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DESIGN OF A 6 TESLA WIGGLER FOR THE NATIONAL SYNCHROTRON LIGHT SOURCE*

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Abstract

A 6-pole, 6 Tesla wiggler with Nb-Ti superconducting windings has been designed, to be installed in a straight section of the 2.5 GeV X-ray storage ring of the NSLS. The technical problems of this magnet are discussed, in particular the optimization of the two-layer magnetic windings and the mechanical structure designed to counteract the strong magnetic forces. The effects of the insertion of the wiggler in the storage ring lattice are also studied.

1. Introduction

The power radiated as synchrotron radiation by an electron beam of energy $\gamma m_o c^2$ travelling in the field B (Tesla) of a bending sector of a storage ring is given, per unit beam current, by[1 2 3]

$$\frac{dP}{dI} = 3.312\ 10^{-6}\ \gamma^2 \int B^2 ds \quad \frac{\text{watt}}{\text{A}} \tag{1}$$

(the integral being taken along the trajectory measured in cm). The well-known spectrum of the synchrotron radiation is characterized by a critical wavelength, λ_c, expressed as

$$\lambda_c = 7.135\ 10^7\ \frac{1}{\gamma^2 B}\ \text{Å} \tag{2}$$

For a given electron energy, it follows from Equations (1) and (2) that in order to increase the photon output and to shift the spectrum toward shorter wavelengths, it is necessary to increase the local magnetic field. This can be achieved by inserting in one of the straight sections of the storage ring a transverse wiggler magnet, consisting of a series of pole pairs of opposite polarities, that produces a local field more intense than in the ring's bending section, and that does not cause any net deviation of the electron beam, provided that the following condition holds for the field B

$$\int B\ ds = 0 \tag{3}$$

In a transverse wiggler the electrons perform oscillatory trajectories in a plane perpendicular to B. Generally this plane is chosen to coincide with the orbit plane of the unperturbed storage ring. The radiation emitted at each oscillation is peaked forward and is contained in a vertical angle of $1/\gamma$ and in a horizontal angle

$$\Delta\Theta = 0.62\ \frac{B_o \lambda_w}{\gamma} \tag{4}$$

where λ_w (cm) is the wiggler magnetic period and B_o the wiggler peak field.

Wiggler magnets of different characteristics are operated or are being constructed for electron storage rings in various laboratories,[2,3] notably SSRL at Stanford, Adone at Frascati, SRS at Daresbury, VEPP-3 at Novosibirsk, ACO at Orsay.

For the 2.5 GeV Storage Ring of the National Synchrotron Light Source at Brookhaven,[4] a 6 Tesla superconducting transverse wiggler has been designed, that will provide the experimenters with a much harder spectrum and more photon flux than the conventional synchrotron radiation ports. A single pole model is presently being fabricated to verify the superconductor current density capability under actual conditions and soundness of mechanical design.

2. Magnet Design

The wiggler Magnet design is based on the following criteria:

According to Equation (2) a critical wavelength of a fraction of an Angstrom at the electron energy of 2.5 GeV of the Storage Ring can be achieved with a wiggler magnetic field on the median plane, B, of a few Tesla.

The angle of emission of the radiation from the wiggler in the horizontal plane, given by Equation (4), should be smaller than the minimum acceptance angle determined by the geometry of the storage ring lattice elements, in this case the ring quadrupoles. Since $\Delta\theta$ is proportional to the wiggler period, λ_w, the latter should not be so long that excessive radiated energy is incident on the vacuum chamber.

The magnetic gap is dictated by the minimum permissible vertical distance between electron beam and the vacuum chamber wall.

Another essential requirement for a wiggler magnet is that the field integral must vanish along the axis, according to Equation (3). This is generally done by tayloring the field of the end poles, with two different methods.

a. The end poles can produce a peak field similar to that of the other poles, but the effective length of the end poles is half of the others.

b. Same effective length of the end poles, but lower end pole field.

The second method has been chosen for convenience of coil fabrication. In addition, a pair of dipole coils are also added to enhance the ability for compensation. The end pole coils and compensation coils will be energized by separate power supplies.

A superconducting wiggler has been designed according to the aforementioned criteria. The important parameters are shown in Table I.

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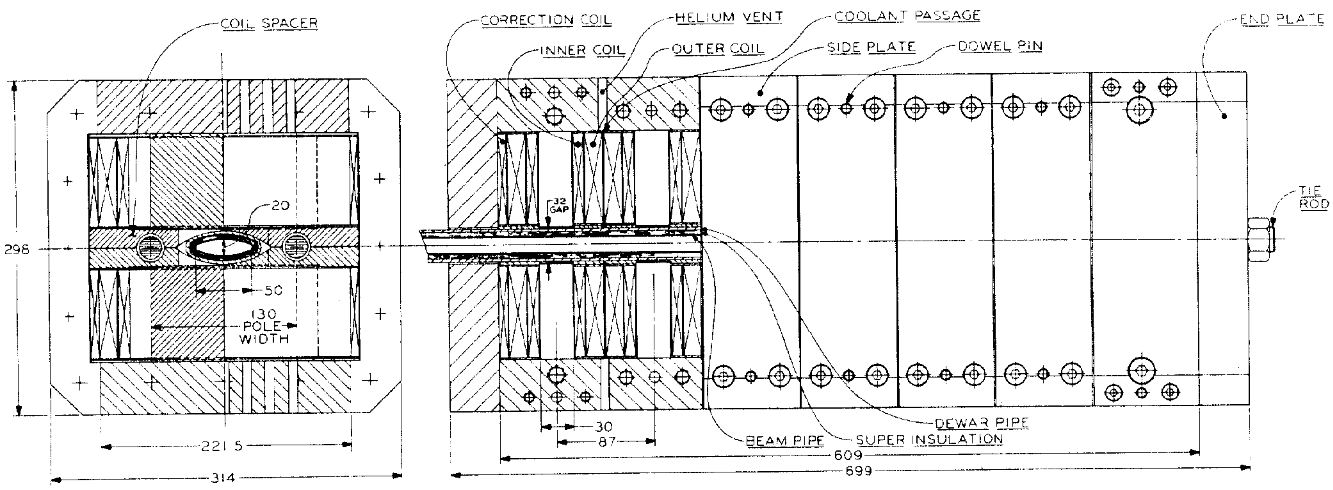

Figure 1. Cross section and elevation of the wiggler

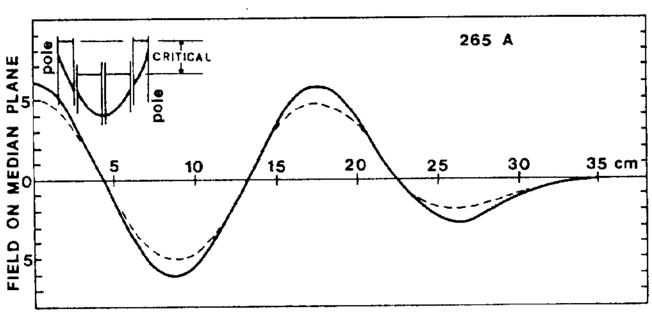

Figure 2. Calculated wiggler field on the median plane for 265 A. The field in the coils is also shown, together with the limiting field in the superconductor.

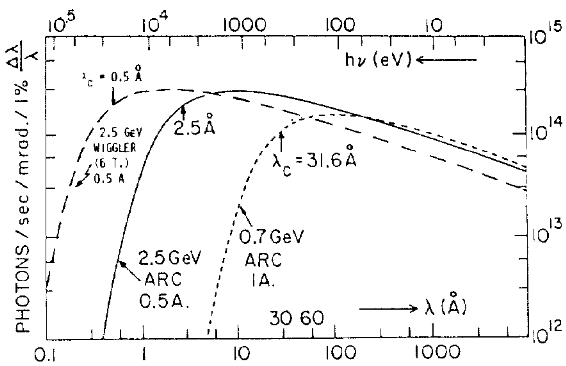

Figure 3. Spectrum of the synchrotron radiation emitted by the NSLS VUV and X-ray rings, and by the wiggler inserted in the X-ray ring.

Table I. Wiggler parameters and expected performances (beam current = 100 mA)

No. of poles	5" full + 2 "half"
Period, λ_w	17.42 cm
Magnetic full gap	3.2 cm
Vertical beam stay-clear	2 cm
Excitation (full poles)	265A x 2385 turns
Maximum field on median plane	6 Tesla
Stored energy	88 Kjoules
Critical wavelength, λ_c	0.49 Å
Radiation emission angle	±13 mrad
Photon flux at $\lambda = \frac{\lambda_c}{3.5}$	$2\ 10^{14}\ sec^{-1}$-$mrad^{-1}$-1% $\Delta\nu/\nu$
Total radiated power	7 Kwatt

The wiggler in elevation and cross section is shown in Figure 1. The calculated field on the median plane for the current of 265 A is shown in Figure 3. This figures shows also the total field seen by the superconductors.

Figure 3 shows the spectrum of radiation expected, as compared with the radiation from a "normal" bending magnet of the X-ray ring of the NSLS.

3. Magnet Core and Windings

The magnet core is made of SAE 1008 hot rolled steel. The steel core approach was chosen for the following reasons.

Although iron is highly saturated at the design field, a benefit of 20% field increase for the same excitation is realized due to its presence.

The core is utilized as mechanical support structure to sustain the heavy load on coils due to the high magnetic field.

The iron core helps to shape the magnetic field more favorably in comparison with air core magnets.

The coil package consists of inner and outer coil layers. The outer coils are located in a lower field region and are made of smaller diameter wire, carrying therefore a higher current density. The inner coils, in series with the former, have a lower current density. This arrangement permits to match better the critical current limits in the superconductor. Table II lists the superconductor parameters.

Table II. Wiggler superconducting coils

		Inner Coil	Outer Coil
No. of turns		695	1690
Bare wire dia.	(mm)	1	0.813
Ins. wire dia.	(mm)	1.06	0.88
Cu/SC ratio		1.25	1.8
No. of strands		367	180
Filament dia.	(μm)	35	37
Twist Pitch	(mm)	25	25
Current density / field	$\frac{KA}{cm^2\text{-Tesla}}$	33.7	5.5

The coils are wound with the wet lay-up method, using Bondmaster E645 as adhesive. This epoxy system has long pot life and good adhesion property at 4.2°K temperature. The wires are loaded up to 58.5 Kg/cm^2 during winding. Ground insulation consists of one serving of 0.08 mm thick fiberglass tape, half lapped and epoxy impregnated.

The clearance between coil and core created by differential contraction of materials will be compensated by stainless steel side plates. Therefore, a sudden release of energy due to coil motion is minimized. A pair of heavy stainless steel end plates and tie rods are provided to take up longitudinal magnetic pressure from the end coils.

Semi-warm bore is being contemplated for this magnet, cooling of the beam pipe will be achieved by flowing vaporized helium gas from the helium vessel. This will enable us to intercept the majority of thermal load created by the synchrotron radiation emitted by the electrons in the upstream bending magnet.

4. The Wiggler in the Storage Ring Lattice

The wiggler magnet will be situated at the centerof a 4.5 m insertion, specifically designed to optimize the brightness of the wiggler radiation source. Due to the quadrupole triplets bounding the insertion, the betatron functions are focussed to minimize values at the wiggler location, β_x=1.4 m and β_z=0.33 m. Since the full length of the wiggler magnet is less than $2\beta_z$, the brightness due to the "six" poles is six times that resulting from a single pole.

The transverse dimensions and angular spread of the electron beam at the wiggler are σ_x=0.35 mm, $\sigma_{x'}$=0.25 mrad and σ_z=0.02 mm, $\sigma_{z'}$=0.05 mrad.

The wiggler magnetic field will produce an orbit wiggle of amplitude 0.55 mm and maximum angular deviation $\pm$15 mrad. A vertical tune shift $\Delta\nu_z$=0.004 will result from the operation of the wiggler, and it is expected this is small enough that it will not be necessary to trim the quadrupole settings in the storage ring.

The energy radiated at the wiggler is about 13% of that radiated by all the bending magnets in the storage ring. Operation of the wiggler wil reduce the radiation damping time by 13% and increase the energy spread by 17%. Because the dispersion is zero in the insertion, the electron beam emittance will be decreased by 13%.

4. References

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