ELECTRO-OPTIC SAMPLING METHOD USING HIGH DC VOLTAGE APPLYING SETUP*

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Abstract

A RF photo-cathode (RF PC) gun with 1.6 cell cavity is installed at GTS(Gun Test Stand) being built at the Pohang Accelerator Laboratory (PAL). The short, intense, and low emittance electron beams are produced by the RF PC gun. For the successful construction of PAL-XFEL, the timing jitter and bunch length of the beam at the exit of the gun should be measured accurately. EOS (Electro-Optic Sampling) is a very promising method to measure the jitter without any interference with the electron beam. The spatially resolved method will be used in this experiment, which is a single shot measurement using cooled CCD carmera due to very low energy. Before the measurement with the beam at the exit of the gun, the calibration experiment is done with DC high voltage applying setup with 1mm thick ZnTe crystal. The broadening of our laser pulse by the ZnTe crystal will be measured with auto-correlation method to know the resolution limit in this experiment and to do data analysis properly. In this presentation, the result of calibration experiment will be presented with a description of the experiment in detail and simulation result for low energy beam.

INTRODUCTION

EOS (Electro Optic Sampling) method to measure short, intense electron beam which is essential to construct XFEL light source is developed greatly in last few year [1,2,3,4]. For the successful construction of XFEL light source, the monitoring of timing jitter of electron beam is crucial in online condition. The method can be used for monitoring the timing jitter of all section of the light source for example injector, bunch compressor, undulator sections. We are now trying to measure the electron beam at the injector part of XFEL to be constructed in PAL. A 2 MeV electron beam with a tunable bunch length and 0.2nC bunch charge has recently been realized at PAL[5,6].

THEORY

The theory for the signal detection scheme of EOS is well described in ref[7], so we give only a short summary of it here.

Balanced detection scheme

The vertical and horizontal polarized part intensities of the incident laser to the ZnTe crystal is changed due to the birefringence of the crystal induced from the electron electric field. The analytic expression is in Eq.(1),(2)

$$\Gamma = \frac{\omega_0 d}{c}\left(n_h - n_v\right) = \frac{\pi d}{\lambda_0} n_0^3 r_{41} E_0 \tag{1}$$

$$I_h - I_v = \left|\mathrm{E}_h\right|^2 - \left|\mathrm{E}_v\right|^2 = E_0^2 \sin\left(\Gamma\right) \tag{2}$$

where the Γ is the relative phase shift between the two polarized parts of the laser field, and d is the crystal thickness.

Layout

In order to understand the theory for the signal detection scheme of EOS, the layout is described in detail in Fig. 1. The linearly polarzed laser experiences the birefringence in EO crystal due to electric field from the electron beam. The difference of the vertical and horizontal part of the laser field can be measured with quarter wave plate and Wollaston prism with sine function proportionality as mention in above section.

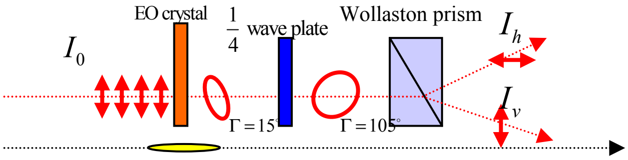

Figure 1: Layout of Electro-optic sampling

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DC SETUP EXPERIMENT

To test the EO crystal response to the electric field strength, we made a high DC voltage applying setup. The result is shown in Fig. 2.

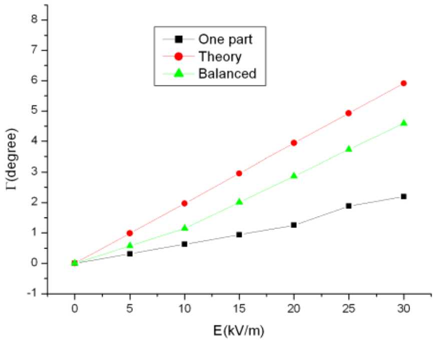

Figure 2: The response of the ZnTe crystal in DC electric field. The circle(red line) is theory, the triangle(green line) is balanced detected result and the square(black line) is measured result from the vertical part of the laser using single photodiode

The result showed that the crystal which thickness is 3.2 mm used in this experiment followed the theory well.

SIMULATION

Simulation method for Thz propagation

The ZnTe crystal showed frequency dependent refractive index which is propotional to the electric field called Pockel effect. The electric field profile due to the electron longitudinal profile is Fourier transformed to know the response of the electric field inside the crystal. We know the speed of each Fourier component in the crystal, which make us possible to reconstruct the field profile passing through the crystal. The field profile is shown in Fig. 3 with time domain representation.

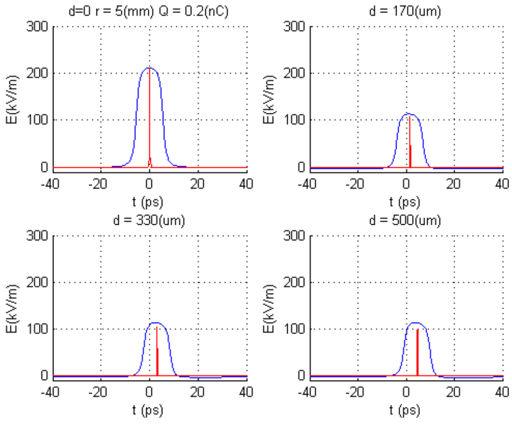

Figure 3: Electric field propagation in the crystal. The blue line showed the electric field strength, the red line showed the laser pulse. The r is the distance between the laser and electron beam and d is the thickness of the crystal.

Ring approximation of electron beam

The exact field profile of the electron beam is complicated to expressed in an analytic form. Instead of the exact field profile, we can use the ring approximation which has an exact solution which allowed the relativistic expression. The result showed that we can make almost exact field profile with only two terms, one is monopole term and the other is quadrupole term. The quadrupole term amplitude is very small compared to the monopole term. The Equation(3) showed the relativitic expression of the ring approximation.

$$E_r = \frac{q\gamma}{4\pi\varepsilon_0}\left[\begin{array}{c} \dfrac{r}{\left(\gamma^2 v^2 t^2 + r^2\right)^{3/2}} \\ -\dfrac{a^2}{4}\left(\dfrac{2r}{\left(\gamma^2 v^2 t^2 + r^2\right)^{5/2}} + \dfrac{5r\left(2\gamma^2 v^2 t^2 - r^2\right)}{\left(\gamma^2 v^2 t^2 + r^2\right)^{7/2}}\right) \end{array}\right] \quad (3)$$

In the above equation, q is the charge of the electron beam and v is the velocity of the beam and r is the distance between the laser passing point and the electron beam. In Fig. 4, the green line shows the field profile in the free space and the blue line sowes it in the crystal which is smaller than free space case because of the reflection in the surface of the crystal due to the boundary condition of electro-magnetic theory.

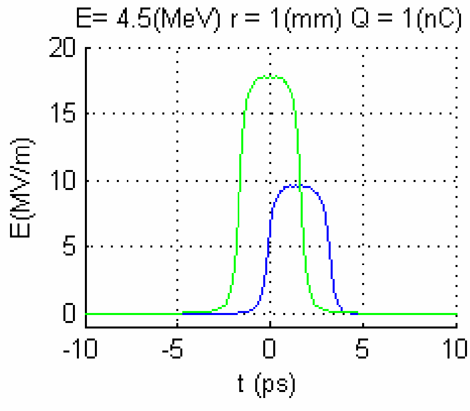

Figure 4: Electric field strength in free space (green) and in the crystal (blue).

Balanced signal

The laser pulse speed and the Thz radiation speed in the crystal is not same which makes the slippage between two pulse. In our simulation, we calculate the relative phase shift from the integral with 50 sections of the crystal.

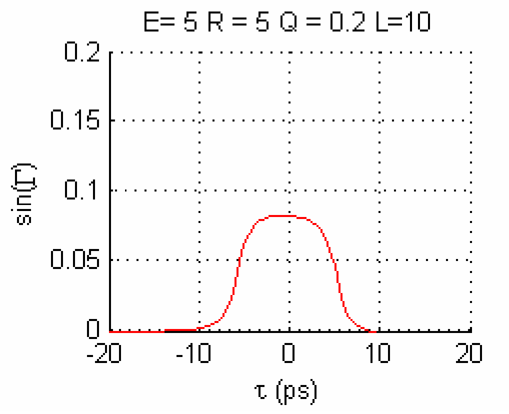

Figure 5: The simulated balanced signal of low energy beam which energy is 5MeV, beam charge is 0.2nC and the pulse length is 10ps uniform beam. R the distance between the laser and electron beam is 5mm. τ is the arrival time of the laser at the crystal compared to the electron beam.

The result showed that the low energy beam of the injector of XFEL can also be measured with EOS very successfully. The signal level is almost 1/10 of initial laser intensity incident in the crystal which is very easily detected using phtodiode or balanced detector.

LOW ENERGY BEAM DIAGNOSITICS

At present, we completely installed the EOS experiment setup in the GTS(Gun Test Stand) in PAL. The coarse timing of the arrival time of electron beam and laser beam at the crystal is solved with measurement of all path of the UV and IR laser and the distance between the gun cathode and electro optic crystal chamber. Belanced detector signal is observed easily in the oscillocope which is not saturated. We moved two mirrors in the path of 800nm laser beam to make time delay between electron beam and laser beam to find exact synchronization to see the change of the signal. The precision timing will be done very accurately with balanced detector. Sampling method is not appropiate to measure the bunchlength due to the electron arrival time jitter. Instead of the sampling method, the spatial method which is using the CCD carmera to take a picture of the laser gives a way to measure the bunch length and timing jitter simultaneously.

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