Development of a New SR Beam Monitor using Compton Scattering

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Introduction

Blade-type SR beam position monitors have been used for SR beam position measurements because of their simple structures [1].

In the near future, the brightness of SR beams is expected to become large, making it impossible to measure such SR beams by convenient methods. More specifically, the SR beam will damage the blade SR position monitor. At that time, non-destructive SR beam position monitors will be needed instead.

We are planning the design of an SR beam position monitor with a new conceptual design using Compton scattering [2,3]. To measure the SR beam profile, we plan to use a low-energy electron beam (<1KeV, 100mA). This electron beam, emitted from an electron gun, will be injected into the SR beam, made to collide with the SR beam, and will be recoiled by Compton scattering. By measuring the amount of recoil electrons, we expect to obtain information on the photon beam flux.

Schematic Design and Construction

The monitoring system will consist of an electron gun (0-1KeV, 0-100mA), high-voltage regulator, vacuum chamber, ion pump, electron beam collector, average current meter, and so on.

Figure 1 shows a schematic illustration of an SR beam monitor. A low-energy electron beam is injected into the SR beam at a right angle. After this interaction, the low-energy electron beam is recoiled by the SR beam, and then, the SR flux profile is recognized as the recoil electron particle count measured by a micro channel plate image intensifier (MCPII).

The electron beam is moved like a wire scanner [4], and a signal is obtained continuously. Therefore, we possibly are able to obtain information on the SR profile.

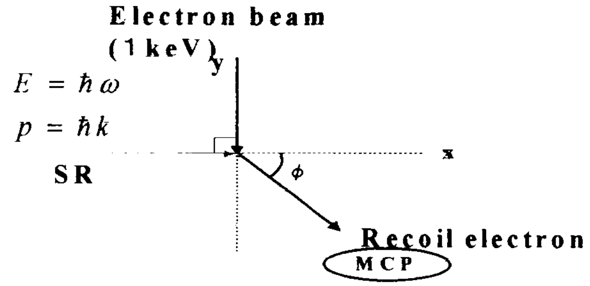

Fig. 1 Schematic illustration of a non-destructive SR beam monitor using recoil electrons

Simulation Results of the Recoiling Angle of Electrons and Signal Level

By way of Lorentz's conversion, the coordinate shown in Fig.1 is converted to move along the electron beam as shown in Fig.2. Following this, the electron remains at the origin, and the direction of the photon beam comes to an incline, as shown in Fig. 2.

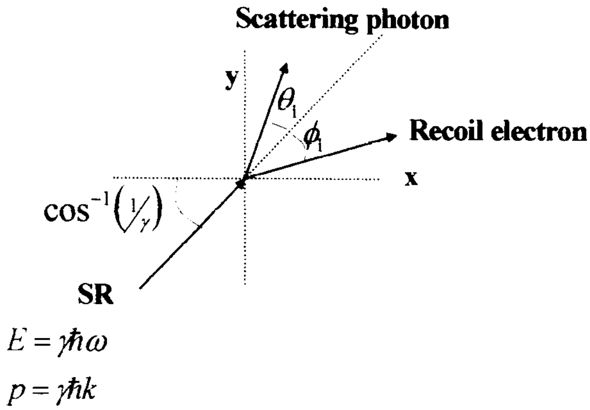

Figure 2. Compton scattering in the corollary which moves along the electron beam

The wave number of the scattered photon is

$$k' = \frac{k\gamma}{1+\frac{\hbar k\gamma}{mc}\left(1-\cos\theta_1\right)} \qquad (1)$$

γ is the Lorentz factor of the relative probe electron in the original coordinate, which depends on the energy of the probe electron gun.

The differential cross-sectional area of the scattering is shown by Klein-Nishina's equation.

$$d\sigma = \frac{r_e}{2}\frac{k'}{k\gamma}\left(\frac{k\gamma}{k'}+\frac{k'}{k\gamma}-\sin^2\theta_1\right)d\Omega \qquad (2)$$

By integrating (2), the total cross-sectional area of the Compton scattering can be calculated as shown in Fig.3.

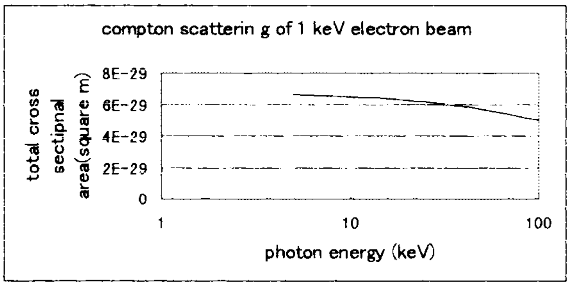

Figure 3. Total cross-sectional area of Compton scattering.

The cross-sectional area is not so much different from that of Thomson scattering, when a 1keV electron and 100keV> photon are used.

On the other hand, the momentum of the recoil electron is shown as

$$p_1 = \hbar\sqrt{(k\gamma)^2 + k'^2 - 2kk'\gamma\cos\theta} \qquad (3)$$

The momentum is converted again into the original coordinate by Lorentz's conversion, then

$$p_x = p_1\left(\frac{\cos\phi_1}{\gamma}+\beta\sin\phi_1\right) \qquad (4)$$

$$p_y = p_1\left(\beta\gamma\cos\phi_1 - \sin\phi\right) - \beta\gamma\sqrt{m_0^2C^2 + p_1^2} \qquad (5)$$

where

$$\phi_1 = \tan^{-1}\left(\frac{k'\sin\theta_1}{k\gamma - k'\cos\theta_1}\right) \qquad (6)$$

The recoiling angle of the electron in the original coordinate in Fig.1, is shown as

$$\phi = \cos^{-1}\left(\frac{p_x}{\sqrt{p_x^2 + p_y^2}}\right) \qquad (7)$$

Therefore, the differential cross-sectional area of the recoil electron in the original coordinate can be calculated from the above equations, and the results are shown in Fig.4.

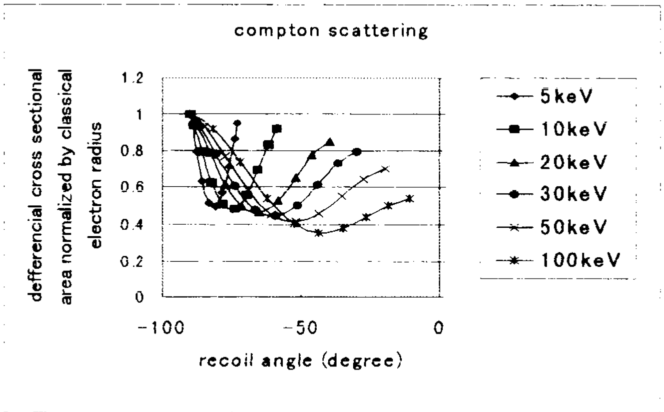

Figure 4. Recoiling angle of an electron calculated in another SR beam energy. A 1keV electron beam is used as a probe.

The simulation results show that the recoil angle of the electron, which is generated by Compton scattering with a 5keV to 100keV photon beam, mainly varies from −90 degrees to 0 degree, where a 1keV electron beam is used as a probe. Then, if MCP is installed at the point where the recoil electron can be effectively collected, the SR beam profile can be recognized as the electron count. Although only the phenomenon in the x-y plane is considered in this discussion, the outline of this concept is not so different in a 3-dimensional coordinate.

We also estimated the amount of signals in this system, assuming a photon flux of SR: 3.5×10^{21} photons/sec/m^2 (10keV to 100keV), and a probe electron beam (1keV, 100mA, r=0.5mm). This SR flux is the same as that of the normal type undulator

(UV32) beam in SPring-8, which is driven by a ring current of 100mA, and has a K value of 2.6 [5]. Based on the total cross-sectional area above, the total number of recoil electrons is approximately 150/s, which is enough to be counted by MCP, but requires that a high quantum efficiency be attained. The more the brightness becomes, the more the signal amount increases, so, the situation might be good for this system [6].

Design of Electron Beam

The cross-sectional area of the Compton scattering is proportional to the number of electron particles, and therefore, the electron beam current should be large enough to store a sufficient number of particles. Therefore, the electron beam should be focused into the points of interaction by an electric lens.

By use of the relativistic electron optics program EGUN, we examined the possibility of producing a pencil-size probe electron beam to be used for this purpose.

In the calculation, the electron beam energy was assumed as 1keV. The results are shown in Fig.5 and 6.

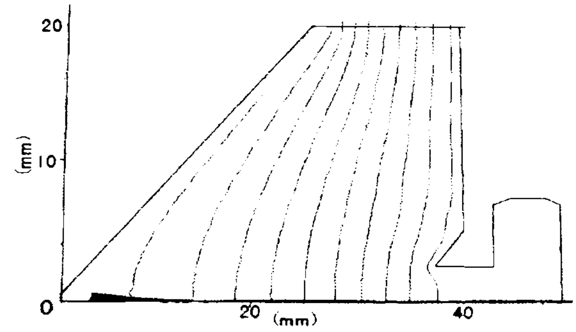

Figure 5. Electron beam optics for a Compton scattering SR monitor. The cathode voltage is −1kV.

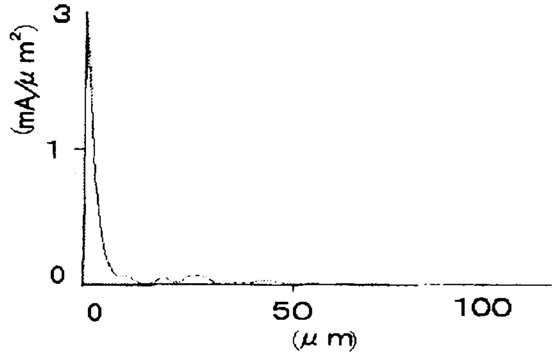

Figure 6. Profile of a 1keV electron beam. The central part contains a 3mA/μm square.

The results show that it is possible to produce a low-energy pencil-size electron beam for this purpose. As shown in Fig.6, the electron beam can be made to have a large current density (200mA in 10 micrometers squared).

Conclusions

We created a conceptual design of a non-destructive position monitor for an SR beam. By the use of Compton scattering with a low-energy electron beam, it was possible to produce the SR monitoring system. It is therefore important now to develop a well-designed probe electron gun.

In our near-future plans, we plan to check the performance of the SR beam position monitor using Compton scattering, by using an SR beam (1-100KeV) from a storage ring. This system might also be applied to an electron beam monitor [6].

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