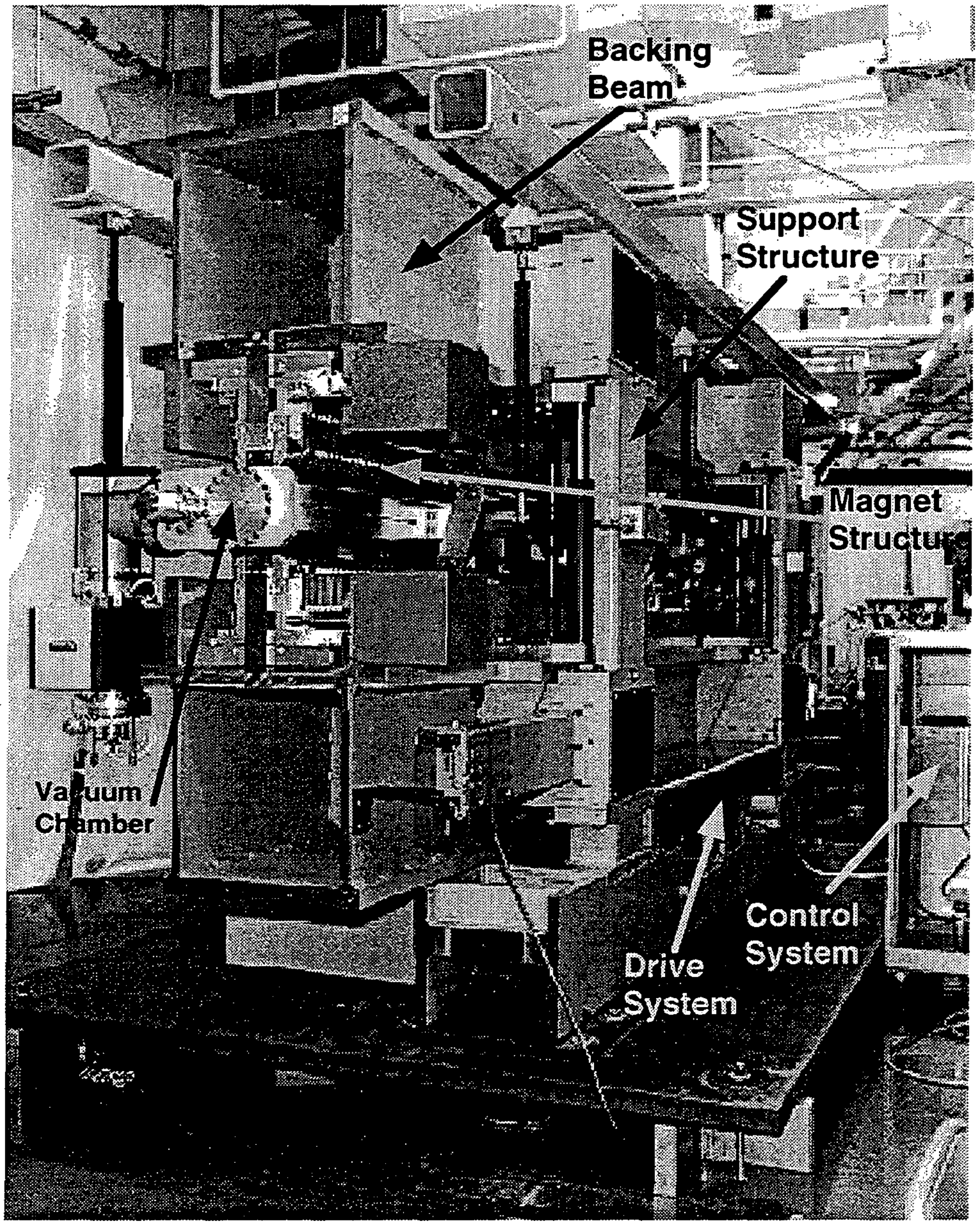

Fig. 1 U5.0 Undulator

MAGNETIC STRUCTURE

As seen in Fig. 1, the magnetic structure includes two large backing beams, each with five assembly sections and two end pole structures attached. Six low-reluctance flux shunts connect the two backing beams magnetically. A U5.0 assembly section, Fig. 2, consists of 35 half-period pole assemblies, each bolted to a pole mount.

The basic building block of the magnetic structure is the half-period pole assembly which consists of an aluminum keeper, a Vanadium Permendur pole and six Nd-Fe-B magnetized blocks.[5]

Assembly section fabrication utilizes a milling machine and a pole assembly holding fixture to place and bolt the half-period pole assemblies to the pole mount. To achieve the 25 μm vertical and 50 μm longitudinal pole tip positional tolerances, the half-period pole assemblies are aligned using an automated coordinate measurement machine, statistically-based error reference planes, and shimming techniques.

The vertical alignment of the assembly section reference planes, to within a 12 μm tolerance, is obtained by using an angular interferometer, and performing an integrated angle calculation on the data.[6] Repeatability error for these measurements is typically less than 3 μm.

The magnetic structure is terminated with end structures that contain Nd-Fe-B rotor assemblies to null the undulator dipole field. These rotors are driven through linkages from the backing beams and can be positioned to within 2°.[7,8]

Each end structure is outfitted with a multiple trim magnet cartridge that corrects higher order magnetic field errors in the undulator. A cartridge contains up to nine transversely located permanent magnets (Nd-Fe-B) that are vertically oriented and adjustable to correct for both vertical and horizontal field integral errors.[9]

The backing beams are of low carbon steel construction and stress-relieved at 600–700°C for four hours. The Ni-Fe flux shunts connecting the upper and lower backing beams reduce the effect of environmental magnetic fields on the undulator magnetic field.[10]

Table 1. Parameters for ALS Undulators

Parameter (units)	U5.0	U8.0	U10.0
Spectrum @1.5 GeV(eV)	130-1900*	18-1200	5-950
Min. Oper. Mag. gap (cm)	2.3*	2.5**	2.3
Effective Peak Field (T)	0.46*	0.70**	0.98
Period length (cm)	5.0	8.0	10.0
No of periods	89	55	43
No of full field poles	179	111	86
Entrance/exit Sequence	0,-1/2, 1,-1		0,-1/4, 3/4,-1,1
Vert end cor. range (G cm)	1500	1500	1500
MTM range (G cm)	+/-3000	+/-3000	+/-3000

* Small Gap Vacuum Chamber allows the 1.4 cm min. oper. mag. gap which gives 0.85 T effective field and energies down to 50 eV available.

** at a 1.4 cm gap, the effective peak field is 1.2 T

SUPPORT/DRIVE/CONTROL SYSTEM

A generic support/drive/control system is used for the ALS undulators. The support and drive systems, shown in Fig. 1, include the support structure that provides the framework for holding the magnetic structure and the drive system that opens and closes the magnetic gap. Gap motion is achieved with a stepper-motor, gear box, and roller chain drive with coupled left-hand and right-hand 2 mm pitch Transrol roller screws attached to the upper and lower backing beams.[11] Adjustment of the magnetic gap can be as fine as 5 µm through the use of offset keys in the roller screw shaft couplings. Compensating springs match the gap-dependent magnetic load to within 20%. Magnetic field taper can be provided manually by stepping one of the main roller chain sprocket's teeth with respect to the chain in increments of 87 µm/sprocket tooth. A Compumotor system, Indexer Model No. 500-Driver Model PK130M-Absolute Rotary Encoder Model ARC, is used to drive and control the magnetic gap. This stepper motor and absolute rotary encoder system is designed such that each motor step and encoder step corresponds to 0.067 µm and 0.106 µm motion of the gap respectively. The motor control system also allows for velocity profiling during a move. The system exhibits some backlash; these nonlinearities are removed with calibration. Results of support, drive, and control system tests are given in Table II.

Each undulator is outfitted with a transparent enclosure for safety, and for maintaining uniform temperature throughout the insertion device. Tests show that the gap sensitivity coefficient, due to a vertical temperature gradient in a backing beam, is 6 µm/0.1°C and that the temperature gradient is eliminated when fans circulate air within the enclosure.

Table II Support/Drive/Control System Test Results

Test	Performance
Magnetic Structure Alignment (upper-to- lower structure)	Gap parallelism within 5 µm; transverse within 250 µm; longitudinal within 150 µm
Gap Range	14 mm - 210 mm
Gap opening-closing time	1 minute
Reproducibility	≤±5 µm; ±20% for 1 µm steps
Backlash (encoder to gap)	≤10 µm
Scan Rate	3.33 mm/sec max.

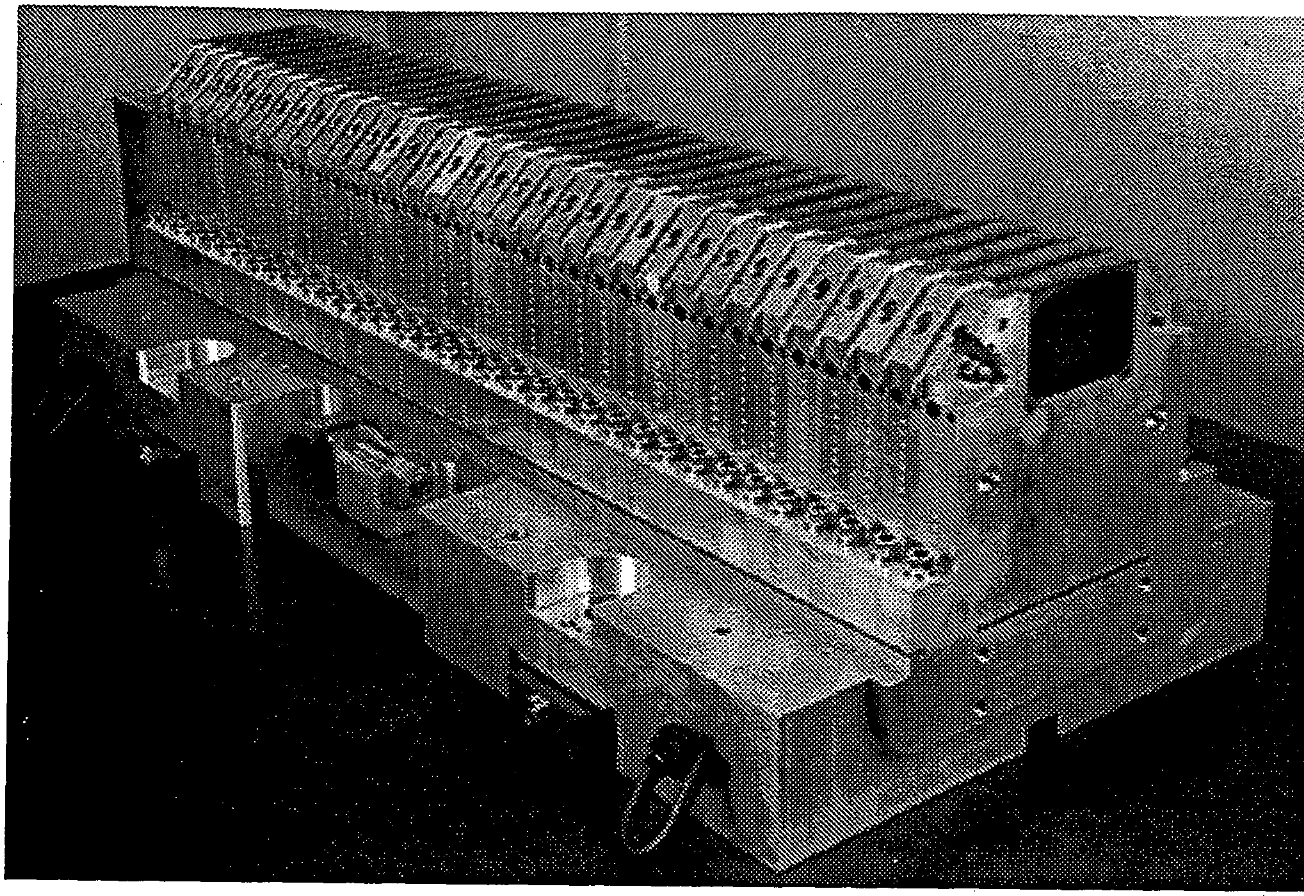

Fig. 2 U5.0 Undulator Assembly Section

VACUUM SYSTEM

The 5.1 m long IDA-U5.0 commissioning vacuum chamber, shown in Fig. 1, is machined from two 5083-H321 aluminum plates and welded together.[12] Pockets machined into the chamber accommodate the poles of the magnetic structure for small magnetic gap operation. Mechanical measurements taken at the completion of final assembly, after UHV conditioning and under vacuum, are given in Table III.

The pumping system of each vacuum chamber includes three combination, 60 l/s ion-600 l/s titanium sublimation pumps, a 2400 l/s ALS absorber tsp pump, and 4800 l/s of non-evaporable getter (Saes-type ST707/CTAM/30D strip).

Chamber ultra-high vacuum conditioning is at 140°C, for a minimum of 48 hrs.[13] Chamber pressures achieved after 400 A hr of beam operation are 1.6×10^{-10} Torr with 0.33 A of beam and 7.1×10^{-11} Torr without beam for the IDA and IDB chambers and for the IDC chamber 5.4×10^{-10} Torr after 12 A hr of operation and no beam.

Table III. ALS Undulator Vacuum Chamber Measurements

Device	Vert. Apert. (mm)	Vert. Straight. (mm)	Horiz. Straight. (mm)	Chamber Gap* (mm)
IDA-U5.0	18.97	0.53	0.08	21.64
IDB-U5.0	18.83	0.74	0.05	21.77
IDC-U8.0	19.07	0.36	0.05	23.77

* Minimum magnetic gap =chamber gap + allowance for stops and switches (0.90mm).

MAGNETIC MEASUREMENTS

Detailed magnetic measurements are performed on each undulator to insure that spectral and electron beam requirements are met before installation in the ALS. A high speed, precision magnetic measurement system has been designed and built for this purpose.[14] Primary magnetic field information, integral and local values, are derived from hall probe measurements. A 5.5 m long integral coil is used to measure field integrals.

A specification on spectral performance is to achieve 70% of the ideal brightness for the fifth harmonic. Brightness of spectral harmonics is degraded by magnetic field errors. This sets field error tolerances for the U5.0s and U8.0 at 0.25% and 0.35% respectively at the minimum gaps. The rms harmonic residual, defined as the rms value of the deviation of the measured field on axis from the best fit of allowed harmonics, is evaluated from magnetic measurement data and compared to the tolerances. The residuals for the U5.0s are 0.23% and the U8.0 is 0.20%.

Spectral output was calculated from the measured magnetic fields using RADID.[15] Results show that flux density for the fifth harmonic is greater than 70% of ideal for the U5.0s at all gaps and greater than 80% of ideal at all gaps for the U8.0. The U5.0 calculated spectrum, without emittance effects, at a 14 mm gap with 0.4A current and 1.5 GeV beam energy is shown in Fig. 3.

Integrated magnetic fields through the undulator are acceptable over the ±3 cm horizontal aperture to maintain dynamic aperture. IDA-U5.0 integrated magnetic fields are shown in Fig. 4 and Fig. 5. Dipole correction is with adjacent external corrector magnets.

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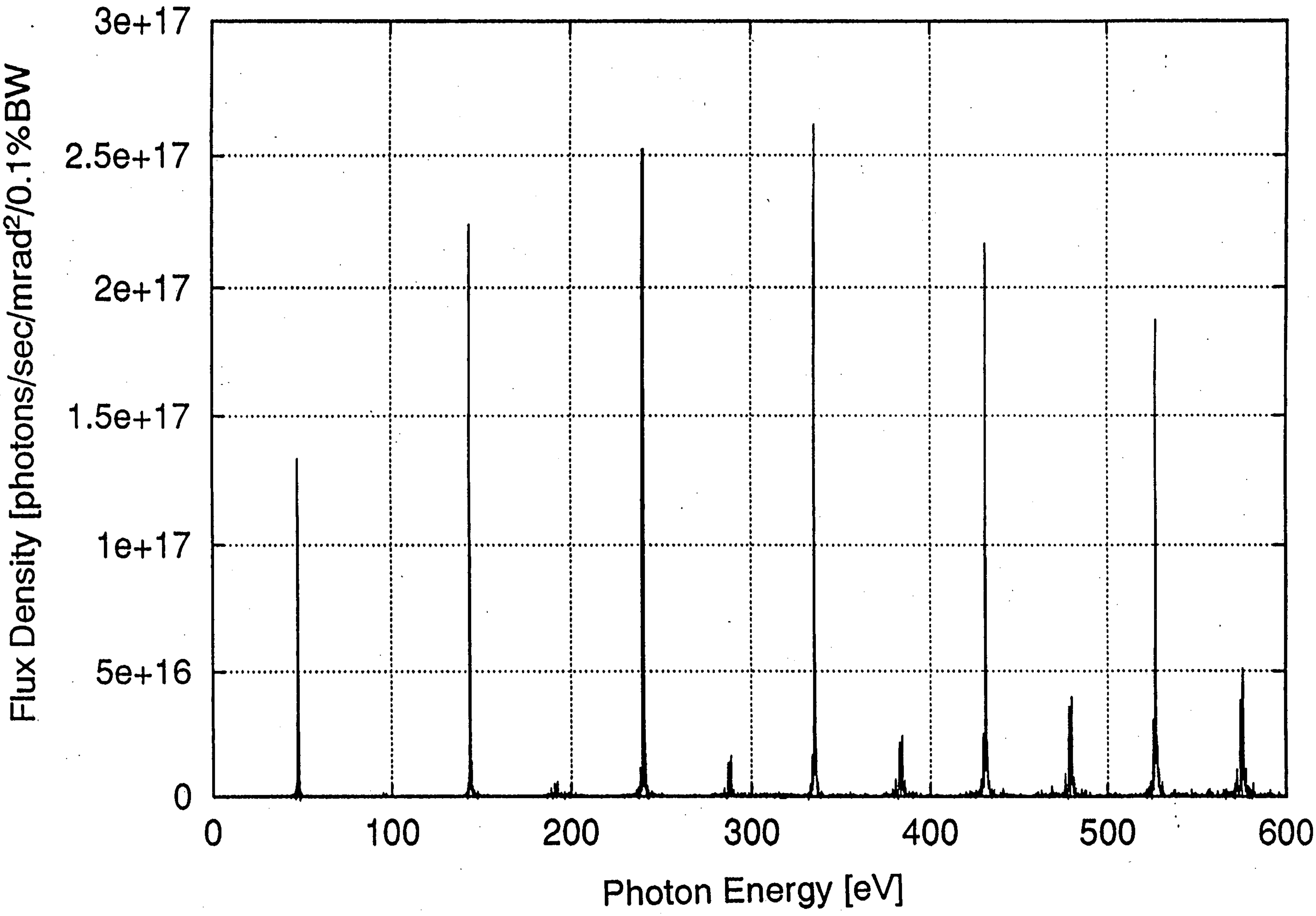

Fig. 3 IDA - U5.0 Spectral Output for a 14mm Magnetic Gap and the ALS Operating at 1.5GeV-0.4A (emittance effects not included).

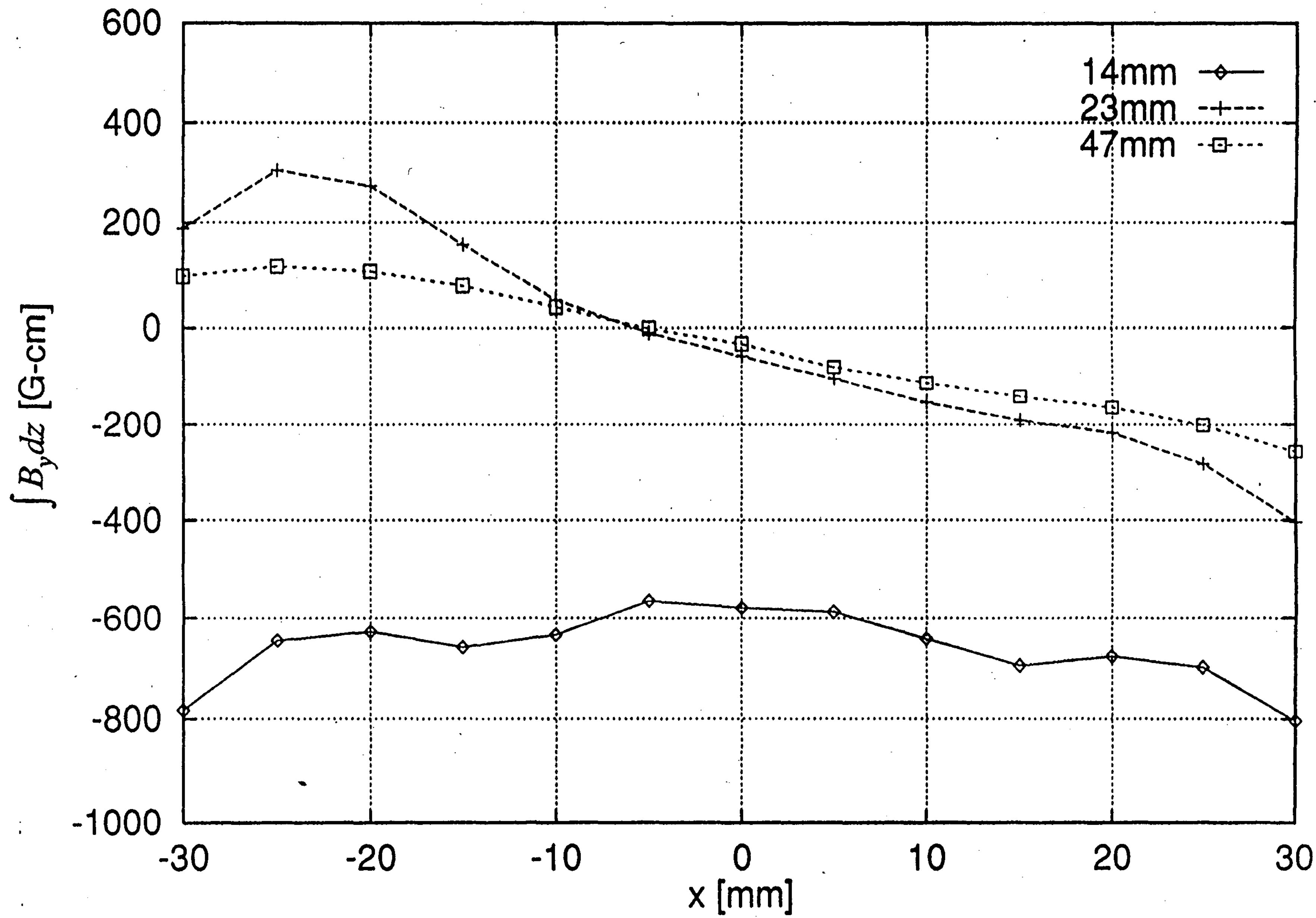

Fig. 4 IDA-U5.0 Integrated Normal Magnetic Fields

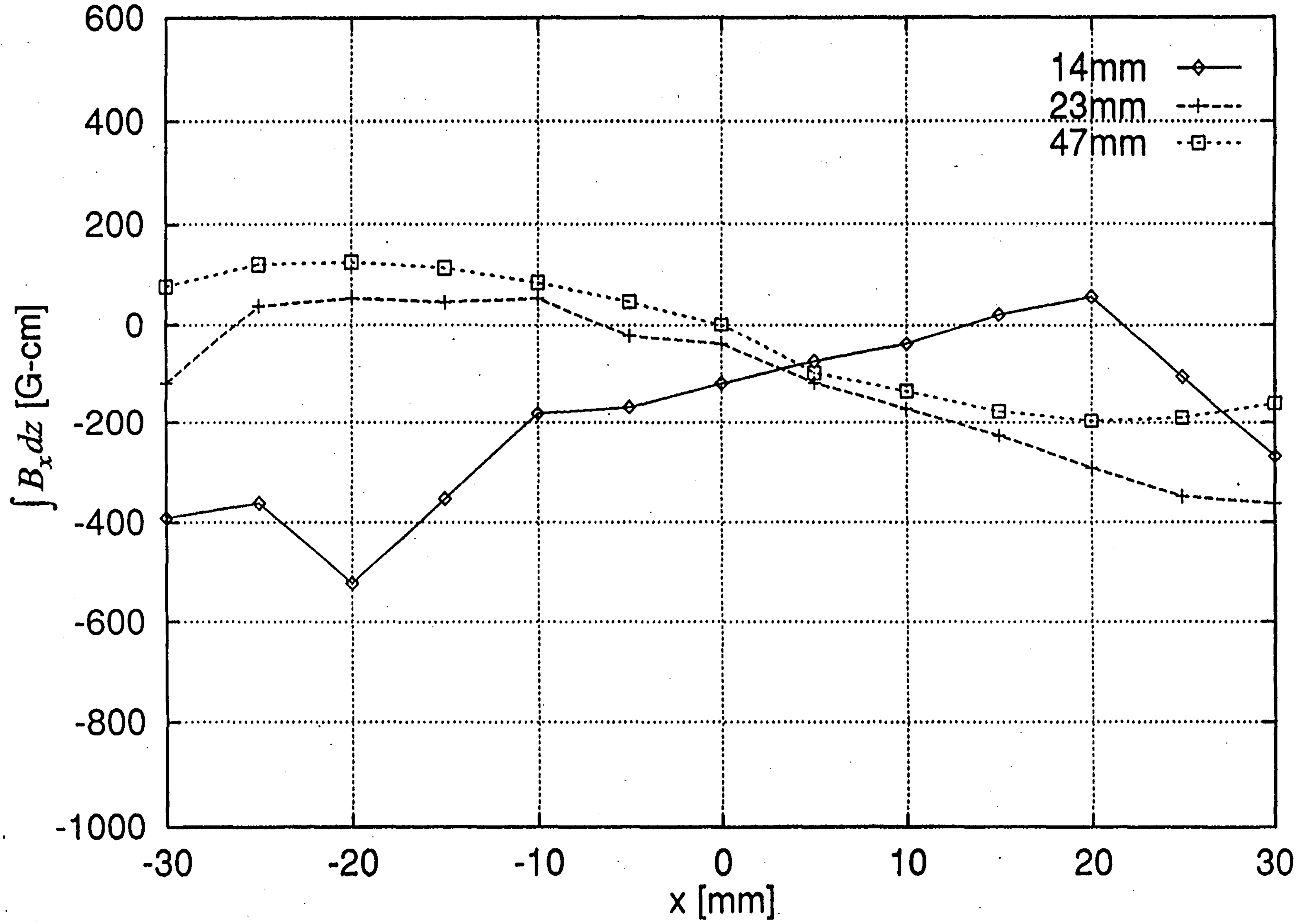

Fig. 5 IDA-U5.0 Integrated Skew Magnetic Fields