

1.8 KEV COMPTON X-RAY SOURCE DRIVEN BY SC LINAC AT KAERI

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Abstract

A quasi-monochromatic X-rays source based on a KAERI SC linac system has been designed and is being manufactured now. 10 MeV 10 mA electron beam together with 20 W 1.06 μm laser beam will be used for 1.8 keV Compton X-ray generation with a few percentage of energy spread and 10^7 photons per second flux. A simple straight beamline was designed to deliver the electron beam with no degradation of its emittance and energy spread and to focus it to a proper size to produce the desired X-rays. We expect the first demonstration of 1.8 keV Compton X-ray generation in autumn, 2006.

INTRODUCTION

Being scattered on a relativistic electron, a photon gains high energy ($E=4\gamma^2 h\nu$, where γ is the relativistic factor of the electron) as a result of Compton effect [1]. This effect can be used in a monochromatic X-ray source based on an electron accelerator. A prototype of this source considered in the paper will be installed at KAERI on a superconducting linac.

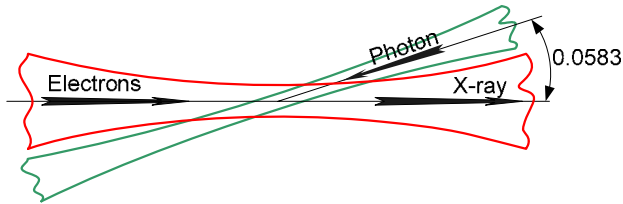


Figure 1: Interaction point of Compton backscattering X-ray source.

X-ray photons are born in the interaction point fig. 1, where electrons and laser beam collide at a small angle. The angle between the beams is necessary to separate the generated X-ray and the laser beam.

The source will be driven by a superconducting (SC) linac with the following electron beam parameters:

- bunch duration: 100 ps;
- number of electrons per bunch: 10^{10} ;
- electron energy (full): 10 MeV;

- repetition rate: 5.6 MHz;
- emittance: $2\pi \text{ mm}\cdot\text{mrad}$;
- energy spread (relative): $6\cdot 10^{-3}$.

The parameters of the laser to be used in the source are expected the following:

- wavelength: 1.06 μm ;
- average laser power: 20 W;
- laser pulse repetition rate: 88 MHz;
- pulse duration: 100 ps..

NUMERICAL SIMULATION OF SOURCES PARAMETERS

Most important calculated parameters of the source, the number of photons from a bunch and the energy spread, are presented in fig. 2 and 3 respectively. Both the transverse and longitudinal structures of the bunch were taken into account.

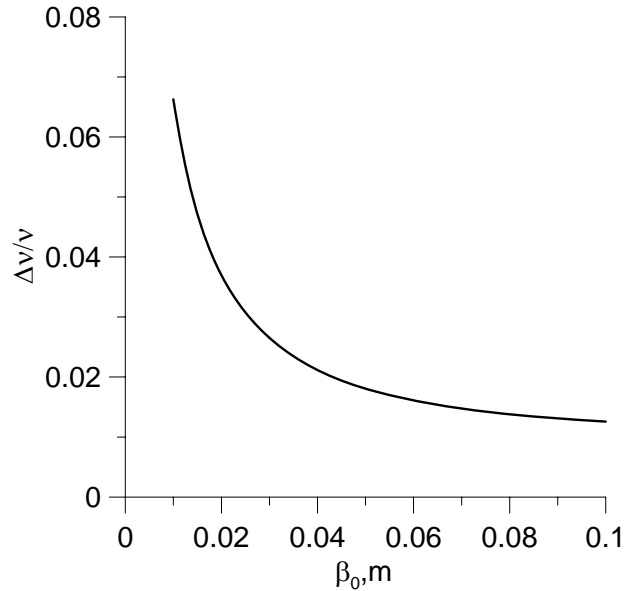


Figure 2: Relative energy spread vs. β -function at the interaction point.

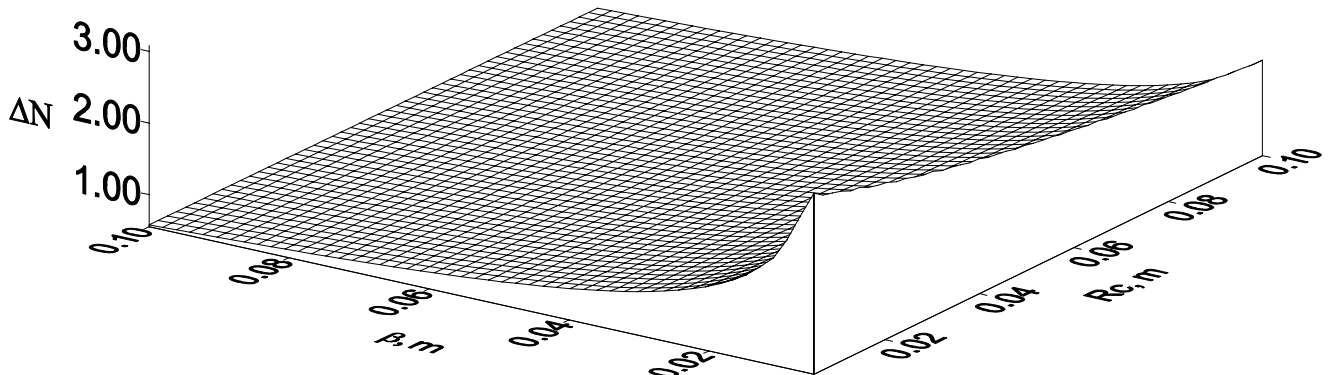


Figure 3: Number of X-ray photons ΔN per bunch vs. β -function and Rayleigh range R_c in interaction point.

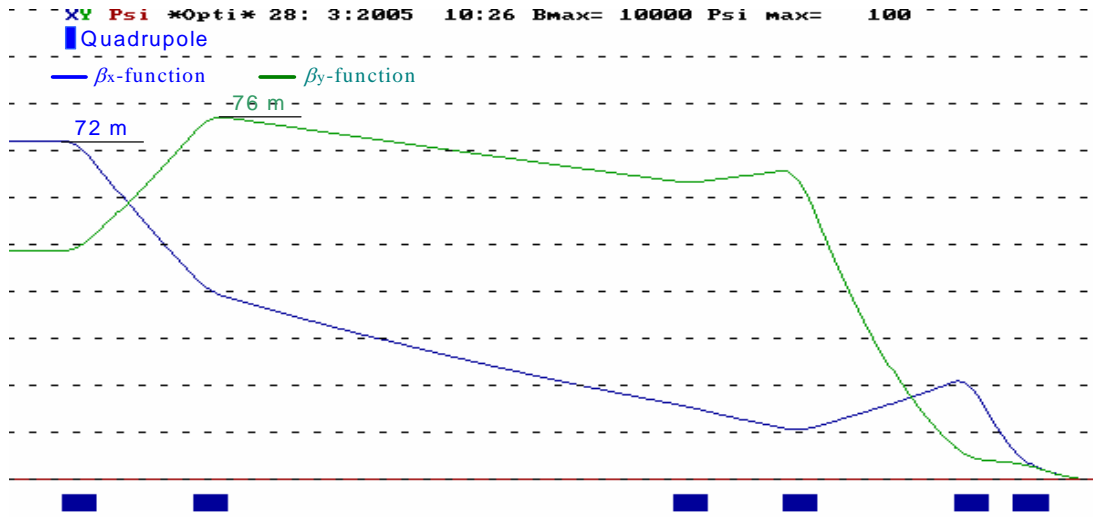


Figure 4: Lattice functions of the electron beamline for the Compton backscattering source.

Note that the energy spread almost doesn't depend on the Rayleigh range R_c , as the scattered photon energy nearly is not affected by the angle of collision. As it is clear from fig. 3, the flux also nearly doesn't depend on the Rayleigh range. In our case, ε (emittance) is much larger than $\lambda/4\pi$ (wavelength), so that the electron beam size $\sqrt{\beta\varepsilon}$, where β is the betatron function, is larger than the laser beam one $\sqrt{R_c\lambda/4\pi}$ within a wide range of R_c . Thus, the laser beam ever encounters the densest central part of the electron one.

The β -function at the interaction point is to be controlled from 15 to 100 mm. It is a trade-off between the higher flux and the lower energy spread. In this case the average flux will be $9.5 \dots 3.1 \cdot 10^6 \text{ s}^{-1}$, while the relative energy spread of X-ray photons will be $0.045 \dots 0.013$. The brilliance can be estimated from these two values. The average brilliance will be $\approx 5.5 \cdot 10^3 \text{ 1/(s}\cdot\text{mm}^2\cdot\text{mrad}^2\cdot 0.1\% \text{ bandwidth)}$, and almost

independent on the β -function. The peak brilliance will be $\approx 10^7 \text{ 1/(s}\cdot\text{mm}^2\cdot\text{mrad}^2\cdot 0.1\% \text{ bandwidth)}$.

ELECTRON OPTICS

The β -function at the exit of the SC linac is large enough ($\beta_x \approx 72 \text{ m}$, $\beta_y \approx 49 \text{ m}$) while about three orders smaller at the interaction point, so comparably strong focusing is to be applied in the beamline. First of all, the beamline was simulated with OPTI code based on the linear transverse single-particle dynamics model. The lattice functions of the optimized beamline until the interaction point are presented in fig. 4. The beamline contains six quadrupole lenses to distribute the total strength between them and decrease emittance dilution due to aberrations. Relative emittance growth in the beamline due to spherical aberration is

$$\frac{\sqrt{\Delta\varepsilon^2}}{\varepsilon} \approx 0.3 \dots 0.4,$$

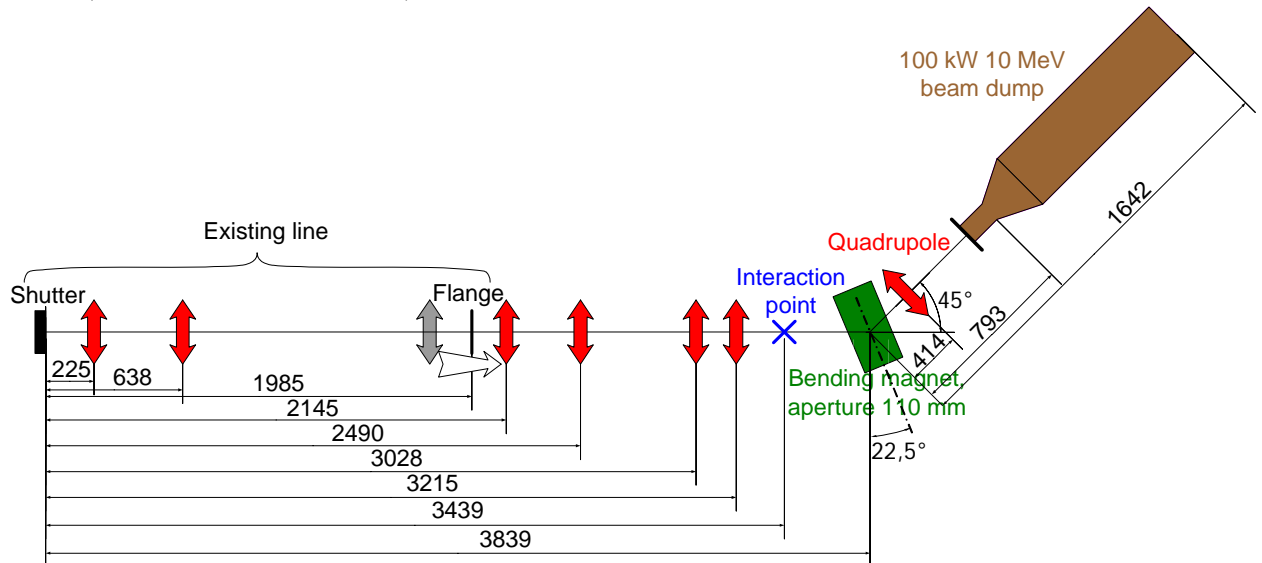


Figure 5: The layout of the electron beamline for the Compton backscattering source.

while due to chromatic aberration is

$$\frac{\sqrt{\Delta \epsilon^2}}{\epsilon} \approx 0.5 \dots 0.6 .$$

Space charge effect is to be taken into account here as the second (phase) criterion [2] (3) is not fulfilled

$$\int_L \sqrt{\frac{I}{I_0(\beta\gamma)^3}} \frac{1}{(x+y)(x-y)} dz \sim 0.25 ,$$

that is comparable with 1. So the results were checked with I&Eps code [2] with space charge effect. It was found that it is possible to obtain the declared state of the beam at the interaction point, although with little differing gradients in quadrupoles. This code was also used to conduct the exhausted beam to the beam dump without loss. Finally the layout of the beamline was chosen as in fig 5.

SUMMARY

Thus, the beamline for the Compton X-ray generator was designed taking into account all the significant effects. The prototype commissioning is expected in October 2006. Future upgrades include matching the repetition rates of the laser and electron bunches, increasing the laser beam power, the electron bunches repetition rate, and the electron energy. These upgrades will improve the flux, the energy and the brilliance (both average and peak) of X-ray by several orders.

REFERENCES

- [1] B.T.Price, C.C.Horton, K.T.Spinney. Radiation shielding. Pergamon press, 1957.
- [2] S.V.Miginsky An optimizer for high-current beamlines, NIM. **A 558** (2006) 127-130.