A SUPERCONDUCTING WIGGLER MAGNET FOR THE NSLS X-RAY RING

E.B. Blum, D.R. Lynch, P. Mortazavi, O.V. Singh, W. Thomlinson, and M.H. Woodle
Brookhaven National Laboratory, Upton, NY 11764 USA

A.J. Broadbent, M.C. Coates, S.R. Milward, E.J.F. Moor, and K.D. Smith
Oxford Instruments Accelerator Technology Group
Unit 14 Oakfield Industrial Estate, Eynsham, Witney, Oxon OX8 1TH UK

Abstract

The superconducting 5 pole, 5 Tesla wiggler which has been operating in the X-17 straight section of the x-ray storage ring at the National Synchrotron Light Source (NSLS) since 1989 will soon be replaced by a new wiggler being built by Oxford Instruments with lower operating costs, higher reliability, and greater performance. The new wiggler has three modes of operation: the full wiggler with 11 poles producing 3.0 T, the partial wiggler with 5 poles at 4.7 T, and the wavelength shifter with a single pole producing 5.5 T. The full wiggler, optimized for the digital subtraction radiography program, will produce the same x-ray flux at the 33 KeV iodine K-edge as the existing wiggler operating at 4.7 T but will reduce the higher energy harmonics delivered to the target. The partial wiggler will deliver the same flux for solid state physics experiments as the existing wiggler, and the wavelength shifter will provide an elliptically polarized x-ray beam that is not now available.

1 INTRODUCTION

A 4.7 T, five pole superconducting wiggler[1] has been operating in the X-Ray storage ring at the National Synchrotron Light Source since 1989. The existing wiggler has been an important source of radiation for material science, high pressure research, and biomedical studies including, especially, digital subtraction angiography. The wiggler and its associated electronics and cryogenics systems, however, are aging and no longer represent the state of the art. Oxford Instruments is now building a new wiggler that will exceed all of the capabilities of the current wiggler but will be more reliable and less expensive to operate. The wiggler, shown schematically in fig.1, will have 13 iron poles that are excited by superconducting NbTi coils. Some important characteristics of the wiggler are listed in Table 1.

Table 1. Superconducting Wiggler Characteristics

Beam Energy	2.584	GeV
Maximum Beam Current	438	mA
Period	17.16	cm
Number of Poles	13	
Maximum Field	5.5	T
Horiz. Beam Aperture	59.5	mm
Vert. Beam Aperture	19.5	mm

The wiggler will have three different modes of operation: full wiggler, partial wiggler, and wavelength shifter. In the full wiggler mode, the central 11 poles will be excited to produce a field of 3.0 T on the beam axis and the two end poles will produce half of that field to close the trajectory. In the partial wiggler mode, the poles labeled 0, ±1, and ±2 in fig. 1 will produce 4.7 T on-axis, poles ±3 will be powered to half-strength and the remaining poles will be unpowered. In the wavelength shifter mode, pole 0 will produce 5.5 T, poles ±1 will be powered to half-strength, and the remaining poles will be unpowered. Switching between the modes will be accomplished by changing the connections of the magnet leads to the

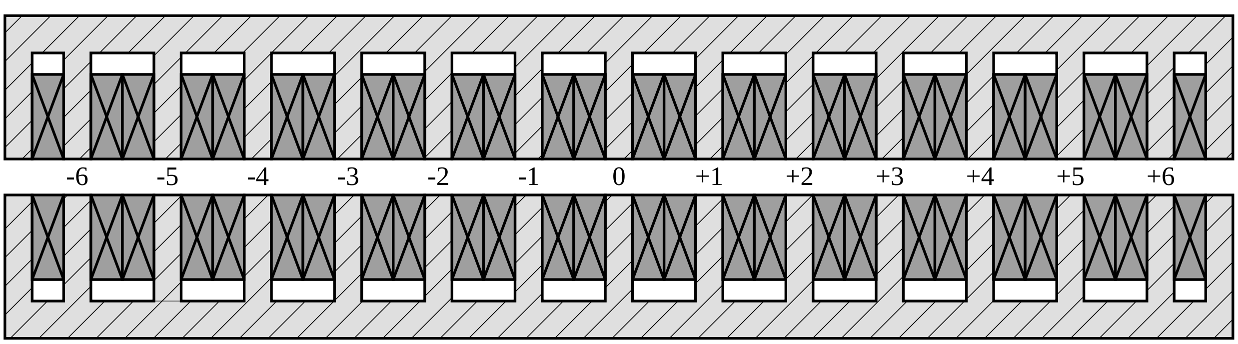

Figure. 1. Schematic cross section of the superconducting wiggler. The iron poles are indicated by diagonal lines and the superconducting coils by crossed, diagonal lines.

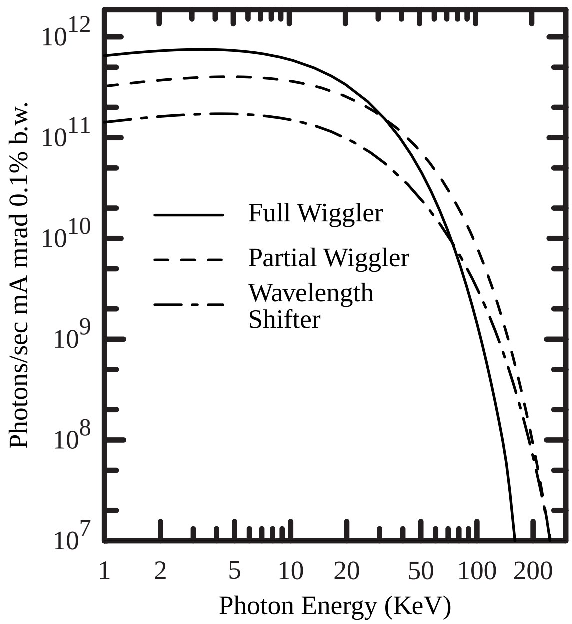

Figure. 2. On-axis flux in each wiggler operating mode.

power supply. A plot of the on-axis flux produced by the wiggler as a function of photon energy in each of the three operating modes is shown in fig. 2.

The full wiggler mode will be used for high intensity imaging experiments. In particular, it will be used for the coronary angiography and computed tomography medical programs. The 3.0 T peak field has been chosen because the critical energy is low enough that the higher energy harmonics in the (nearly) monochromatic beam that can be produced by diffracting the wiggler radiation in Si(111) crystals does not contaminate the images. The 11 poles produce the maximum allowable power level in the white beam, thereby maximizing the available flux at the 33 KeV iodine absorption edge used in digital subtraction imaging.

In the partial wiggler mode, the wiggler will produce the same flux as the present wiggler. This option will be used by high pressure materials science researchers in experiments using both high volume presses and diamond anvil cells. The higher fields raise the critical energy and hence the available energy spectrum for transmission through the cells for diffraction experiments. Most diffraction experiments will also use this field value as will other experiments where high flux above about 40 KeV is desirable.

The wavelength-shifter mode is designed for experiments where beam polarization is an important parameter. In particular, scattering and absorption by magnetic materials may be dependent on the polarization. Although the polarized radiation from bending magnet sources is readily available for surface diffraction experiments, the elliptically polarized, high energy photons from the wavelength shifter will permit measurements in transmission.

2 WIGGLER CONSTRUCTION

A warm bore–cold iron design was chosen in which the poles and coils are mounted in a 4.5 K liquid helium (lHe) bath and an insulated bore tube is provided for the electron beam. Heaters are incorporated to keep the temperature of the beam tube above 0° C so that water vapor will not freeze on the tube in the event of a vacuum leak in the storage ring. To minimize the heat leak, the stainless steel cryostat incorporates a 20 K shield cooled by the boiled-off helium vapor and a liquid nitrogen cooled 80 K shield. High temperature superconducting leads are used for the magnet current to further reduce losses. In steady operation, the wiggler will use 0.35 l/hr of LHe. The LHe will be supplied from a pressurized dewar by an automatic transfer system.

The magnet poles are constructed of a special low carbon steel called REMKO B in order to minimize the residual magnetization. The superconducting coils are made from round wires of NbTi stabilized with copper. The ratio of NbTi to Cu is 1:1. The coil around each pole is divided into two sections in order to reduce the current density in the high field region nearest the pole. The wire diameter in the inner coil is 1.0 mm and it is 0.7 mm in the outer coil. The maximum current is approximately 295 A and the current densities are 485 A/mm^2 in the outer coil and 285 A/mm^2 in the inner. The maximum stored energy in the wiggler is170 KJ.

The magnetic field of the wiggler must be ramped to accommodate storage ring injection. Electrons are injected into the ring at an energy of 750 MeV. After the desired current is stored, the ring energy is ramped to 2.584 GeV. The wiggler was designed so that it can be ramped between an injection level of 1.1 T and the maximum operating field in each mode at a rate of 1.14 T/min. The maximum voltage required to achieve this rate is 16.5 V.

The coil design, small ramping voltages, and low stored energy permit the use of passive quench protection. Diode–resistor networks are placed across the coil leads inside the cryostat to absorb the stored energy in the event of a quench. Calculations have shown that the magnet power supply can safely remain on during a quench.

3 WAVELENGTH SHIFTER POLARIZATION

It is well known[2] that the synchrotron radiation from the electrons in a bending magnet is linearly polarized in the bending plane and elliptically polarized out of the plane, with the polarization growing increasingly circular with the vertical angle ψ. In most wigglers, the transversely polarized component of the radiation from alternate poles cancels, resulting in radiation that is linearly polarized in the bending plane at all vertical angles. In a wavelength shifter, however, the transversely polarized radiation from the strong central pole is only partially canceled by the radiation from the half-strength end poles, leaving strong elliptical polarization off-axis.

We will now estimate the degree of circular polarization from the wavelength shifter. When the wiggler parameter K>>1 most of the radiation observed with an energy that is near or above the critical energy is emitted from the portions of the electron trajectory that are tangential to the axis of observation.[3] Because the emitting regions are small they can be approximated by circular arcs. The radiation from the wiggler magnet can therefore be approximated as the radiation from a series of bending magnet sources. This is called the *bend source* approximation.[4] The wavelength shifter will hence be modeled by a magnet with bending radius ρ sandwiched between two magnets with radius 2ρ.

The degree of circular polarization from a radiation source can be defined in terms of the Stokes parameters as[3]

$$P_C = S_3 / S_0$$

where

$$S_3(\rho) \propto \frac{8}{3}\rho^2 \psi\left(\psi^2 + 1/\gamma^2\right)^{3/2} K_{1/3}(\eta) K_{2/3}(\eta)$$

is the intensity of the circularly polarized radiation,

$$S_0(\rho) \propto \frac{4}{3}\rho^2 \psi^2\left(\psi^2 + 1/\gamma^2\right) K_{1/3}^2(\eta) + \frac{4}{3}\rho^2\left(\psi^2 + 1/\gamma^2\right)^2 K_{2/3}^2(\eta)$$

is the total radiation intensity,

$$\eta(\rho) = \frac{E}{2E_C(\rho)}\left(1 + \gamma^2\psi^2\right)^{3/2},$$

$$E_C(\rho) = 3\hbar\gamma^3 c / 2\rho$$

is the critical energy, E is the photon energy, γ is the Lorentz parameter, ψ is the angle at which the radiation is observed relative to the bending plane, $K_{1/3}$ and $K_{2/3}$ are modified Bessel functions. The direction of polarization is opposite for the central and end poles. The degree of circular polarization of the radiation from the wavelength shifter is therefore

$$P_{C,total} = \left[S_3(\rho) - 2S_3(2\rho)\right] / \left[S_0(\rho) + 2S_0(2\rho)\right].$$

Fig. 3 shows a plot of the degree of circular polarization of the radiation shifter as a function of photon energy for a series of vertical angles. The circularly polarized component of the radiation from the central pole becomes predominant at energies above critical as the angle approaches $1/\gamma$. The polarization at low energies is dominated by the half-strength end poles and is in the opposite direction. This is not normally of much interest because wavelength shifters are built as a source of high energy radiation. The dependence of the intensity of the circularly polarized radiation on photon energy will not be discussed in this paper.

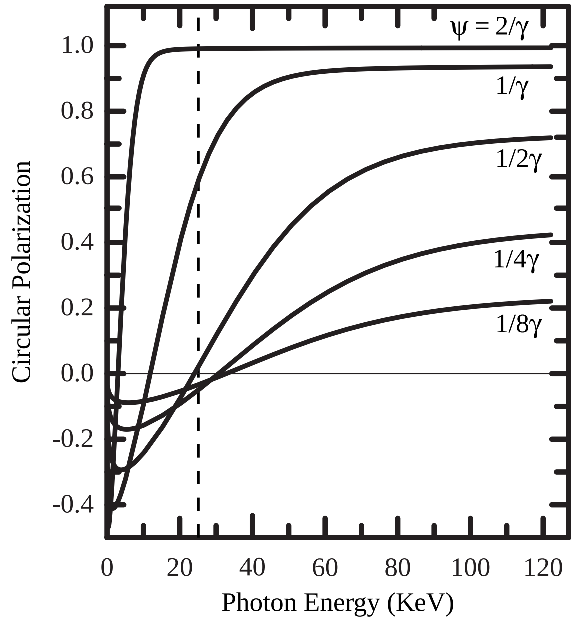

Figure 3. Degree of circular polarization for the wavelength shifter mode at various vertical angles. The broken line represents the critical energy for the central pole.

4 PLANS FOR INSTALLATION

The wiggler is now under construction at Oxford Instruments. Delivery at Brookhaven National Laboratory is expected in the Fall of 1997 and installation in the NSLS X-Ray Ring is planned for December 1997.

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