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Proposal of a high-field superconducting wiggler for a slow positron source at SPring-8

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A low-energy positron beam is a unique probe of materials. In high-energy electron and positron storage rings it is possible to generate intense synchrotron radiation with a photon energy of 1–3 MeV by installing a high-field (8–10 T) superconducting wiggler. High-energy photons are converted to low-energy positrons by using a suitable target–moderator system. For an 8 GeV electron storage ring at a beam current of 100 mA, final yields are estimated to be about 10^8–10^{10} slow-e^+ s^{-1} or larger depending on the moderation efficiency, with the size of the positron source 10^1–10^2 cm^2. In the present work a wiggler magnetic system of 10 T is proposed. The main parameters of the superconducting wiggler are presented.

Keywords: superconducting wigglers; positron sources.

1. Introduction

A low-energy positron beam is a useful probe in the fields of atomic physics, solid-state physics, surface and thin-film physics *etc*. For obtaining high-intensity low-energy positron beams, a scheme of using linacs is adopted in many facilities. However, such a scheme suffers from radiation hazards and the induced radioactivity of a target–moderator system. It has been pointed out (Kulipanov & Skrinsky, 1988; Kulipanov *et al.*, 1992; Kulipanov, 1992; Belyaev *et al.*, 1992) that this problem can be solved if one adopts the method of using synchrotron radiation for producing positrons. An intense beam of photons with an energy above 1 MeV can be produced by installing a high-field superconducting wiggler in high-energy electron storage rings.

In the present paper we describe the first step of the project supported by ISTC grant N767-97, 'RIKEN/Budker INP Slow Positron Source'. The final objective of this project is to create a slow positron source of high brightness by installing a superconducting wiggler with a magnetic field of 8–10 T in the SPring-8 storage ring, to provide a high-intensity low-energy positron beamline and offer a unique method of probing materials (Ando *et al.*, 1996). The key element of the project is an 8–10 T superconducting wiggler which will be developed and fabricated during the grant term.

2. Positron production with synchrotron radiation

We first show in Fig. 1(*a*) the photon flux after integration over photon energy in the range from 1 MeV to infinity per 1 mrad of horizontal angle as a function of wiggler field at a beam current of 100 mA and a beam energy of 8 GeV.

When the field is higher than 10 T, the integrated photon flux is proportional to the magnetic field strength as $\Delta N/\Delta B \simeq 5 \times 10^{14}$ photons T^{-1}, whereas the flux drastically decreases if the field is lower than 8 T. Fig. 1(*b*) shows the necessary pole number of a multipole wiggler at different fields to generate the same integrated photon flux, 1.6×10^{15} photons s^{-1} $mrad^{-1}$, as that from a one-pole 10 T wiggler. The figure also shows how much total power is radiated. For example, in order to receive the same photon flux as produced by a one-pole 10 T wiggler, one should use a seven-pole 6 T multipole wiggler. The total radiated power from this device will increase to 250 kW inside the horizontal fan angle of ±15 mrad, and the power density on an absorber will be four times larger compared with a one-pole 10 T wiggler. To our mind the one-pole 10 T wiggler is a realistic proposal, and hereafter we assume that the maximum magnetic field strength of the wiggler is 10 T.

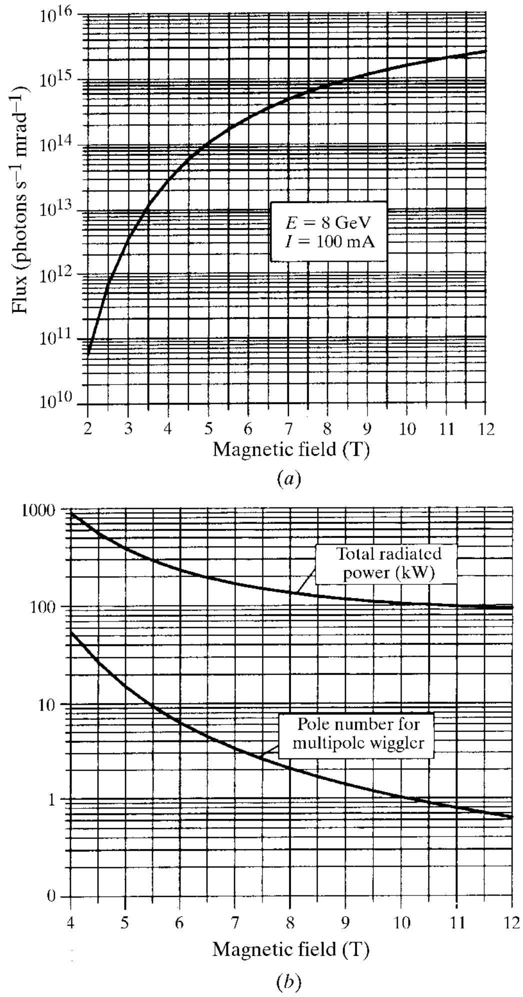

Figure 1
(*a*) Integrated photon flux with energies above 1 MeV per 1 mrad of horizontal angle *versus* magnetic field level. (*b*) Pole number and total radiated power for multipole wigglers with different magnetic fields in the case of a fixed total photon flux which corresponds to that of a one-pole 10 T superconducting wiggler.

Table 1
Positron production efficiency for 8 and 10 T wigglers for a Pb target of size 35 mm × 20 mm × thickness.

Photons are incident on the target inclined at 5 mrad relative to the beam direction. The third column is the total number of incident photons within 1 mrad with energy higher than 1 MeV, and the final column is the total number of positrons emitted from the target.

Wiggler field (T)	Target thickness (mm)	Photon number (s^{-1})	Positrons per photon (produced)	Positrons per photon (emitted)	Positron number (emitted) (s^{-1})
8	0.1	3.83×10^{14}	1.8×10^{-2}	7.2×10^{-3}	2.7×10^{12}
10	0.1	7.15×10^{14}	2.2×10^{-2}	1.0×10^{-2}	7.4×10^{12}

By using a simulation code (Kiselev, 1995) we estimated positron yields when the synchrotron radiation beam is incident on a target. We assumed that the energy of the stored electron beam is 8 GeV, the stored beam current is 100 mA, the distance from the wiggler to a target–moderator system is 35 m, and that the vacuum chamber and magnets are designed appropriately to extract photons within a horizontal divergence angle of 1 mrad. The results are shown in Table 1.

Positrons emitted from the target then irradiate a moderator, and a small fraction of incident positrons are re-emitted from the surface. According to calculation results performed by Okada *et al.* (Okada & Sunaga, 1991; Okada & Kaneko, 1995), there is a possibility that moderation efficiencies for positrons whose energies are below 1 MeV can be as high as $\sim(1/3) \times 10^{-2}$ if we use an assembly of thin foils as the moderator. We can also estimate the efficiency of moderation by using typical values $(0.1–7) \times 10^{-3}$ in the isotope method (Schultz & Lynn, 1988). In the present work we take a conservative estimate of 10^{-3} for moderation efficiency. Then, we can expect from Table 1 that final yields are $10^8–10^{10}$ slow-e^+ s^{-1} or larger depending on the moderation efficiency for 1 mrad of the orbit arc.

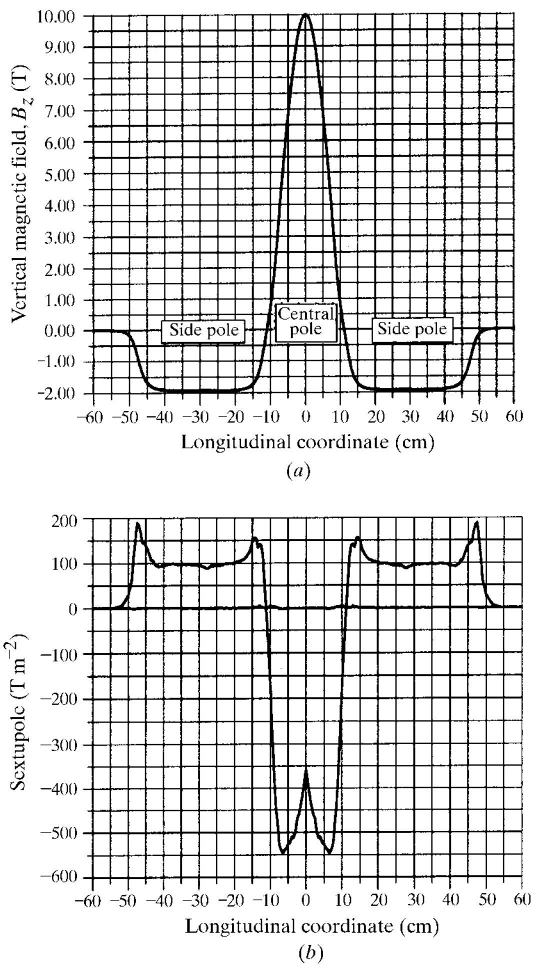

Figure 2
Magnetic field distribution along the wiggler longitudinal axis: (*a*) vertical component B_z of the field (T) and (*b*) sextupole component d^2B_z/dx^2 (T m^{-2}).

Table 2
Parameters of a proposed superconducting wiggler.

Maximum field on beam axis	
Central pole	10 T
Side poles	−1.9 T
Pole gap	41 mm
Vertical aperture of vacuum chamber	20 mm
Horizontal aperture of vacuum chamber	~100 mm
Stored energy	~200 kJ
Total weight of cooled parts	~1200 kg
Working temperature	4.2 K

3. Superconducting wiggler

The superconducting magnet design is based on three superconducting dipoles. The wiggler magnetic field is produced by six superconducting coils assembled symmetrically above and below the vacuum chamber. On the basis of previous work (Grudiev *et al.*, 1995; Borovikov *et al.*, 1998), the design of the central coils is conducted assuming three section central coils and a pole gap of 41 mm. In the case of a room-temperature beam vacuum chamber inside the wiggler, the clearance for the beam is 20 mm and 100 mm in the vertical and horizontal directions, respectively. The internal coil section is supposed to be produced with Nb_3Sn rectangular superconducting wire; two others are fabricated with NbTi round superconducting wire. The central pole is made of ARMCO steel which is saturated at a field higher than 2 T on the beam axis. The magnetic flux is closed by a non-saturated iron yoke so that a stray field does not exceed the field level of 0.001 T at the cryostat walls.

The simulation of the wiggler field was made with the two-dimensional *MERMAID* code and three-dimensional *MASTAC* code developed at BINP (Dubrovin & Simonov, 1993; Rojak *et al.*, 1995). The magnetic field distribution along the wiggler longitudinal axis and sextupole component d^2B_z/dx^2 are shown in Figs. 2(*a*) and 2(*b*). The main parameters of the wiggler are listed in Table 2.

The maximum angle deviation and orbit displacement of the electron beam are ±25 mrad and 6.6 mm, respectively (see Figs. 3*a* and 3*b*).

To satisfy the requirements for the first field integral to be zero at any wiggler field level, two power supplies are proposed to feed the wiggler coils. At a field level of 10 T, these currents are as follows: the inner winding of the central coil is supplied by I_1 = 200 A current, the second one is supplied by I_2 = 100 A and the third is supplied by their sum $I_3 = I_1 + I_2$ = 300 A. All these currents are optimized for the maximum possible field inside the

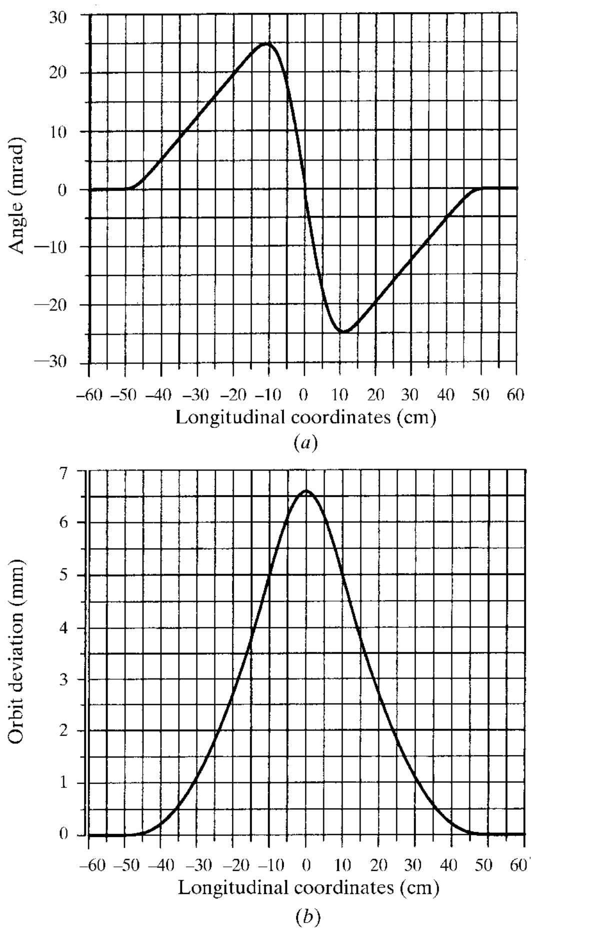

Figure 3
Electron trajectory inside the wiggler: (*a*) angle deviation and (*b*) orbit displacement.

coils in accordance with superconducting wire load curves assuming 90% efficiency. The requirement for the second field integral to vanish is satisfied by high-precision alignment of side coils relative to the central coils and between upper and lower parts. Orbit distortion due to the second integral mismatching will not exceed ± 5 µm in the horizontal plane. The integral of a sextupole field component can be also compensated by proper choice of side poles, as shown in Fig. 2(*b*).

4. Summary and outlook

The main problem of installing the high-field wiggler in SPring-8 is absorption of high-power ($\sim$100 kW) radiation which spreads within the horizontal fan angle of $\pm$25 mrad. Present magnetic elements of the storage ring limit the extraction angle down to 1 mrad. The angular power distribution is shown in Fig. 4. A special design of the absorber is needed. Since the extracted photon beam has a power of $\sim$2 kW of γ-rays, solving the problem of radiation safety is also necessary.

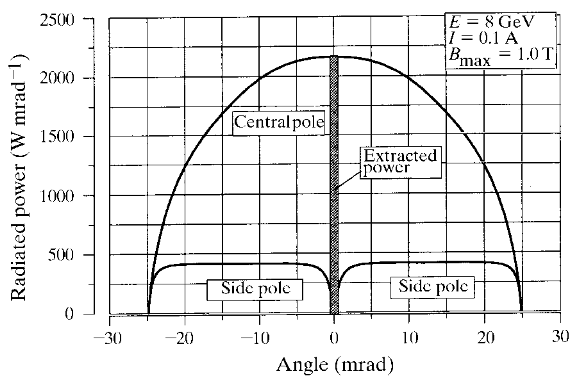

Figure 4
Angle distribution of the radiated power from the wiggler at 8 GeV beam energy and 100 mA beam current.

We have shown that synchrotron radiation is available for producing intense low-energy positron beams. High-energy photons are obtained by installing a high-field (8–10 T) superconducting wiggler in high-energy storage rings. For an 8 GeV storage ring with 100 mA beam current, final yields of positrons are estimated to be about 10^8–10^{10} slow-e^+ s^{-1} or larger depending on the moderation efficiency, though further studies are required on target–moderator systems, beam size, intensity, monochromaticity, heat removal for the target, slow-positron extraction efficiency *etc.*

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