GENERATION OF SOFT X-RAY RADIATION USING THOMSON SCATTERING OF COHERENT DIFFRACTION RADIATION BY A SHORT ELECTRON BUNCH

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Abstract

The processes of generation of coherent diffraction radiation (CDR) by a short electron bunch of 45-MeV electron accelerator and its Thomson scattering on one of the subsequent bunches have been simulated. Backward CDR is emitted when electron bunch with population N_e and length σ passes in the vicinity of a conducting target along the direction of specular reflection. In the wavelength region $\lambda \geq \pi\sigma$ all electrons in a bunch emit coherently and CDR intensity becomes proportional to the square of a bunch population N_e.

In order to increase concentration of CDR in the interaction point we propose to use two semi-paraboloidal targets for generation of stimulated forward and backward CDR and its focusing.

We simulated CDR spectral-angular distribution in the interaction point and showed that maximal overlapping of CDR pulse and subsequent electron bunch may be achieved for double focal distance between concave targets coinciding with distance between bunches. In this case one may obtain hard radiation in forward direction for the photon energy range $\hbar\omega \sim 8\gamma^2 \frac{\hbar c}{\sigma}$ due to Thomson scattering with an yield of hard photons proportional to N_e^3. The efficiency of considered schemes for obtaining of THz radiation and soft X-ray radiation ($\hbar\omega \sim 10 \div 100\, eV$) with duration $\frac{\sigma}{c} \leq 1\, ps$ is estimated.

INTRODUCTION

Compact, high-brightness and reliable sources in the VUV and the soft X-ray region may be used for numerous applications (see, for instance, [1]). We propose a new approach to produce an intensive beam of X-rays in the range $\leq 500\, eV$ based on use of the compact electron accelerator. Backscattering of an intense laser pulse with a relativistic electron beam allows to obtain bright short X-ray radiation pulse [2]. However, effective overlapping of the laser and accelerator bunches is a rather complicated task while linear dependence of the resulting X-ray yield on the number of electrons in a bunch poses natural restrictions on the intensity of the scattered photons. If a beam of incident photons is to be generated by one of the preceding short electron bunches via diffraction radiation mechanism, then the temporal and longitudinal structure of the colliding bunches will be the same. On the other hand an intensity of scattered photons will increase nonlinearly with the rise of bunch population N_e [3,4].

EXPERIMENTAL LAYOUT AND GENERATION OF CDR

Fig 1. shows the scheme of experiment that will be carried out on the small electron accelerator at KEK-ATF with following parameters. (Table 1):

Table 1: Parameters of beam source test-bench for KEK-ATF.

Energy	43MeV
Intensity	2nC/bunch
Number of Bunches	100 bunches/train
Bunch spacing	2.8ns
Bunch length	1ps
Repetition Rate	12.5Hz
Beam size at the collision point(rms), (x,y)	64um, 32um
Emittance	20 pi mm mrad

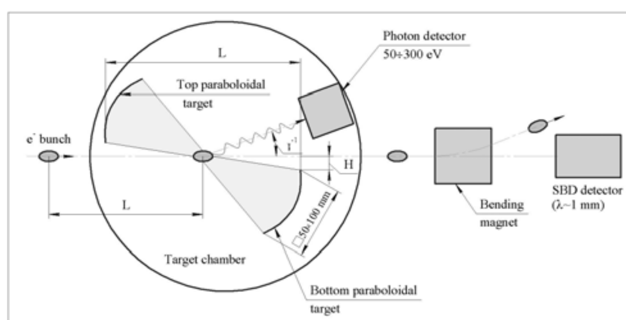

Figure 1: Experimental scheme.

Electron bunches pass in the vicinity of two semi-parabolic DR targets (top and bottom ones) to produce forward and backward CDR which may be considered as an open resonator. The distance between two subsequent bunches is 2.8 ns (840 mm), so the resonator length L should be chosen to be just around this value. In this case the interaction point is placed between DR targets (in other words, in the focus of target, $P = 420\, mm$). This geometry may provide, firstly, focusing of CDR in the interaction point [5], and, secondly, the increasing of

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CDR intensity in the interaction point due to the process of stimulated CDR. A similar scheme was investigated in experiment [6] where stimulated process of coherent transition radiation from two flat targets was detected with enhancement of more than 1 order of magnitude relative to spontaneous coherent transition radiation process.

X-ray yield will be measured at the angle $\theta = \gamma^{-1}$ and CDR yield at forward direction by Shottky barrier diode.

The transversal distribution of backward DR (BDR) generated by an electron with $\gamma = 90$ passing near bottom target with impact parameter $H = 1mm$ in the interaction point is shown on figure 2a,b for two wavelengths.

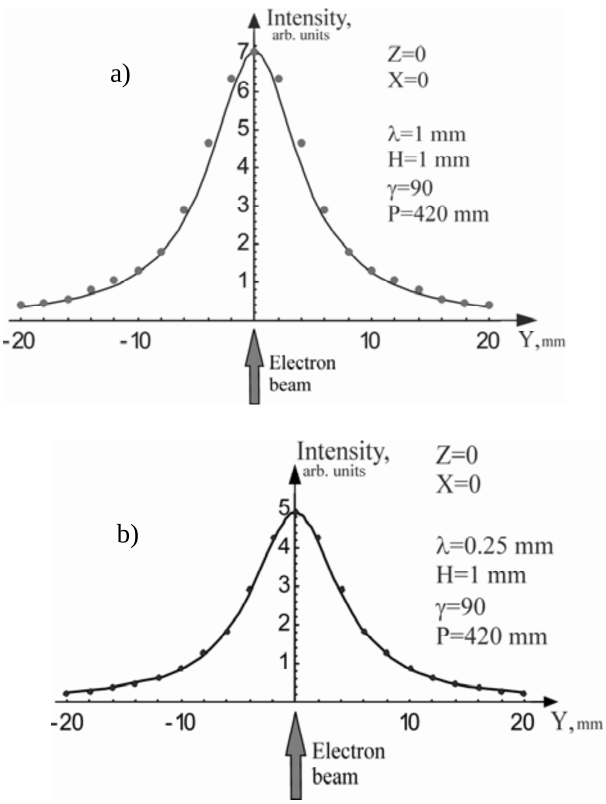

Figure 2: Distribution of DR in a vertical plane. Points – focused DR from a concave target, solid line – “far-field model” for a flat target, fig.2a– $\lambda = 1mm$, fig.2b– $\lambda = 0.25mm$.

Figure 3 shows distribution of backward DR on surface of the top target where the consequent bunch generates forward DR beam.

In the latter case one may see that BDR beam with $\lambda = 0.25\ mm$ propagates just at the angle $\theta \sim {y_M}/{L} = \gamma^{-1} \sim 1/90$ relative to the electron beam. It means that a beam, reflected from the top target may be considered as “slow wave” and it may lead to an effective stimulation of FDR process from the subsequent bunch.

One may expect that the train of bunches consisting of 100 bunches may provide a gain much higher than one order of magnitude.

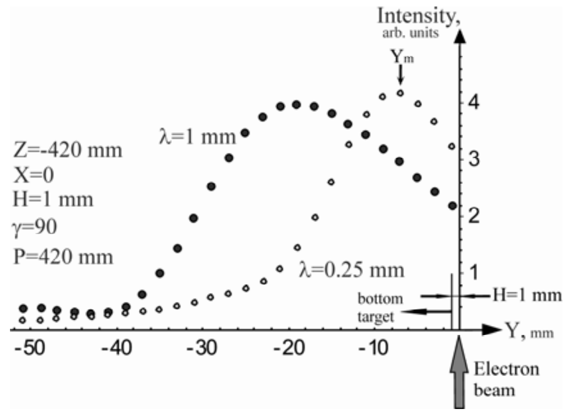

Figure 3: Distribution of DR in a vertical on a surface of the top target.

SPECTRA OF CDR AND SOFT X-RAY BEAMS.

The spectrum of incoherent BDR in the interaction point from an electron with $\gamma = 90$ passing near the target at impact parameter of $H = 1mm$ is presented in Figure 4.

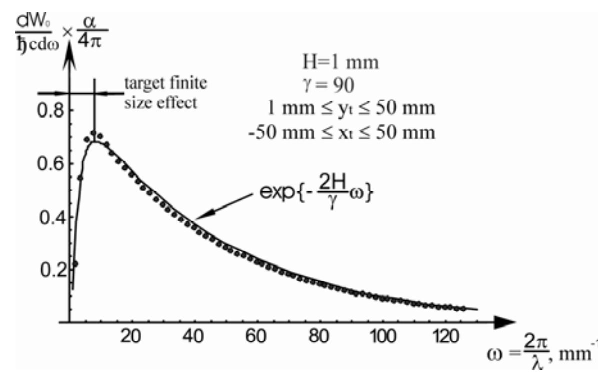

Figure 4: Spectrum of incoherent DR in the interaction point.

Calculations were performed according to the model [5] where Coulomb field of relativistic particle is replaced by a set of real electromagnetic waves. The suppression in the soft part of the spectrum is defined by finite size of concave target. Spectra of coherent BDR from the bunch with population of $N_e = 10^{10}\, e^-/bunch$ are shown in Fig. 5 for different bunch lengths, σ, (the longitudinal shape of bunch was approximated by Gaussian $f(z) \sim \exp(-z^2/\sigma^2)$). The spectra are presented for a single electron in a bunch.

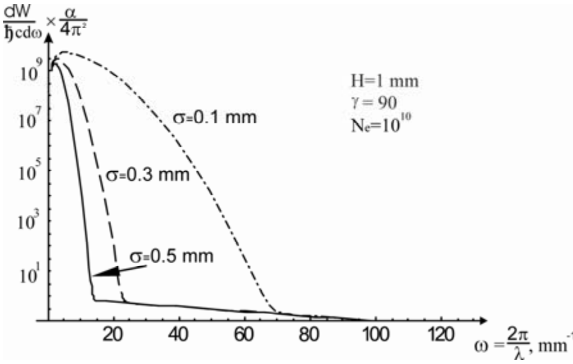

Figure 5: Spectrum of coherent DR in the interaction point.

After integration over CDR spectrum one may calculate an intensity of CDR. For instance, the energy emitted into a solid angle $\Delta\Omega = \pi\gamma^{-2}$ from bunch with $N_e = 10^{10}\, e^{-}/_{bunch}$ and $\sigma = 0.3\,mm$ (see Fig.5) is equal to $\sim 10^{13}\, eV \sim 1\mu J$.

It may be noted that authors of experiment [7] had measured the yield of coherent transition radiation from modulated 73 MeV and 20 ps bunch at the level $\sim 1.5\, pJ$.

The yield of hard photons scattered by a counter propagating electron bunch may be estimated using the model [3]:

$$N_{sc} = N_e N_{ph}^0 \frac{8/_3 \pi r_0^2}{2\pi (r_e^2 + r_{ph}^2)} \qquad (1)$$

Here N_{ph}^0 is a total number of CDR photons, generated by a preceding bunch which is proportional to N_e^2; $8/_3 \pi r_0^2$ is the Thomson cross-section ($r_0 = 2.82\cdot 10^{-13} cm$); r_e and r_{ph} are the radii of electron bunch and photon beam correspondingly. From estimation (1) one may see a cubic dependence of the scattered photon yield on the bunch population.

The spectral-angular distribution of scattered photons per each bunch may be evaluated from the same model including the spectrum of CDR (see Fig.5) into consideration and taking into account the dependence of scattered photon energy ε_γ on the emission angle θ_γ :

$$\varepsilon_\gamma = \hbar c \omega \frac{4\gamma^2}{1 + (\gamma\theta)^2} \qquad (2)$$

For the simplest geometry ($\theta = 0$, backscattering case) it is possible to obtain the resulting formula allowing to estimate the number of photons per bunch per steradian per eV:

$$\frac{dN}{d\varepsilon_\gamma d\Omega} = \frac{\alpha}{2\pi^2} N_e^3 \gamma^2 \frac{r_0^2}{r_{ph}^2} f(\varepsilon_\gamma, \sigma) \frac{\exp(-\frac{\varepsilon_\gamma}{\varepsilon_{ch}})}{\varepsilon_\gamma} \qquad (3)$$

$\alpha = 1/_{137}$, r_{ph} is the radius of photon beam in the interaction point ($r_{ph} = 4.5\,mm$ for our case, see Fig. 2a,b), $f(\varepsilon_\gamma, \sigma) = \exp[-\frac{1}{8}\left(\frac{\sigma\varepsilon_\gamma}{\gamma\hbar c}\right)^2]$, $\varepsilon_{ch} = 4\gamma^2 \frac{\gamma h c}{2H}$, $\hbar c = 0.2\ eV\cdot\mu$ is the conversion constant.

The spectral distribution (3) for angles $\theta = 0$ and $\theta = \gamma^{-1}$ are presented at Figure 6.

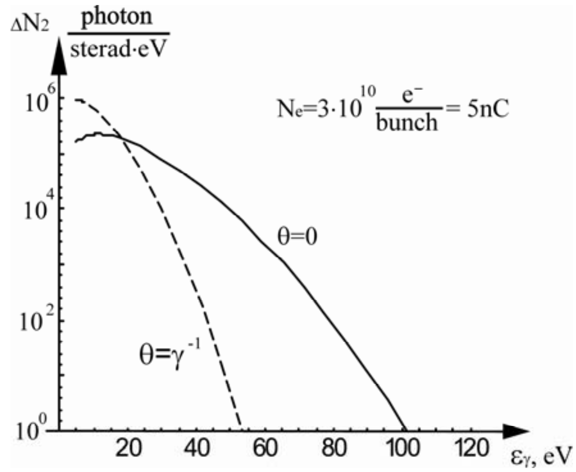

Figure 6: Photon spectrum per bunch for scattering angle $\theta = 0$ (solid line) and $\theta = \gamma^{-1}$ (dashed line).

CONCLUSION

Estimations (1) and (3) have been evaluated for a spontaneous process of CDR. One may expect that due to stimulated CDR in the "opened resonator" the "concentration" of CDR photons in the interaction point will be defined not only by a bunch population but by a number of bunches in a train also. Another possibility to increase the intensity of scattered photons is connected with using of DR targets with sizes much larger than $\gamma\lambda$. We plan to carry out a proof-of-principle experiment to observe the focusing of optical DR at the KEK-ATF extraction line using the electron beam with $\gamma = 2500$ in the nearest future.

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