Calculation of Gas Bremsstrahlung Power from Straight Section of Storage Ring at SSRF

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Abstract The Shanghai Synchrotron Radiation Facility (SSRF) is a third-generation synchrotron radiation light source with 3.5GeV in energy, which is composed of the linear accelerator, the booster and the storage ring. The storage ring provides 16 standard straight sections of 6.5m and 4 long straight sections of 12 meters. Gas Bremsstrahlung (GB) produced by the interaction of the stored beam with the residual gas molecules in straight section, which is so intense and has a very small angular that the GB spectra, the GB power and the GB power distribution should be known. The characters of GB are studied by means of Fluka Monte Carlo code. Our result shows agreement with those obtained by the experiential formulae.

Key words gas bremsstrahlung, straight section, radiation power, radiation length

1 Introduction

The Shanghai Synchrotron Radiation Facility (SSRF) is a third-generation synchrotron radiation light source with 3.5GeV in energy, which is composed of the linear accelerator, the booster and the storage ring. The storage ring provides 16 standard straight sections of 6.5m and 4 long straight sections of 12m for the inclusion of insertion devices, injection components and RF cavities[1]. Up to 300mA average current of electron beam with 4nm.rad low emittance can be stored in the storage ring for over 10 hours long average lifetime. Gas Bremsstrahlung (GB) produced by the interaction of the stored beam with the residual gas molecules in the storage ring vacuum chamber. The GB is to be produced in a very small angular cone along the beam direction (the mean value of the emission angle is= m_oc^2/E[2], where m_oc^2 is the electron rest mass and E is the stored beam energy). The GB becomes very important for long straight sections in the storage ring, since the contribution from each interaction adds up to produce a narrow cone beam. These beams are channeled along the SR beam lines to hit the mirrors or monochromators when the long straight sections are used to produce synchrotron radiation. Most of the long straight sections are not used in the first phase of the project at SSRF, in this case the GB will strike on the vacuum flange directly.

There are not many measurements available for GB, especially for high-energy beam. The quantitative estimates of GB from straight section as evaluated by Monte Carlo codes also have several uncertainties. In order to get the GB spectra, the GB power and the GB power distribution, the Fluka Monte Carlo program was used to perform those.

The Fluka Monte Carlo Program was developed by Italian National Institute for Nuclear Physics (INFN) and European Organization for Nuclear Research (CERN).It is a general purpose tool for calculations of particle transport and interactions with matter, covering an extended range of applications spanning from proton and electron accelerator shielding to target design, calorimetry, activation, dosimetry, detector design, radiotherapy, etc. It can handle even very complex geometries, using an improved version of the well-known Combinatorial Geometry (CG) package[3].

Received 7 January 2008

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2 The Monte Carlo simulation

2.1 Simulation Condition

The SSRF storage ring provides 16 standard straight sections and 4 long straight sections. For standard straight section, the storage ring beam straight path is 12.5m long (in the line of sight of its beamline). For long straight section, the storage ring beam straight path is 18m long. The residual gas pressure of the vacuum is less than 10^{-9} Torr.

The actual chemical composition of the residual gas inside the storage ring vacuum chamber is much different from that of air[2]. For conservative consideration, the residual gas inside the vacuum chamber was replaced by air with gas pressure of 0.1 atm in the simulation. The results are then extrapolated to typical storage ring vacuum values (of the order of 10^{-9} Torr). In actual low density of storage ring vacuum chambers, the interaction of Bhabha and Moller scattering and multiple Coulomb scattering can be ignored entirety[3]. Therefore these interactions are suppressed in the air target. In order to study the GB spectra changes as the gas pressure, four gas pressures of air (1, 0.1, 0.01, 0.001 atm) were used. According to Ref. [2], the GB power and GB yield changes as a function of length of the storage ring the beam straight path, the GB produced in the standard straight section was studied.

2.2 Geometry model

An illustration of the geometry used for simulations involving the target is shown in Fig. 1. A is the stored beam with energy of 3.5GeV and current 300mA. B is the air target with the length of 12.5m and the gas pressure of 0.1 atm[4]. C, E, G and I are the black hole (any particle is discarded when reaching a black hole boundary), but C, G, I are used to discard the GB, E is used to discard the remnants of electrons and positrons. D, F (8.56m) and H (0.01m) are the vacuum, but D is a magnetic field with 1.27T and the length of 1.44m used to change the path of remnants electrons and positrons to black hole E, F is used to transport the GB and H is used to score the GB power distribution and GB spectra. C and G are used to score the remnant GB with bigger scattering angle. C, G and I are used to score the total GB power. B, D, F and H are the concentric cylinder with the radius of 3cm. In order to get the GB power distribution, the scored area of I was divided into 61 concentric cylinders in the beam line direction, the radius of 60 cylinders were increased from 0 to 0.9cm in the liner step size of 0.015cm, the range of the last one's radius was varied from 0.9 to 3cm. In order to obtain the GB spectra, the scored energy of GB was divided into 20 parts from 10keV to 3.5GeV in the logarithmic step size.

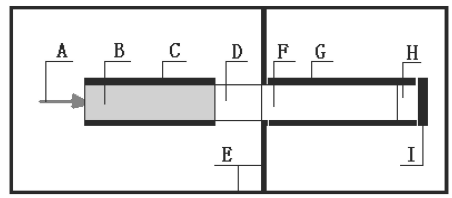

Fig. 1. The calculation model of GB.

2.3 Simulation result

The GB spectra simulated by using the four different gas pressures (1, 0.1, 0.01, 0.001 atm) of vacuum chamber when one stored electron passed through the standard straight sections are shown in Fig. 2. The results show that the GB yield varies directly with the gas pressure when the photon energy is above 50keV. The photon energy below 50keV of GB spectra obtained from the gas pressure of 1atm shows that some are different from the others, because the Compton scattering sections of low-energy photons in the air with gas pressure of 1 atm are much more than others.

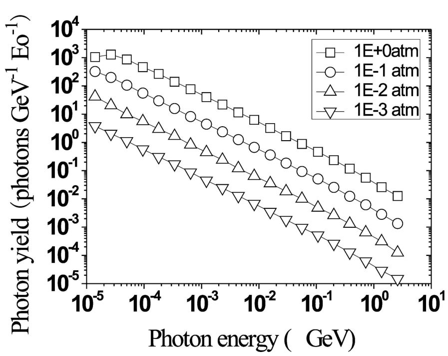

Fig. 2. Photon yield per stored electron through the standard straight section.

The ratio of GB power and primary stored electron energy was evaluated by using the four different gas pressures (1, 0.1, 0.01, 0.001 atm) of vacuum chamber when one stored electron passed through the standard straight sections as shown in Table 1. The ratio rises proportionately to the gas pressure in the vacuum chamber. Therefore the GB power formula can be expressed in this way:

$$P_{\mathrm{GB}}(\mathrm{W}) = 4.46\times10^{6}\times I(\mathrm{A})\times \frac{L(\mathrm{m})}{L_1(\mathrm{m})}\times\frac{P(\mathrm{Pa})}{P_1(\mathrm{Pa})}\times E_0(\mathrm{GeV}) \quad . \tag{1}$$

Here P_{GB} is the GB power produced when the stored beam (beam current: I A, beam energy: E_0 GeV) passed through the straight path (length: L m, gas pressure: P Pa), L_1 is 12.5m, P_1 is 0.1 atm. According to the formula (1), the GB power produced in the standard straight section is 61.7μW.

The GB power distribution when one stored electron passed through the standard straight sections with the gas pressure of 10^{-9} Torr is shown in Fig. 3. The FWHM of GB power distribution is 0.24cm when the GB power distribution is scored downstream the end of the standard straight section with 10m.

Table 1. A comparison of the GB power per stored electron passing through the standard straight section among different gas pressures inside the storage ring vacuum chamber.

	gas pressure		1atm	0.1atm	0.01atm	0.001atm
		B	3.1919×10^{-3}	3.4492×10^{-4}	3.6830×10^{-5}	3.8717×10^{-6}
	GB part	C	1.9609×10^{-2}	1.2586×10^{-3}	1.0993×10^{-4}	3.3355×10^{-6}
(GeV)		G+I	1.3683×10^{-1}	1.3989×10^{-2}	1.4968×10^{-3}	1.4606×10^{-4}
	remnants	E	3.3404	3.4844	3.4984	3.4998
	electrons and positrons					
	GB/E_0		4.561×10^{-2}	4.455×10^{-3}	$4.696\times^{-4}$	4.379×10^{-5}

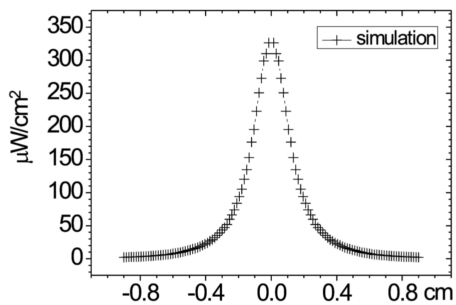

Fig. 3. The GB power distribution (located 10.0m from the end of the standard straight section.

3 Comparison with the experimental data

There is an analytical formula (2) that is often used to evaluate the GB power[5].

$$P_{\mathrm{gb}}\approx\frac{x}{X\mathrm{o}}Ps \quad , \tag{2}$$

where X_0 is the radiation length (for air, X_0 = 36.818g/cm^2), x is the thickness of thin targets in g/cm^2, and Ps is the stored beam power. For formula (2), the GB power of the SSRF standard straight section is 61.4 μW. Both results agree with each other within the uncertainty of 1%.

Because the residual gas path is much less than the radiation length, the spectrum of GB photons of energy k per energy interval dk, dN/dk, can be approximated by[6]:

$$\frac{\mathrm{d}N}{\mathrm{d}k}\approx\frac{x}{X\mathrm{o}}\frac{1}{k} \quad . \tag{3}$$

The GB spectra from simulation and formula (3) are shown in Fig. 4. The GB spectra obtained by this work show agreement with formula (3).

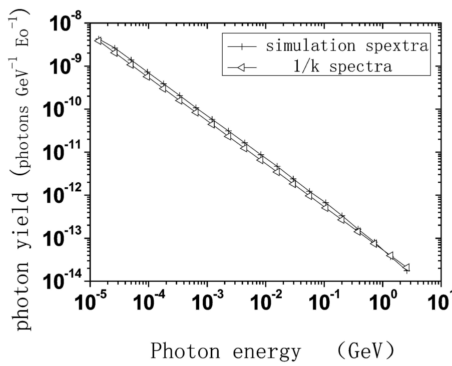

Fig. 4. A comparison of GB spectra between this work and other published data in the standard straight section at SSRF.

4 Summary

In this study we use the Fluka Monte Carlo program to simulate the GB spectra and GB power and GB power distribution of the standard straight section of the storage ring at SSRF. The simulation was preformed under the gas pressure of 0.1 atm inside the vacuum chamber. The results are scaled to the actual gas pressure of 10^{-9} Torr. The result of our study is in good agreement with the experimental data obtained by various workers. This work will provide one method to prepare for further gas bremsstrahlung study and GB shielding calculation.

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SSRF 储存环直线节气体韧致辐射功率计算

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摘要 上海光源 (SSRF) 属第三代同步辐射专用装置, 现正在建设之中. 能量为 3.5GeV、流强为 300mA 的电子经过 SSRF 储存环直线节时, 不可避免的与真空室内的残余气体产生气体韧致辐射. 因气体韧致辐射的前冲性比较强, 且辐射功率比较集中. 所以了解直线节所产生的气体韧致辐射功率、能谱及辐射功率分布是非常必要的. 采用多粒子输运代码 Fluka 对 SSRF 直线节产生的气体韧致辐射功率及韧致辐射光子产额等进行计算. 通过与经验公式的对比及其他文献数据的比较, 论证了本计算模型的合理性.

关键词 气体韧致辐射 直线节 辐射功率 辐射长度

2008 – 01 – 07 收稿

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