COMPARISON OF COHERENT SMITH-PURCELL RADIATION
AND COHERENT TRANSITION RADIATION

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Abstract

Smith-Purcell radiation and Transition Radiation are two radiative phenomenon that occur in charged particles accelerators. For both the emission can be significantly enhanced with sufficiently short pulses and both can be used to measure the form factor of the pulse. We compare the yield of these phenomenon in different configurations and look at their application as bunch length monitors, including background filtering and rejection. We apply these calculations to the specific case of the CLIO Free Electron laser.

INTRODUCTION

Coherent Transition Radiation (CTR)

When a relativistic charged particle crosses the interface between two media of different dielectric properties, transition radiation (TR) is emitted. This process was calculated analytically by Ginzburg and Frank [1].

\[ \frac{d^2 I_{GF}}{d\omega d\Theta} = \frac{q_0^2}{4\pi\epsilon_0 c} \frac{\beta^2 \sin^2 \Theta}{(1 - \beta^2 \cos^2 \Theta)^2}, \]

where \( q_0 \) is electron charge, \( \epsilon_0 \) – vacuum permittivity, \( c \) is the speed of light, \( \beta \) is relativistic velocity and \( \Theta \) is the observation angle.

We use their formula with virtual-quanta method to compute the backward TR from a finite screen [2].

\[ \frac{d^2 I_{disk}}{d\omega d\Theta} = \frac{d^2 I_{GF}}{d\omega d\Theta} [1 - T(\gamma, \omega, \Theta)]^2 \]

where \( T \) is correction term to finite size of the screen. This gives the single electron yield (SEY). From the SEY the whole spectrum can be derived using the following formula:

\[ \frac{dI}{d\Omega} = \frac{2\pi e}{Z} n^2 \beta^3 (1 - \beta \cos \Theta)^3 R^2 \]

where \( Z \) is the grating length, \( e \) is the electron charge and \( R^2 \) is the grating efficiency factor.

Comparison

Single Electron Yield

Calculation of the SEY for SP and TR are presented on figure [1]. The screen used in this case for TR is a metallic disk with radius 20 mm and the grating for SP has a length of 180 mm and a width of 40 mm with a pitch of 8 mm and a 30 degrees blaze angle. The beam-grating distance from center of the beam to the top of the teeth) is 3 mm. The lorentz factor \( \gamma \) for both cases is 118 (60.3 MeV). The other parameters were taken from the CLIO accelerator simulation in ASTRA reported in [3].

The SEY spatial energy distribution for SP and TR are also significantly different.
Coherent Radiation

The calculation of coherent radiation was done with the same parameters than for the SEY. For others grating this distribution would be different, but this gives us an approximate space distribution of the CSPR. From these simulations, we can conclude that most of the radiation is confined in approximately ±6° in azimuthal (ϕ) angle. So a standard 50 mm parabolic mirror at a distance of 300 mm from the grating will collect most of the radiation.

To choose the most appropriate grating pitch, one should use the condition given in equation 4. For maximum emission at 90 deg. the formula is applicable.

\[
l = \frac{2\pi c}{2\sqrt{2}\ln(2)} p_t \approx 8 \times 10^8 p_t
\]

where l is grating pitch in meters and \(p_t\) is the bunch FWHM in seconds.

The relation between the the grating pitch, the pulse length and the angle of maximum emission is given on figure 4. We can see that the green band (90° emission) follows the rule given in equation 6. We can also look at the total energy emitted by the grating as a function of the pulse length and the grating energy. This is shown on figure 5. On this figure the transition between the coherent and incoherent regime can clearly be seen.

In the case of CSPR as the pulse length change the angular distribution of the energy will also change. This is shown on figure 6. Same dependence for CTR is shown on figure 7.

Using the bunch profile predicted for the CLIO Free Electron Laser [5], as shown on figure 8 we can predict the spectrum for both CSPR and CTR as shown on figure 9. We can see that the intensity of the CTR signal is lower, but it is concentrated in a small solid angle. For CSPR the signal intensity depends on the beam-grating separation.
CONCLUSION

We have studied both CSPR and CTR and studied how to optimize the experimental parameters. Using the CLIO parameters we expect a signal (in the range 0.03-3 THz (0.1 - 10 mm)) of $8.37 \times 10^{-7}$ J for CSPR and $7.35 \times 10^{-8}$ J for CTR.

REFERENCES

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Figure 5: Total energy for SP effect presented as function of pulselength and grating pitch. Grating is $40 \times 180$ mm$^2$ with 30$^\circ$ blaze angle.

Figure 6: Evolution of the CSPR spectrum with a constant grating pitch and a wavelength changing with the angle. The grating dimensions are $40 \times 180$ mm$^2$ with 8 mm pitch and 30$^\circ$ blaze angle.

Figure 7: Evolution of CTR spectrum with changing wavelength. The screen has a diameter of 40 mm.

Figure 8: Profile of the bunch at the exit of the CLIO accelerating section (see [5]).

Figure 9: CSPR and CTR energy density as function of wavelength. The CSPR spectrum is presented for beam-grating separations of 3 mm, 6 mm and 9 mm. The grating dimensions are $40 \times 180$ mm$^2$ with 8 mm pitch and 30$^\circ$ blaze angle. The screen diameter for TR is 40 mm. The signal is measured as integrated with a 50 mm diameter parabolic mirror located 300 mm from the beam axis.
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