ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUPJE021

INTERACTION CHAMBER DESIGN FOR A SUB-MeV LASER-COMPTON GAMMA-RAY SOURCE

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Abstract

Previously, fixed angle Laser-Compton Scattering (LCS) experiments have been conducted at the terminal of the 100MeV LINAC of the Shanghai Institute of Applied Physics, using SINAP-I [1] and SINAP-II [2] facility. Sub-MeV energy continuously tunable laser-Compton light source device (SINAP-Ⅲ) is an updated facility that will allow the collision angle between the laser and electron beam continuously adjustable from 20° to 160°. This new feature will enable convenient control on the peak energy of the generated X/γ ray, especially when the energy of electrons cannot be momentarily adjusted, e.g. on the storage ring.

Keeping the electron beam and laser beam waist coincident at arbitrary angle is crucial for LCS gamma-ray production, an interaction chamber containing a rotatable bracket that holds a series of plane mirrors and convex lens is presented. This work is a summary of its design.

The simulation of photon production's variation caused by the system errors is performed using a MC code [3]. The accuracies of installation and adjustment of mirrors and lens are given according to the simulation results. The sizes of these optical devices are also optimized to make the chamber as compact as possible due to space limitation.

INTRODUCTION

In the past ten years, with the development of advanced accelerator and laser technology, the new X / γ-ray source based on Compton scattering obtain a rapid development and was rated as one of the most potential in the field of ultra- short pulse light sources. It uses high-power short-pulse laser beam with high brightness relativistic electron beam interaction, Compton scattering to produce high flux, short-pulse, quasi-monochromatic X/γ-rays. Currently, many research institutions such as LLNL [4], BNL [5], SLAC, IAC, MIT, Spring8, JAEA, INFN and ESRF are committed to the construction of the experimental device of LCS. The peak energy of produced X/γ-rays have wide applications in nuclear physics, medicine, energy, defence and industrial applications. The peak energy of the scattered X/γ-ray photon [2] is

$$E_x = E_L \frac{(1-\beta\cos\theta_L)}{1-\beta+\frac{E_L}{E_e}(1-\cos\theta_L)}$$

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Where β is the electron velocity normalized to the speed of light, E_e and E_L are the energies of the incident electron and laser photon, and θ_L is the incident angle of the laser photon with respect to the direction of the incident electron beam. Traditionally, this value can only be varied by changing E_e (electron's energy) or E_L (the wave length of laser), which is inconvenient.

SINAP-III facility [6] is a sub-MeV gamma-ray source based on Laser Compton scattering. It is constructed on the branch line of SDUV-FEL [7]. The electrons and laser are both imported from the principle line into an interaction chamber. A specially designed laser transport system enables θ_L to be continuously changed from 20° to 160°, scattered photon energy E_x is thus continuously adjustable easily without changing E_e, E_L.

In this paper, we present the optical design of the interaction chamber and the study on the tolerance of mirrors.

LASER TRANSPORT SYSTEM

To achieve the continuously adjustability of the colliding angle of the electron beam and laser beam, a rotatable structure is designed.

Basic Structure

As shown in Fig.1, laser beam would propagate along the path from mirror No.6 to mirror No.0. The green lines in Fig. 1 is the maximum envelope of laser beam that these Optical elements' apertures can hold.

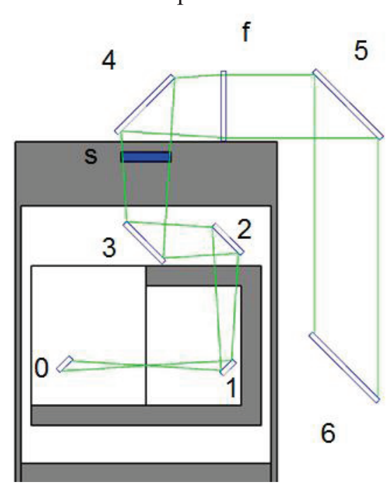

Figure 1: Basic optical structure (side view). The rectangles with number 0-6 represent plane mirrors, the rectangle referring to "f" is a convex lens, and the one with "s" is a transparent glass which covers the chamber.

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Mirror No. 4-6 and convex lens are placed in the atmosphere, while mirror No. 0-3 are set inside the vacuum chamber on the "C" like bracket. Laser beam is expected to be focused at the centre of mirror No.1 and mirror No.0, colliding with electron bunches that come across the chamber through bellows, and the produced X / γ-rays will come outside, along with the electron beam's incident direction.

A 3D view of the designed rotatable bracket holding mirror No.0-3 is shown in Fig.2 (a).

Additional Structures

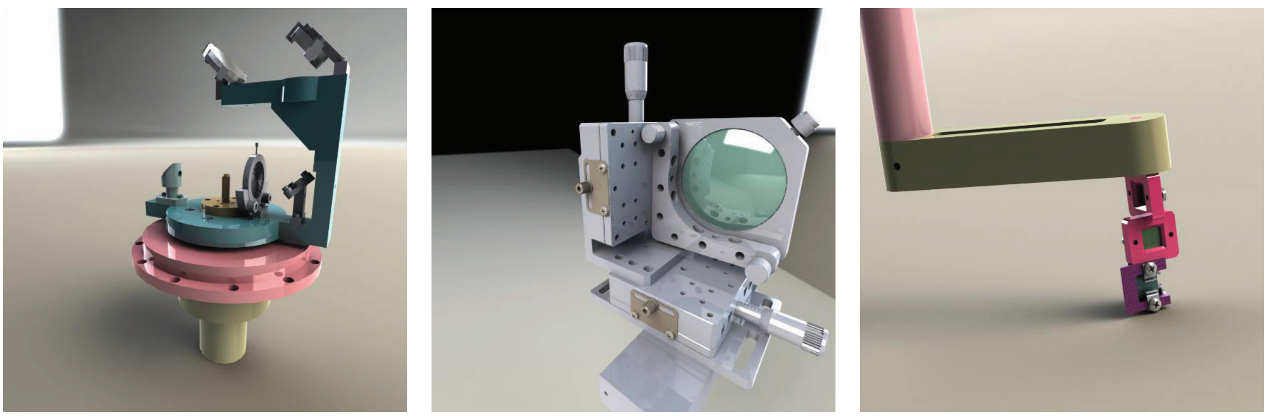
In order to control waist position, we set up several remote control devices and observation devices on the basic optical path.

A two dimensional frame combined with a linear stage shown in Fig.2 (b) is designed to hold and adjust the convex lens. This device can make translation of the lens's position.

Another similar device is set up for mirror No. 4, but the linear stage is replaced with a piezoelectric ceramic driven flexible micro positioning platform, which can make careful adjustment of the orientation of mirror No. 4.

The colliding point will be observed and measured by inserting fluorescent target. The target will be fixed on a lifting bracket, as shown in Fig.2 (c). Both the spot of laser and fluorescence caused by electron bunches will be shot through the observation windows by cameras, offering feedback to the remote control devices.

These three devices are expected to work together to make fine adjustment of the laser focus point after the coarse adjustment manually.



(a) (b) (c)

Figure 2: (a) Effect diagram of the rotatable bracket holding mirror No 0-3. (b) Translation device of convex. (c) Lifting bracket for fluorescent target.

TOLERANCE STUDY OF MIRRORS

Next, in order to specify the accuracies of installation and adjustment of mirrors and lens, the simulation of photon production's variation caused by the system errors is performed using a MC code.

The main parameter used in simulation is listed in Table 1.

Table 1: Simulation Parameters

Electron in Linear accelerator	
Electron energy (MeV)	150
Energy spread	(%)0.1
Normalized emittance (mm•mrad)	6
Bunch length (rms) (σ_{le}) (mm)	0.72
RMS beamsize (σ_{we}/σ_{he}) (μm)	20/20
Ti:Sa laser	
Laser wavelength (nm)	800
Energy/pulse (mJ)	1.75
Repetition rate (Hz)	1000
Pulse length (rms) (σ_{lp})	1ps
RMS beamsize (σ_{wp}/σ_{hp}) (μm)	20/20
Incident angle (°)	20-160

Optimization of Mirrors' Sizes and Positions

To decide the mirrors' tolerance, the size and position of mirrors which is constrained by the waist radius of laser have to be obtained first.

The flux of gamma-ray is simulated with the laser beam radius set from 5 to 320 and the incident angle set from 20° to 160°, as shown in Fig.3. We can see that the waist radius of laser reaches 2 times of the radius of the electron beam when gamma-ray's flux is decreased by half. So the max laser waist should be less than 40μm to achieve an acceptable flux.

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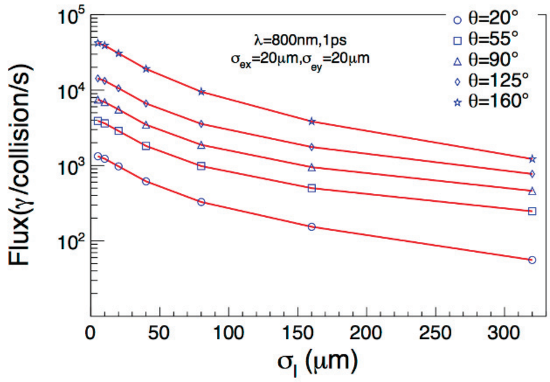

Figure 3: Flux of gamma ray changed caused by waist radius.

Then, we perform an optimization on the mirror size and position using the laser waist radius. When the laser waist radius is fixed, the mirror size is mainly affected by its position. As shown in Fig.1, the laser's envelop grow rapidly as the mirror moves away from the waist of laser. The mirror size is optimized to be as small as possible to avoid the disadvantage caused by larger mirror size, e.g. bending, unevenness, larger space cost which means an ion pump of greater pumping speed need to be applied. The results are collected in Table 2.

Table 2: Optimized Mirrors' Size and Positions

Mirror's No	Thickness /mm	Radius /mm	Horizontal distance from the centre of laser waist /mm	Vertical distance from the centre of laser waist /mm
1	5	18	80	0.0
2	5	40	80	125.0
3	5	55	0	125.0
4	10	80	0	290.0
5	10	95	240	290
6	10	95	240	150
0	5	18	-80	0
f	6	70	80	290
s	10	63	0	200

In order to leave room for laser adjustment, we use the laser radius of 20μm as input.

Tolerance of Mirrors' Installation and Adjustment

The deviation of waist position of laser beam from the best interacting point is also analysed. The drop of gamma-ray flux caused by deviation in horizontal direction is shown in Fig 4.

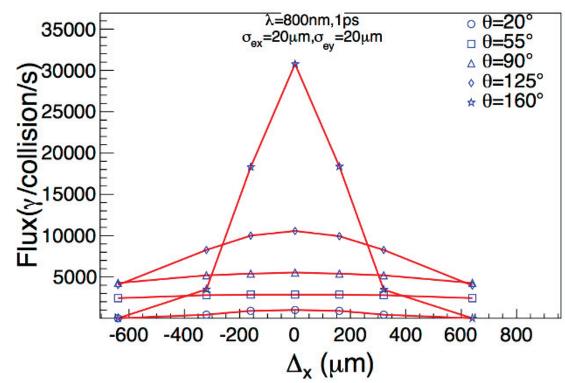

Figure 4: Flux change of gamma ray caused by Δx.

Similar to the requirement of waist radius, the half decrease is set as the threshold, we obtain the allowed waist position deviation (shown in Table 3), which are exactly the upper limits of the cumulative errors of installation and adjustment of mirrors and lens.

Table 3: Allowed Waist Position Deviations

Δx (μm)	200
Δy (μm)	30
Δz (μm)	800

Δx, Δy, Δz are referring to deviation of the waist position in horizontal, vertical and laser propagation directions respectively, as shown in Fig.5.

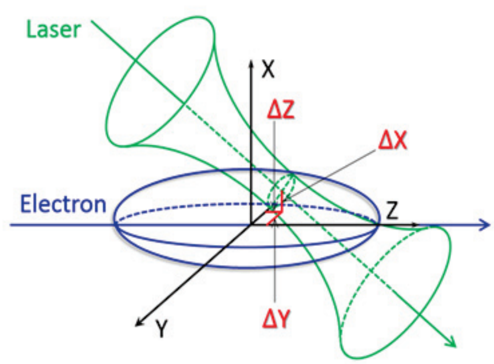

Figure 5: schematic diagram showing the deviation of laser waist centre from the centre of electron bunch.

CONCLUSION

In this paper, we present a design of an interaction chamber to achieve continuously adjustment of the angle between the electron beam and laser beam in laser Compton scattering. This feature will enable convenient control on the peak energy of the generated X/γ ray, especially when the energy of electrons cannot be momentarily adjusted, e.g. on the storage ring.

The simulation of photon production's variation caused by the change of laser waist radius and position is performed using a MC code, giving a feasible

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requirement on the tolerance of mirrors' installation and adjustment.

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