



TITLE:

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Design Study for Direction Variable Compton Scattering Gamma Ray

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Abstract. A monochromatic gamma ray beam is attractive for isotope-specific material/medical imaging or non-destructive inspection. A laser Compton scattering (LCS) gamma ray source which is based on the backward Compton scattering of laser light on high-energy electrons can generate energy variable quasi-monochromatic gamma ray. Due to the principle of the LCS gamma ray, the direction of the gamma beam is limited to the direction of the high-energy electrons. Then the target object is placed on the beam axis, and is usually moved if spatial scanning is required. In this work, we proposed an electron beam transport system consisting of four bending magnets which can stick the collision point and control the electron beam direction, and a laser system consisting of a spheroidal mirror and a parabolic mirror which can also stick the collision point. Then the collision point can be placed on one focus of the spheroid. Thus gamma ray direction and collision angle between the electron beam and the laser beam can be easily controlled. As the results, travelling direction of the LCS gamma ray can be controlled under the limitation of the beam transport system, energy of the gamma ray can be controlled by controlling incident angle of the colliding beams, and energy spread can be controlled by changing the divergence of the laser beam.

1. Introduction

A tunable quasi-monochromatic gamma-ray is useful not only for fundamental nuclear experiments using gamma quanta, but also industrial and medical applications such as non-destructive imaging or angiography. Especially in such practical applications, reduction of radiation exposure is important. In order to increase the ratio of useful gamma ray to the total gamma ray, the bandwidth of the gamma ray should be narrowed.

A laser Compton scattering (LCS) gamma ray is generated through Compton scattering of laser light on high-energy relativistic electron. The energy of the LCS gamma ray E_γ is given by equation (1) [1].

$$E_\gamma = \frac{\varepsilon_L(1 - \beta \cos \theta_L)}{1 - \beta \cos \theta + \varepsilon_L(1 - \cos(\theta_L - \theta))} \frac{1}{E_e}. \quad (1)$$

Here, ε_L , E_e , β , θ_L , θ , are laser photon energy, electron beam energy, velocity of electron in unit of the speed of light, laser incident angle, and scattered angle of the gamma quanta respectively. The gamma ray energy is tunable by controlling the laser incident angle θ_L even when the laser photon energy ε_L

and the electron beam energy E_e are fixed. In order to obtain a quasi-monochromatic gamma ray, the scattered angle of the gamma quanta θ is limited by using a lead collimator with small cut-off angle θ_{cut} . The cut-off angle is much smaller than 1 mrad in typical. The actual energy distribution of the gamma ray beam after the lead collimator is determined by energy and energy spread of the electron beam and laser photon, the cut-off angle θ_{cut} , and the relative angle between electron and laser beam θ_L including divergence of the electron and laser beam.

The LCS gamma ray is widely used in nuclear physics experiment, but in the field of practical application, the use of the LCS gamma ray is limited to the demonstration. Especially in their application to nuclear resonance fluorescence (NRF) imaging [2], in spite of great potential of the LCS gamma is reported [3], the several demonstrations [3-6] have been just carried out. This is due to relative low flux of gamma ray beam for these experiments. At the LCS photon beam line of electron storage ring TERAS in the National Institute of Advanced Industrial Science and Technology (AIST) or, High Intensity Gamma-Ray Source (HIγS) in Duke University, a photon flux of approximately 10^{5-7} photons/s is obtained. In order to overcome the limit of the existing facilities, Hajima et al. proposed an energy recovery linac base LCS facility, the expected total photon flux is 1.0×10^{13} photons/s and a peak spectral density is 7.0×10^9 photons/s/keV [7]. If such high flux gamma ray facility is developed, practical applications such as scanning of large cargo at harbor, or whole-body angiography for human can be possible.

However, the gamma ray beam scanning method will be required for large target, because the 3D scanning of large target such as international containers whose maximum weight reach to 40 ton with collimated LCS gamma beam is not easy. Thus we have proposed a scheme for direction variable gamma ray generation in the future LCS gamma facility.

2. Basic Design

Direction of the LCS gamma ray can be controlled by changing the travelling direction of electron beam, because gamma quanta is emitted in the direction of electron beam in the rest frame. As the gamma ray flux of the LCS is determined by the luminosity of the electron beam and laser beam, we designed the beam and laser transport such that the collision point is pinned to the home position; red circle in the drawing of the direction variable gamma ray generation scheme shown figure 1.

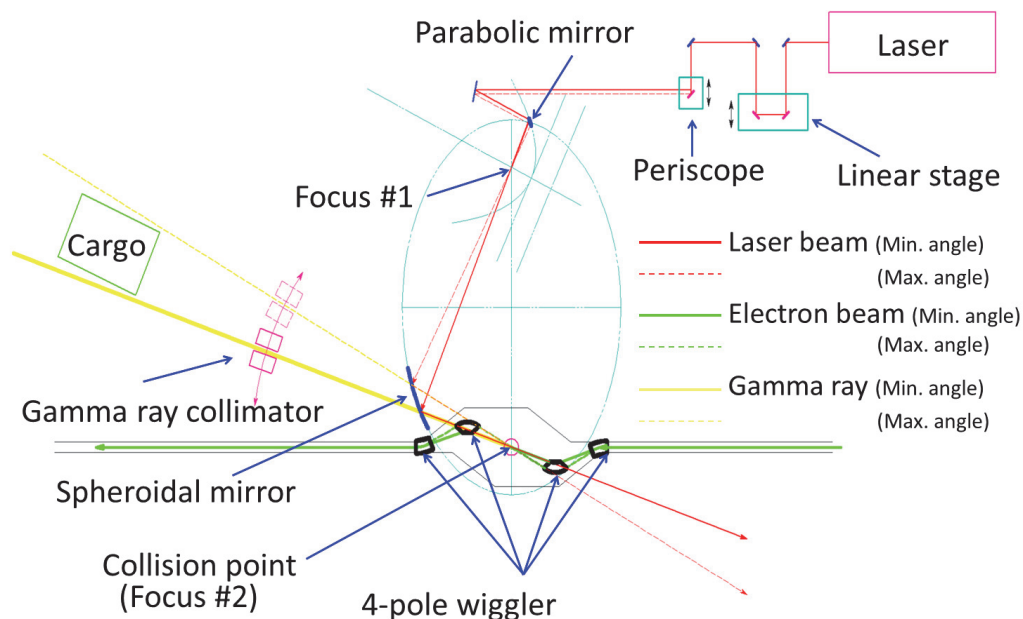


Figure 1. Schematic drawing of the direction variable LCS gamma ray generator. The direction variable range is between minimum angle (solid lines) and maximum angle (dashed lines).

The electron beam transport consists of 4-pole wiggler: combination of four bending magnets and the laser beam transport consists of two aspherical mirrors and several flat mirrors. The parallel laser beam is focused to one focus of a spheroid (Focus #1 in figure 1) by a parabolic mirror and transported to another focus (Focus #2 in figure 1) by a spheroidal mirror. The electron beam trajectory is controlled such that the electron beam is always focused on the collision point. Advantages of this configuration are listed below.

1. Electron beam trajectory is symmetric to the collision point. As the results, complicity of the beam transport is relaxed.
2. Laser beam adjustment can be done at the first focus of the spheroid. As the results, fine adjustment is possible, and focus length compensation from laser oscillator on the first focus can be easily achieved by using linear stages.

Moreover, because the energy of the LCS gamma ray E_γ is given by equation (1), energy of the gamma ray can be tuned by changing relative angle between electron beam and laser beam, and energy spread of the gamma ray can be also controlled by changing divergence of the laser beam. The divergence control is simply achieved by controlling laser beam size injected to the parabolic mirror.

2.1. Laser beam transport

Example of the laser beam transport for a scanning range of 10 degrees is shown in figure 2. In this configuration, maximum bending angles at the 4-pole wiggler are assumed to be about 30 and 60 degrees. If the electron beam energy is 350 MeV [6], the required length of the 4-pole wiggler is about 5 m. Parameters for the parabolic and spheroidal mirrors are listed in Table. 1.

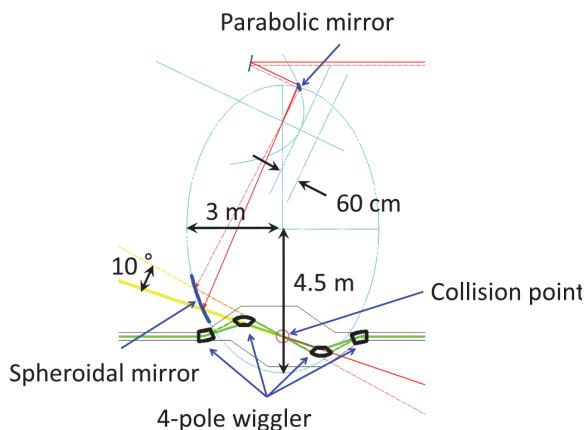


Figure 2. Example of the laser transport.

Table 1. Parameters for aspherical mirros.

Offset Parabolic Mirror	
Focus	60 cm
Mirror diameter	10 cm
Offset Prolate Spheroidal Mirror	
Equatorial radius	300 cm
Polar radius	450 cm
Mirror size	150 × 20 cm

2.2. Electron beam transport

Example of the 4-pole wiggler for scanning range of 10 degrees discussed in section 2.1 is shown in figure 3. In order to fix the collision point of electron and laser, bending angles in dipole magnets should be carefully controlled. In addition, the electron beam size and divergence should be kept as small when the travelling direction of the electron beam is changed. In order to achieve this requirement, combined function bending magnets and multi-pole compensation magnets will be used. For the detailed design, 3D beam tracking simulations will be required.

In order to install the direction variable Compton scattering beam line to an ERL, the total orbital length should be maintained for phase matching when the electron beam angle is changed. The orbital length compensation can be realized using additional 4-pole wiggler as shown in figure 4.

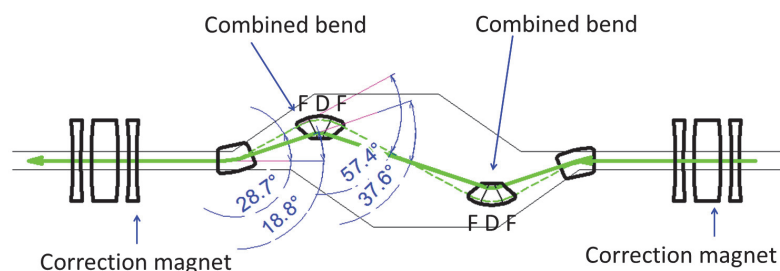


Figure 3. Example of configuration of 4-pole wiggler and correction magnets.



Figure 4. Scheme for compensation of orbital length

3. Summary

Ultra high flux gamma ray generator based on energy recovery linac is proposed as the next generation gamma ray source for practical applications not only for fundamental physics. For such high flux gamma ray source, gamma ray scanning method will be important for such as scanning of large cargo at harbor, or whole-body angiography for human, etc. Thus, we have proposed a direction variable LCS gamma ray generation generator which consists of 4-pole wiggler and aspherical mirrors. This scheme will provide direction, energy, and energy spread tunability to the LCS gamma ray. By adopting this scheme, simple laser beam transport can be used, but the complicity of the electron beam transport remains. In order to make detailed design for the system, 3D beam tracking in the combined function bending magnets, and multi-pole compensation magnets will be required.

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