Elliptical multipole wiggler facility at the Advanced Photon Source

P. A. Montano
Materials Science Division, Argonne National Laboratory, Argonne, Illinois 60439 and Department of Physics, University of Illinois, Chicago, Illinois

G. S. Knapp and G. Jennings
Materials Science Division, Argonne National Laboratory, Argonne, Illinois 60439

E. Gluskin, E. Trakhtenberg, I. B. Vasserman, P. M. Ivanov, D. Frachon, E. R. Moog, L. R. Turner, and G. K. Shenoy
Experimental Facilities Division, APS, Argonne National Laboratory, Argonne, Illinois 60439

M. J. Bedzyk
Materials Science Division, Argonne National Laboratory, Argonne, Illinois 60439 and Department of Materials Science, Northwestern University, Evanston, Illinois 60208

M. Ramanathan and M. A. Beno
Materials Science Division, Argonne National Laboratory, Argonne, Illinois 60439

P. L. Cowan
Physics Division, Argonne National Laboratory, Argonne, Illinois 60439

(Presented on 19 July 1994)

The use of circularly polarized radiation is advantageous for the study of magnetic materials using x-ray scattering techniques. The APS is an ideal source of x-ray radiation for such studies. We present a description of the elliptical multipole wiggler (EMW) [S. Yamamoto, H. Kawata, H. Kitamura, and M. Ando, Phys. Rev. Lett. **62**, 2672 (1989)] to be constructed at the APS. This device has been chosen for reasons of tunability and special polarization properties. This insertion device is capable of producing circularly polarized x rays on axis. The EMW period will be $\lambda_u = 16$ cm, the number of full strength poles in the hybrid structure is 31, and the device length is 2.8 m. The hybrid magnetic structure produces a peak vertical magnetic field with $K_y = 14$ and the electromagnet provides horizontal magnetic field with $K_x = 1-2$. The frequency of the horizontal field change is up to 10 Hz. The beamline will consist of three stations operating in tandem with only one station receiving x rays at any one time. The three stations have three distinct functions, namely Compton scattering, magnetic scattering, and surface scattering. Special considerations will be made to insure the proper control of the polarization when using circular polarized light. The design of the elliptical multipole wiggler beam line will follow an approach very close to that developed by Kawata *et al.* [Rev. Sci. Instrum. **60**, 1885 (1989)]. Our objective is to obtain a high photon flux with energies above 40 keV and well characterized polarization. © *1995 American Institute of Physics.*

I. INTRODUCTION

Magnetic scattering experiments require a high x-ray flux and well defined polarization. Third-generation storage rings are ideal sources of such radiation. Present generation facilities do not have the brilliance needed to tackle some of the most important problems in magnetic scattering using x rays such as, determination of the magnetic structure of thin films. With the ever increasing importance of rare-earth permanent magnets, magnetic recording media, and other fields, the importance of newer and supplementary techniques in the study of magnetic materials is obvious (for example, observation of magnetic Bragg diffraction peaks,[1] measurement of the relative populations of spin-orbit split states in the ground state,[2,3] separation of spin-up and spin-down contributions to the momentum distribution profile of conduction electrons in magnetic systems.[4] This recent increase in research stems directly from the availability of linearly polarized, tunable radiation from synchrotron sources. However, research using circularly polarized radiation has been limited in the past by the lack of readily available circularly polarized sources, with bending magnet radiation observed off axis as the major source of such radiation. In recent years new insertion devices like the elliptical multipole wiggler[5] and the Asymmetric Wiggler[6] have been used successfully to produce circularly polarized radiation in the hard-x-ray regime. Quarter-wave plates are becoming popular tools to produce circularly polarized radiation at least at intermediate x-ray energies.

Sakai *et al.*[7] has shown that using circularly polarized 60 kev x rays from a radioactive source it was possible to measure the momentum distribution of magnetic electrons in Fe and Ni by Compton scattering. Cooper *et al.*[8] used hard x rays (above 40 keV) to measure the momentum distribution of magnetic electrons in magnetic materials. When experiments are performed with linearly polarized or unpolarized x rays, the Compton profile measured represents *the sum* of spin-up and spin-down bands. With a strong tunable source of circularly polarized radiation it will be possible to study the spin-density variations for transition metals and alloys as a function of temperature. It has been demonstrated that the value of the magnetization due to the negative or positive spin polarization can be extracted from Compton scattering and that accurate comparison with band-structure calculations are possible. Recently, the three-dimensional momentum density distribution of magnetic electrons in iron was determined using Compton scattering.[9] This work was indeed possible by the availability of the high brightness of an elliptical multipole wiggler.[10] This device was first proposed by Kitamura and Yamamoto, and two such devices have been operational in Japan. Recently, Kawata *et al.*[5] have described a layout for a beamline for circularly polarized radiation produced by the EMW at the 6 GeV TRISTAN accumulator ring in Japan. This beamline has been extremely successful using a sagittally focusing monochromator. One can predict that such an insertion device beamline at the APS will make the performance of experiments like spin dependent Compton scattering a very powerful tool in the study of the magnetic properties of materials.

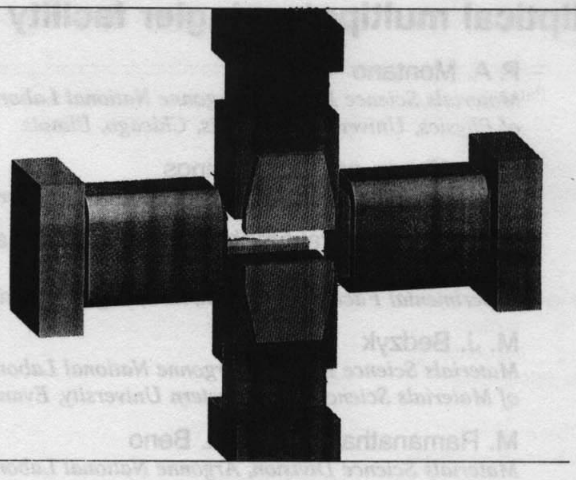

FIG. 1. A schematic design of one quarter period of the insertion device.

II. DESCRIPTION

The central piece in the production of circularly polarized high-energy x rays at this facility is the insertion device. We propose using an elliptical multipole wiggler for such purposes. The EMW vertical magnetic field is produced by the 20 periods of the hybrid magnetic structure with a period length of 15 cm. In the current design a peak field value of 1 T for the vertical component is achieved that corresponds to a vertical K_y of 14. The peak field value for the horizontal component is 0.076 T and the K value is equal 1.06. The EMW has an internal ends compensation system in order to control first and second field integrals with the required accuracy. The EMW electromagnet poles are fabricated from laminated iron in order to operate with a switching frequency up to 10 Hz. The hybrid magnetic structure and the electromagnet are mounted on the support frame with the drive system that permits one to change the gap of the hybrid structure. The vertical K in this case will change from 14 to smaller values and when it reaches a value of 1 the EMW will operate as a helical undulator. Field computations were carried out with the nonlinear 3D magnetostatic code TOSCA. For the geometry shown, $K_y=12$ for the hybrid magnet and $K_x=1.06$ for the electromagnet. K_y can be increased by placing magnet and pole materials more efficiently in the available space. K_x is limited by the large horizontal gap (71 mm). Figure 1 shows a schematic design of one quarter period of the insertion device. Figure 2 shows the magnetic-field profile for a quarter period of the insertion device.

The total length of the straight section where the EMW will be located is 5.59 m and the device is 3 m in length. The vertical aperture of the vacuum chamber is 19.4 mm, large enough to place inside the vacuum chamber (VC) two NEG strips each of 15 mm width. These NEG strips are spot welded to the side walls of the vacuum chamber and can provide enough pumping speed to maintain the necessary pressure inside the vacuum chamber (1×10^{-9} Torr). To activate the NEG strips we are going to bake the whole EMW VC with the NEG strips inside to a temperature up to 450 °C. Two long bellows sections will accommodate the thermal expansion of the EMW VC and make available a smooth temperature transition to other parts of the vacuum system whose temperature during the baking procedure should not be higher then 180 °C. Inside the multifunctional box made of stainless steel there is a cooled copper transition section from the storage ring elliptical aperture to the rectangular aperture of the EMW VC. It has two pumps (30 ℓ/s ion pump and a 220 ℓ/s lamped NEG pump) and two ports for rough pumping and for the ion gauge and RGA heads. On the downstream side of the EMW VC there is a second transition piece from the EMW VC to the storage ring VC. The remaining part of the straight section is occupied by a short section of the standard storage ring vacuum chamber.

Table I lists the characteristic parameters for the EMW insertion device. Figures 3 and 4 show the results of the calculations for the brightness and degree of circular polarization (P_c). The brightness and P_c were evaluated as a function of photon energy using the Stokes parameters. Our procedures follow the method of Kitamura and Yamamoto.[10] We used a vertical angular divergence value σ_y' of 9 μrad. The calculations shown in Figs. 3 and 4 were performed for

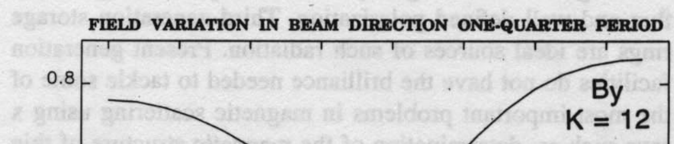

FIG. 2. Magnetic-field profile for a quarter period of the insertion device.

TABLE I. Parameter list characterizing the 15 cm elliptical multipole wiggler.

Parameter		Value	
Ring energy	E	7 GeV	$\gamma = 1.37 \times 10^4$
Period	λ_u	16 cm	
Number of periods	N	16	for permanent magnet structure
		17.5	for electromagnet structure
Length	L	2.8 m	
Gap vertical	g_y	2.3 cm	
horizontal	g_x	7.1cm	
On axis B field	B_y	1 T	
	B_x	0–0.076 T	
Critical energy	E_c	32.5 keV	
Deflection parameter	K_y	13-14	
	K_x	1.-1.5	
Max. angle deflection	δ_x	1.022 mrad ($Ky=14$)	
	δ_y	0.073 mrad	
Total power	P	8.68 kW ($I=100m$ A)	
Peak power density	$dP/d\Omega$	41.49kW/mrad^2	
First optic	Z1	30 m	
Beam width at Z1	Δ_X	48.14 mm	
Beam height at Z1	Δ_Y	3.33 mm	
Power density at Z1	dP/dA	46.1 W/mm^2	

a vertical observation angle equal to zero (on axis). One can observe the high degree of polarization that is attained at high energies as well as with the high brightness of the source. The circular polarization can be changed from right to left by switching the electromagnet polarity; it can be done as fast as 10 Hz. By focusing the beam high brilliance can be achieved which is very favorable for surface scattering experiments.

The EMW beamline will consist of three experimental stations. The beamline optics will deliver monochromatic radiation with tunable energy, bandpass, and polarization. The three stations will operate simultaneously. The three stations

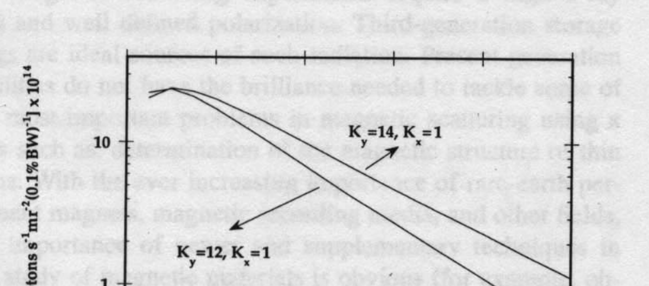

FIG. 3. Brightness vs photon energy calculated using the parameters of Table I; $K_y=12$ is also shown in the figure.

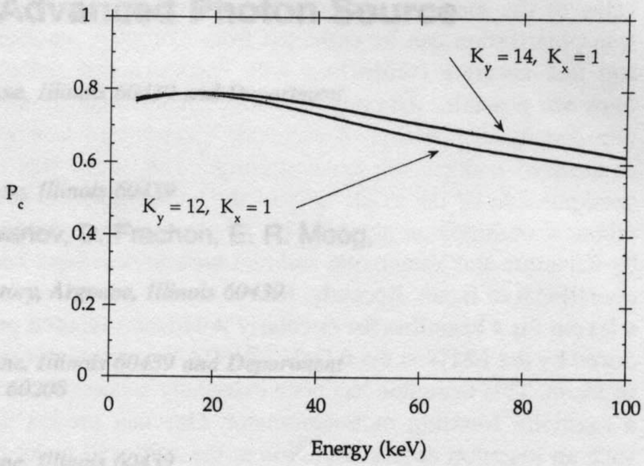

FIG. 4. Degree of circular polarization (P_c) vs photon energy for $K_y=12$ and 14, $K_x=1$.

have three distinguishing functions, namely, Compton scattering, magnetic scattering, and high energy diffraction.

Our objective is to obtain high photon flux with energies above 20 keV and well characterized polarization. For Compton scattering the detectors should have high efficiency for high-energy x rays. We are planning to use an array of solid-state detectors. The sample will be mounted in a magnetic field (an electromagnet for rapid magnetic-field reversal). Electron detection in coincidence with the scattered x ray can also be used in thin-film samples. Such experiments can reveal more details of the energy-momentum space in a small volume than conventional Compton scattering. The realization of such experiments is strongly dependent on the photon flux at the high-energy end of the wiggler's radiation.

In summary, we believe that this facility will offer unique opportunities to perform experiments using tunable circularly polarized x rays at the Advanced Photon Source.

ACKNOWLEDGMENT

Work at Argonne National Laboratory is supported by the US Department of Energy (DOE), Office of Basic Energy Sciences, Division of Material Sciences, under Contract No. W-31-109-ENG-38.

[1] E. D. Isaacs, D. B. McWhan, C. Peters, G. E. Ice, D. P. Siddons, J. B. Hastings, C. Vettier, and O. Vogt, Phys. Rev. Lett. **62**, 1671 (1989).

[2] J. B. Goedkoop, B. T. Thole, G. van der Laan, G. A. Sawatzky, F. M. F. de Groot, and J. C. Fuggle, Phys. Rev. B **37**, 2086 (1988).

[3] E. Keller and E. A. Stern, in *EXAFS and Near Edge Structure III* (Springer, Berlin, 1984), p. 507.

[4] M. J. Cooper, in *Momentum Distributions*, edited by R. N. Silver and P. A. Sokol (Plenum, New York, 1989), p. 307.

[5] H. Kawata, T. Miyahara, S. Yamomoto, T. Shioya, H. Kitamura, S. Sato, S. Asaoka, N. Kanaya, A. Lida, A. Mikuni, M. Sato, T. Iwazumi, Y. Katijima, and M. Ando, Rev. Sci. Instrum. **60**, 1885 (1989).

[6] J. Goulon, P. Elleaume, and D. Raoux, Nucl. Instrum. Methods A **254**, 192 (1987).

[7] N. Sakai and K. Ono, Phys. Rev. Lett. **37**, 351 (1976).

[8] M. J. Cooper, S. P. Collins, D. N. Timms, A. Brahmia, P. P. Kane, R. S. Holt, and D. Laundy, Nature **333**, 151 (1988).

[9] Y. Tanaka, N. Sakai, Y. Kubo, and H. Kawata, Phys. Rev. Lett. **70**, 1537 (1993).

[10] S. Yamamoto, H. Kawata, H. Kitamura, and M. Ando, Phys. Rev. Lett. **62**, 2672 (1989); H. Kitamura and S. Yamamoto, Rev. Sci. Instrum. **63**, 1104 (1991).