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Abstract

A NdFe-steel hybrid configured permanent magnet wiggler is being developed for insertion in the SPEAR ring at the Stanford Synchrotron Radiation Laboratory, SSRL. Featuring 15 complete periods, a 12.9-cm magnetic period length, and a peak magnetic field range of 0.01-1.4 Tesla, the wiggler was designed to provide an intense radiation source for the National Laboratory/University of California participating research team (PRT) facility on Beam Line VIII-W. A new permanent magnet material, neodymium-iron (NdFe), is being used in the magnetic structure instead of rare-earth cobalt, REC, used previously in the 27-period wiggler now on Beam Line VI. NdFe advantages include a 16% higher coercive force (10.6-kOe vs. 9.0-kOe) and lower cost. The wiggler design features a thin walled, rigid vacuum chamber with pole pockets on opposing surfaces allowing a 2.1-cm minimum magnetic gap with a 1.8-cm beam vertical aperture. At 3 GeV the wiggler at peak field is expected to radiate approximately two kilowatts in a 5-mrad horizontal fan with a 7.8 keV critical energy. Calculations are in progress to model the wiggler radiation spatial and spectral radiation emission.

Introduction

This paper describes a NdFe-steel hybrid insertion device being designed at Lawrence Berkeley Laboratory.[1] It is a permanent magnet hybrid configured wiggler/undulator[2] designed for the SPEAR ring at SSRL, BL-VIII-W, to provide an intense radiation source for the PRT consisting of Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Sandia National Laboratory, and the University of California Laboratory for Synchrotron Radiation Research. Initial plans are to divide the 5-mrad wiggler horizontal radiation fan available at 3 GeV into two branch lines. A hard x-ray branch will be implemented first utilizing the forward directed central 2-3 mrad core to provide 3-30 keV monochromatized x-rays at a hutch location. Hard x-ray mirrors with grazing angles between 0.5 and 0.2 degrees are being considered to provide focusing.

Although beam line plans are still under review, a VUV side branch is being strongly considered featuring a 100-to-1200 eV grating monochromator similar to that of BL-VI.[3] A horizontally deflecting mirror will be developed to intercept one side of the horizontal fan at a 2° grazing angle. Translation of this mirror to the center axis will permit good VUV coverage of the insertion device output as an undulator. The mirror will be centered vertically on the orbital plane where the wiggler emission should exhibit a high degree of linear polarization. This layout makes initial VUV branch utilization straightforward, without precluding future exploitation of the more complicated polarization dependence off the orbital plane. Since the longest practical horizontally-deflecting mirror accepts only about 2 mrad, the total horizontal fan required by the x-ray optics is about 5 mrad. The proposed division into two branches is supported by preliminary wiggler emission modeling as will be shown later. Full utilization of the remaining wiggler side lobe has been left for future consideration.

Insertion device design

Magnetic design

The choice of the insertion device magnetic design parameters is a compromise based on the following somewhat conflicting performance requirements: (1) A horizontal fan of 5 mrad at 3 GeV is required for the proposed x-ray optics. (2) Due to the diverse requirements of the PRT, a high x-ray critical energy is needed to provide a wide energy range. (3) Cost considerations have dictated a fixed gap vacuum chamber. The magnetic structure will be out of vacuum and the field will be adjustable by varying the pole-to-pole spacing. (4) For SPEAR beam stability, a transverse vertical peak field tolerance of 3% is required for the 24 mm horizontal aperture over the range 0.01 - 1.24 Tesla. (5) To obtain high intensity and to provide for possible use in the undulator mode, it is desirable to maximize the number of wiggler periods. Based on these requirements, a periodic structure was designed with the specifications[4] in Table 1.

Table 1. Beam Line VIII-W insertion device parameters.

Magnetic period length (cm)	12.85
Number of complete periods	15
Peak magnetic field range (Teslas)	0.01 - 1.4
Peak to peak field uniformity	≤ 2% at minimum gap
Minimum magnetic gap (cm)	2.1
Beam vertical aperture (cm)	1.8 for SPEAR injection
Pole width (cm)	7.5
Transverse good field aperture	$\Delta B/B \leq 3\%$ over 2.4 cm
Effective magnetic length (cm)	202.4

A wiggler design with a 12.85 cm period length was selected to produce a gap field equal to or greater than 1.24 Teslas at the minimum wiggler gap of 21 mm ($g/\lambda = 0.163$). During the course of this work significant progress has been made in understanding the influence of the pole width and transverse end configuration on the performance of the magnetic structure.[4] Magnetic measurements have been obtained from several single pole test assemblies and compared with results from the magnetic modeling code PANDIRA which assumes infinite pole width. To achieve the BL-VIII design criteria, a periodic magnetic structure was developed using 2-D and pseudo 3-D analyses with emphasis on maximizing the gap field and minimizing the amount of rare earth permanent magnet (REPM) material used.[4] This structure, a half-period assembly (pole and adjacent REPM), is shown in Figure 1. By testing a model scaled to a 7-cm period length the calculated magnetic performance was verified, and a basis was obtained for the estimated wiggler performance shown in Figure 2. For the minimum wiggler gap of 21 mm ($g/\lambda = 0.163$), a peak field of 1.39 T was measured. For a 3% (2%) tolerance in the vertical peak field along the transverse direction, the minimum good field aperture obtained is 2.9 (2.2) cm. Thus, model test results verify that the design meets the performance criteria.

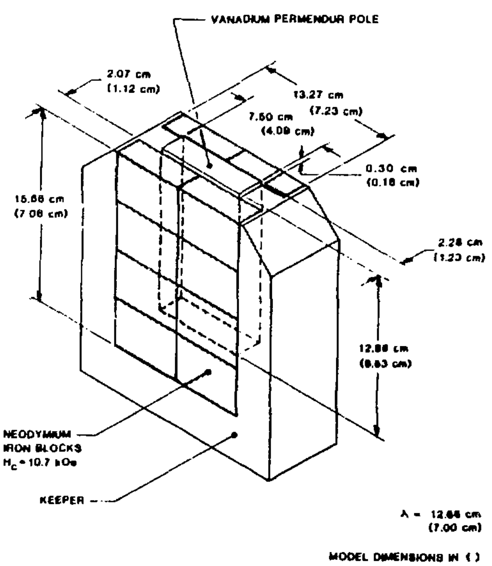

Figure 1. Half-period pole assembly for the 15-period insertion device.

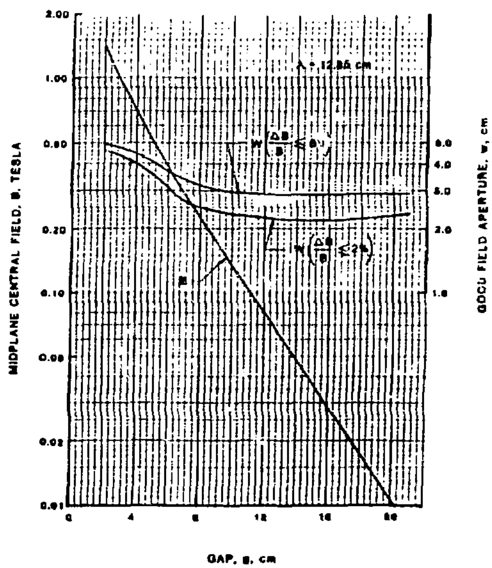

Figure 2. Estimated 15-period insertion device performance.

The end half-pole configurations combine electromagnetic coils with REPM material to allow for active correction of the insertion device field integral. The configuration is designed so that no current is required in the end coils at the largest operating gap (10 cm), and increasing correction current is required when the gap is reduced.

Magnetic structure

Figure 3 shows the overall design of the wiggler. The proposed magnetic structure is a variable field, out of vacuum arrangement, similar to the BL-VI device[5] consisting of two support "I" beams, each having 31 half-period assemblies and 2 end half-period assemblies attached. After preliminary model tests, NdFe (H_c = 10.6-kOe), was selected[6] in favor of REC because it demonstrated higher gap magnetic fields when substituted in a pole configuration ootimized for REC (16% higher fields at large gap-to-period ratios and less with decreasing gap-to-period ratios due to pole saturation). NdFe also exhibits less chipping, is easier to bond to common materials, and is less expensive than REC. Shown in Figure 1, the basic building block of the magnetic structure is the half-period pole assembly each consisting of a Vanadium Permendur pole surrounded with 16 blocks of NdFe material bonded to both the pole and aluminum keeper. The blocks of NdFe will each be measured for total magnetic moment using a Helmholtz coil, then sorted and matched to achieve a uniform total magnetic moment for each pole assembly. Fabrication of these half-period pole assemblies will be in a manner similar to those of the BL-VI wiggler.[5]

The half-period pole assemblies and end half-period pole assemblies will be bolted onto precision flat surfaces of the "I" backing beams and subsequently shimmed such that all pole faces are aligned to a plane within ±0.025 mm. Provision for tuning will be available for each pole assembly. The backing beams are mounted to the drive system which allows the peak field to be adjusted by changing the gap between the two magnet halves.

Vacuum system

The wiggler vacuum system shown in Figure 4 consists of a "fixed gap" vacuum chamber with ports provided for mounting two fixed masks, two 220-liter/sec ion pumps, one nude ion gauge and one right angle bakeable valve. The chamber itself will be fabricated from two stainless steel plates, type 316 LN. The halves will be machined to provide a minimum operating vertical gap of 18 mm and a horizontal gap of 216 mm (60 mm to the inside of the beam centerline and 156 mm to the outside, providing a region designed to properly handle bending magnet radiation by allowing no direct radiation on chamber walls. The top and bottom chamber surfaces will have pole pockets machined into them to achieve the 21-mm minimum magnetic gap. The two halves will be welded together along the neutral axis to minimize warping. The ante-chamber (towards the outside of the SPEAR ring) allows the two masks to absorb radiation produced by both bend magnets adjacent to the wiggler. These fixed masks are designed to deflect desorbed gases downward toward the ion pumps in order to maximize pumping efficiency.

Two transition spools fabricated with bellows and welded to Conflat flanges will be mounted on each end of the vacuum chamber. They will each accommodate a low loss RF transition as well as four sensing elements that together monitor the electron beam position.

Drive system

The wiggler will be equipped with one remote drive system to control the magnetic gap from a minimum of 8 mm during magnetic measurements to a maximum of 300 mm but with an operating gap ranging from 21 to 100 mm. This system includes a main frame supporting 8 ball screw shafts; 4 right-handed ones on the upper half of the wiggler and 4 left-handed ones on the lower half coupled together by 4 drive shafts. The shafts are driven by a stepping motor and a double worm gear reduction unit through a roller chain and sprocket arrangement. The position of the magnet gap opening is encoded via a device directly coupled to the drive system. Limit switches, a torque limiter, and mechanical stops provide system protection.

Insertion device radiation output

Figure 5 shows the expected 15-period wiggler photon flux compared to that from a SPEAR bending magnet. Table 2 summarizes typical wiggler output characteristics. In nominal SPEAR operation, the total power out is comparable to the BL-VI wiggler, but the power density is only 60%, thus, the cooled components designed for BL-VI can be conservatively adapted with minor modifications.

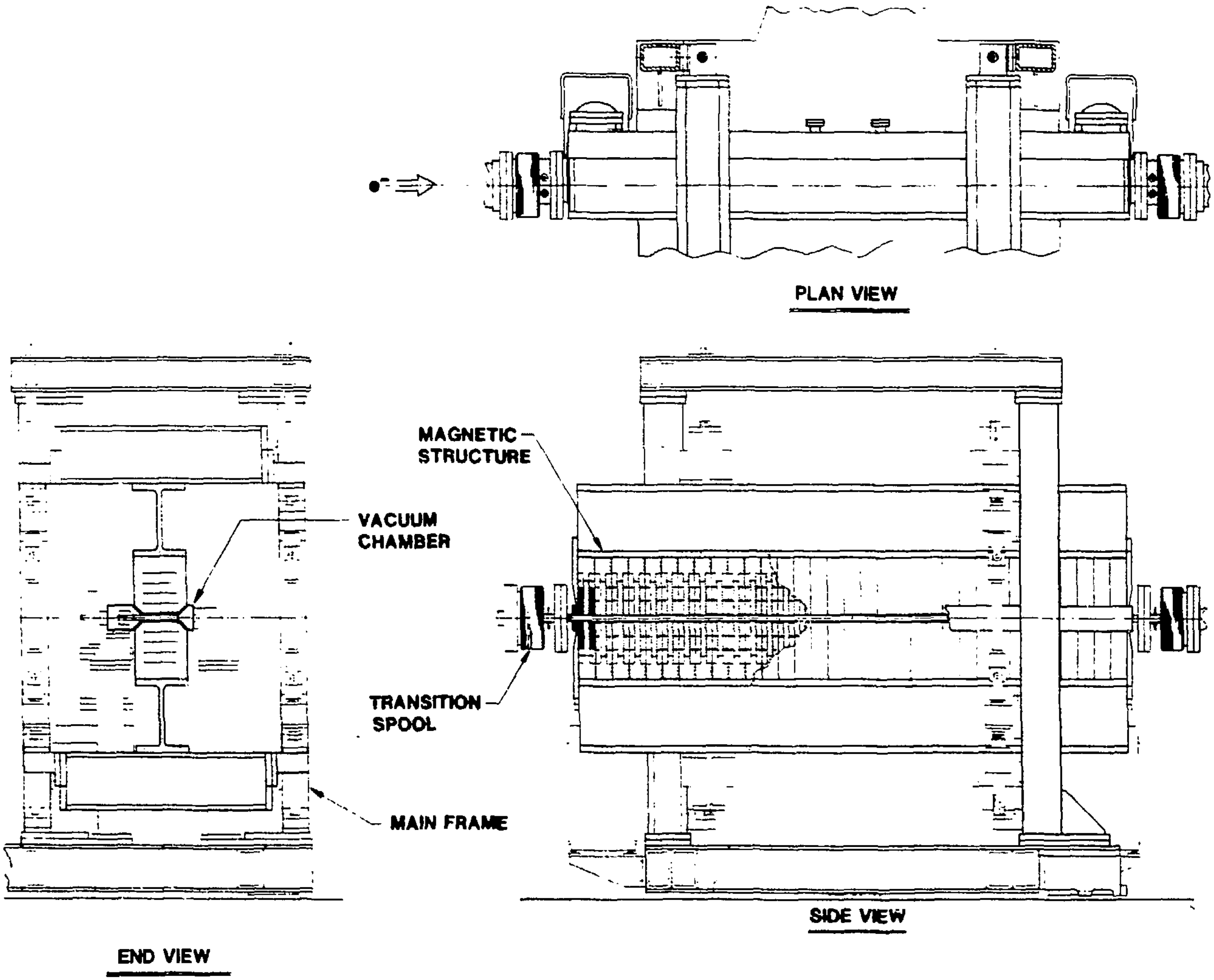

Figure 3. Overall design of the 15-period insertion device.

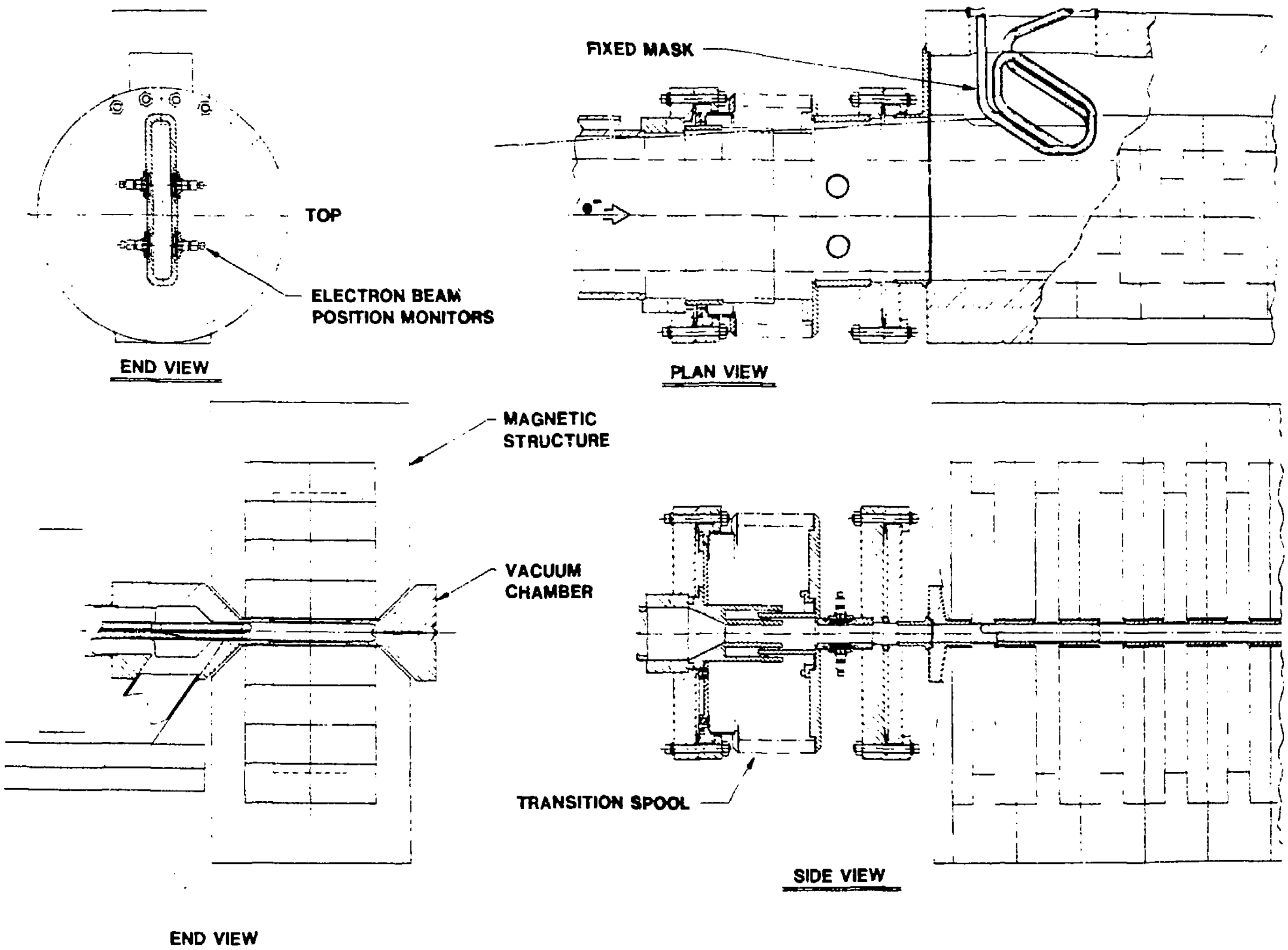

Figure 4. Insertion device vacuum chamber and transition section.

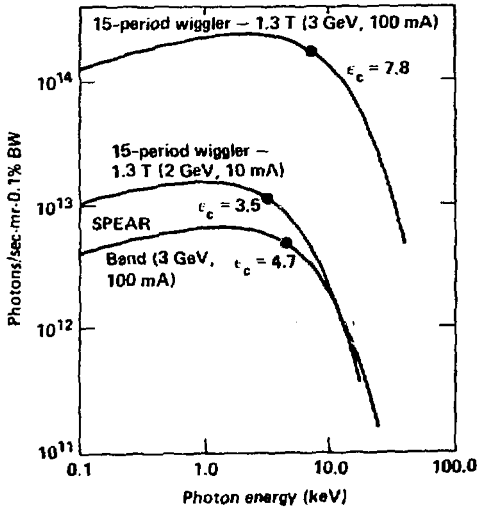

Figure 5. Fifteen-period wiggler photon flux compared to SPEAR bending magnet emission.

Table 2. Beam Line VIII wiggler output characteristics for B=1.3T and K=15.6.

	Typical parasitic (2 GeV, 20 mA)	Nominal dedicated (3 GeV, 100 mA)	Maximum dedicated (3.7 GeV, 100 mA)
Peak critical energy, keV	3.5	7.8	11.8
Horizontal divergence, mrad	8.2	5.4	4.4
Total radiated power, watts	175	1950	2970
Peak kW/cm^2 at 8.5 m from wiggler center	0.11	2.7	6.2

Preliminary wiggler emission modeling

As an aid in designing the beam lines, a computer program was written to calculate the spatial distribution of the radiation from insertion devices.[7] This program has been applied to the 15-period design in nominal wiggler mode for which the incoherent emission dominates and our basic assumption of negligible coherent emission is reasonable. (A more rigorous modelling code on the LLNL Cray computers is planned for the near future). Schwinger's equation[8] was applied over the sinusoidal electron path of the wiggler to obtain the spatial distribution of radiation in the x-y plane normal to the center axis at the first mirror position (8.5 m from wiggler center). For these studies typical SPEAR operating conditions were assumed (1.8, 3.0 and 3.4 GeV, respectively). Account is taken of the effects of the finite wiggler length and the spatial and angular spread of the SPEAR electron beam. At each photon energy an approximation is made to the horizontal spreading of the distribution to account for the intrinsic photon divergence. Figure 6 shows x-ray emission results for one of the four symmetric quadrants calculated for two photon energies, 7.8 keV (the critical energy of the wiggler at 3 GeV and 1.3 Tesla) and 500 eV typical of the proposed hard and soft x-ray branches, respectively. The isointensity curves on this x-y plane each represent a fraction of the absolute intensity given at the center (x=0, y=0).

The 7.8-keV results indicate a rather uniform distribution that decreases smoothly near the edges. In contrast the soft x-ray distributions typified by the 500 eV case display a more complex nature characterized by an increase in intensity at the sides. These results indicate that a horizontally deflecting mirror can be positioned to intercept the more intense side lobes while still making a large fraction of the central core available to the hard x-ray branch.

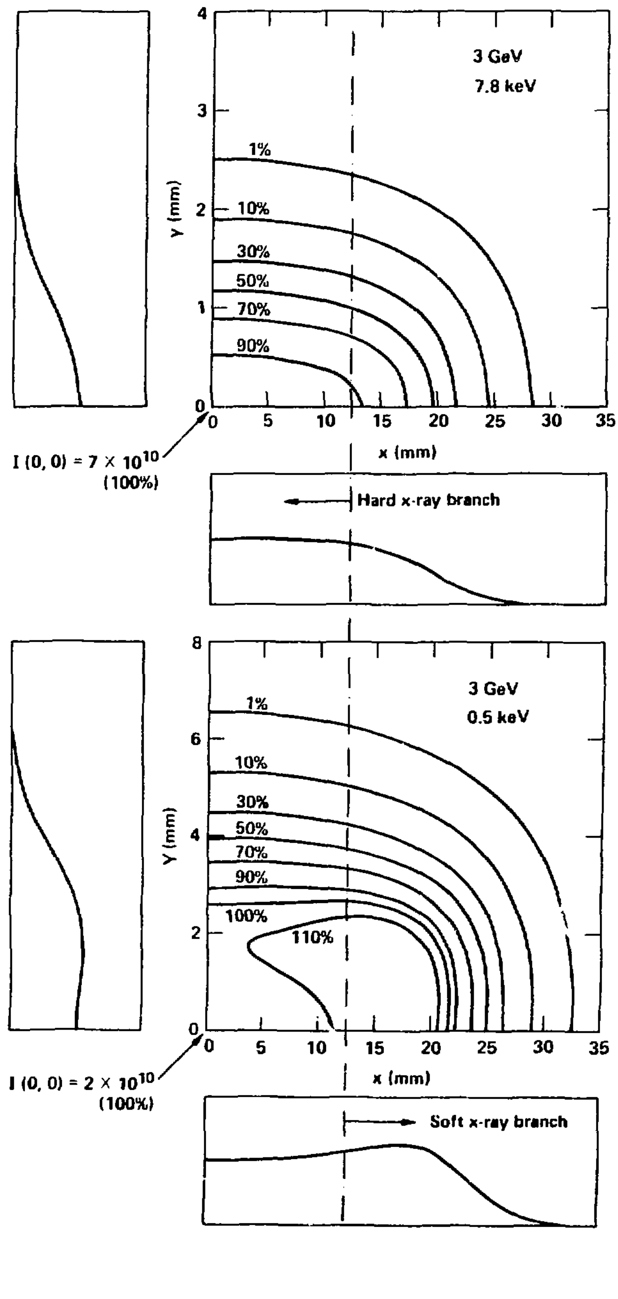

Figure 6. Wiggler photon flux isointensity contours at 3 GeV on the vertical x-y plane at a distance 8.5 m from wiggler center. Reference intensity value, I(0,0), is in units of photons/sec-mA-mm^2 - 0.1% B.W. Dotted line shows preliminary beam branch allocation.

Preliminary work shows the effect of each of the contributions that smear the spatial output distributions. At high energies the only noticeable effect is that due to the spatial and angular spread of the electron beam. At low photon energies both the intrinsic photon spreading and the coherent contribution are more important. Validity of the preliminary hard x-ray results is thus considered rather good, while the low energy distributions will benefit more significantly from the rigorous approach in progress. At any rate, the initial results are sufficient to specify the wiggler design parameters and for conceptual design of the branch line x-ray optics.

Undulator performance

To take advantage of the insertion device performance as an undulator, the capability will be provided to deflect the beam on center axis into the VUV branch. In this mode of operation, of great interest is the spectral range for which the undulator fundamental, E1, is significant, defined roughly by deflection parameter K values from 0.3 to 2. For nominal dedicated SPEAR operation at 3 GeV, the range is 200-600 eV, thus, covering the important carbon, nitrogen and oxygen K-edge regions. For 3.7 and 2 GeV operation (maximum dedicated and typical parasitic) the respective E1 ranges are 300-900 eV and 90-270 eV. Since the low horizontal divergence in undulator mode tends to improve the resolution of a grating monochromator, we expect to have good performance particularly in the dedicated mode. Note that we have not fully analyzed the effect of magnetic field tolerances on undulator performance. For best results careful tuning of each pole assembly may be required during construction.

A 15-period device with a similar period length, 12 cm, has been chosen as one of the interchangeable magnetic structures on Beam Line V at SSRL.[9] Calculated output spectra for this undulator have been presented in these proceedings.[10]

Utilization of the higher order undulator harmonics may prove advantageous for the hard x-ray branch. The development of a UHV double crystal monochromator and/or differential pumping is being considered to extend the range of the hard x-ray branch to lower energies.

Acknowledgments

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