DESIGN OF BUNCH LENGTH MEASUREMENT SYSTEM AT THE IRFEL USING A MARTIN-PUPLETT INTERFEROMETER*

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Abstract

Electron bunch length measurement is of great significance for optimizing IRFEL performance. An optical autocorrelation system using coherent transition radiation (CTR) would be set up to measure the electron bunch length at the IRFEL. CTR can be occurred when short electron bunches traverse a vacuum-metal interface. A Martin-Puplett interferometer allowed measurement of the autocorrelation of the CTR signal. The basic principle and the main components of Martin-Puplett interferometer are elaborated in this paper.

INTRODUCTION

With the development of the high pulse intensity and ultrashort pulse duration of the Infrared Free Electron Laser (IRFEL), which overcomes the shortages of traditional infrared spectroscopy, such as low sensitivity, low spacial and low time resolution. This project will significantly promote the progress in energy chemistry, and establish a fundamental scientific research to reach the international advanced level. A schematic view is shown in Fig. 1, with the design parameters listed in Table 1.

The measurements of bunch length can fall to two categories: time domain measurements and frequency domain measurements [1]. In the time domain techniques, streak camera is usually used. But the resolution limit of streak camera is 200 fs and streak camera is too expensive. Instead of time domain techniques, frequency domain measurements using Coherent Transition Radiation (CTR) is employed.

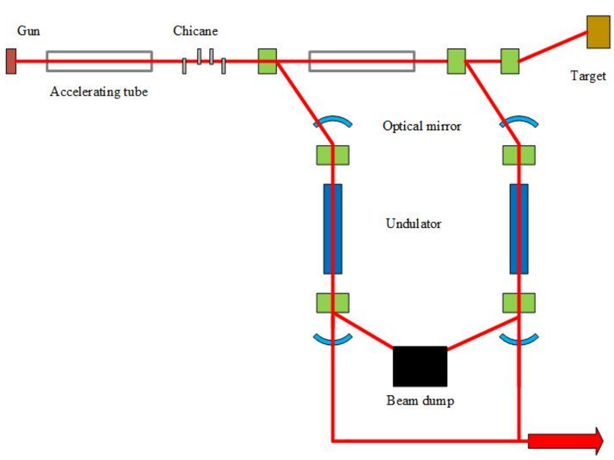

Figure 1: Schematic view of NSRL IRFEL.

Table 1: Parameters of the IRFEL

Parameter	Value
Beam energy	30−50 Mev
Radiation wavelength	2.5−200 μm
Bunch length (FWHM)	2−10 ps
Repetition rate	10 Hz
Marco pulse duration	5−10 μs
Energy spread	<0.2%
Normalized emittance	<20 mm·mrad
Peak power	5 MW

CTR can be occurred when short electron bunches traverse a vacuum-metal interface. A thin aluminum foil is placed at an angle of 45° with respect to the beam direction so that the backward radiation can be attained. The radiation spectrum is expressed as follows [2, 3]

$$I_{\text{tot}}(\omega) = I_s(\omega)\left[N + N(N-1)F(\omega)\right] \quad . \qquad (1)$$

Here $I_s(\omega)$ is the spectral intensity emitted by a single electron, N is the number of the electrons of the bunch and F(ω) is the bunch from factor. For relativistic charge particles, the form factor simplifies to

$$F(\omega) = \left|\int_{-\infty}^{\infty} \rho(z) e^{i\omega z/c} dz\right|^2 \quad , \qquad (2)$$

where $\rho(z)$ is the normalized charge distribution.

THE MARTIN-PUPLETT INTERFEROMETER

The autocorrelation function of the CTR is determined by a Martin-Puplett interferometer (MPI) [4]. The concept design is shown in Fig. 2. The MPI consists of a Z-cut quartz window, two parabolic mirrors, three wire grids, two roof mirrors and two detectors.

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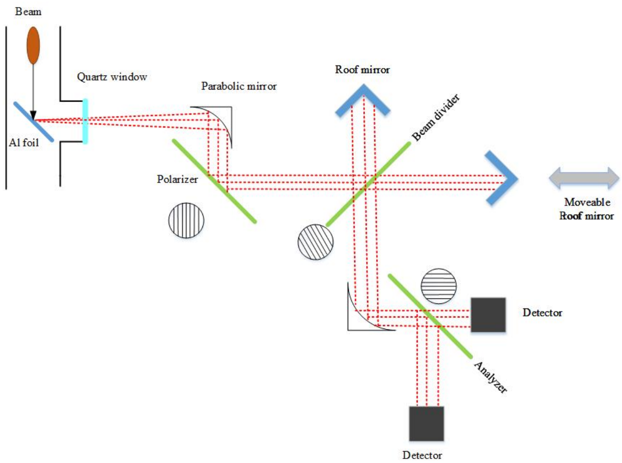

Figure 2: Concept design of the MPI for bunch length measurement.

CTR is occurred by an aluminum foil as thin as 10 μm which is behind the chicane. The diverging CTR is transformed into a parallel pulse entering the MPI by a parabolic mirror. The parallel pulse is horizontally polarized by the first wire grid and then splitted by the beam divider into the roof mirrors. The roof mirror can change the polarization. Finally, the pulse get to the detectors by the analyzer. The design parameters of component of MPI are discussed as follows.

Quartz Window

CTR is extracted from the beam line through a Z-cut crystal quartz window. The acceptance angle is determined by the size of the quartz window and the distance from the Al foil to the window [5]. The small acceptance angle is chosen ±120 mrad by using a quartz window (20 mm diameter) and the window is 83 mm away from the Al foil. This acceptance angle is closed to ±6/γ for a 25 MeV electron beam.

Wire Grids

Wire grids are made from an array of closely spaced parallel metallic wires. The role of grids are as the polarizer, analyzer and beam divider. The reflectivity of the electric field parallel and vertical components are dependent on the thickness *d* of wires, gap *g* and the wavelength. The relationships are [6]

$$\left|r_{\parallel}\right|^2 = \frac{1}{1+(2g/\lambda)^2\ln(g/\pi d)^2}, \qquad (3)$$

$$\left|r_{\perp}\right|^2 = \frac{1}{1+(2\lambda g)^2/(\pi^2 d^2)^2}. \qquad (4)$$

According to Eq. (3) and (4) the parallel and vertical reflectivity as a function of frequency at different *g* (*d*=10 μm) are plotted in Figs. 3 (A) and (B), respectively. Thus the wire grids used in present design are 10μm thickness tungsten wires with a gap of 30 μm.

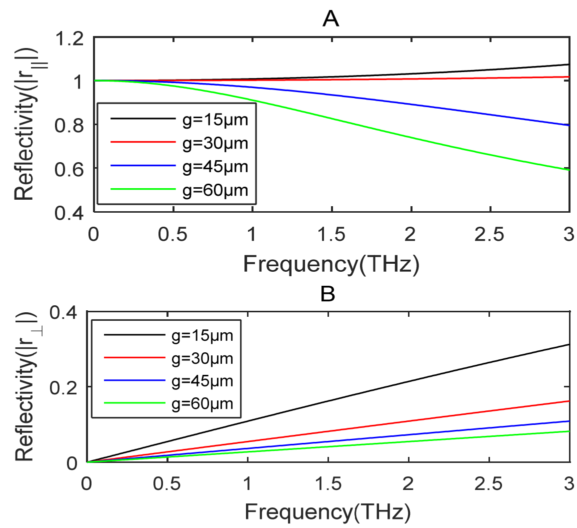

Figure 3: Calculated reflectivity for the parallel and vertical components of an incident electric field on a wire of 10 μm thickness grid with different *g*.

Parabolic Mirrors

The two parabolic mirrors have polished aluminum surfaces. The plasma frequency of aluminum is 3.55×10^{15} Hz. All waves with frequencies much lower than the plasma frequency are almost reflected as the skin effect. Thus for CTR in the infrared or far infrared regime, absorption of the aluminum surface is negligible. Because the diffraction effect should be significantly reduced so that the parabolic mirrors are large enough. The effective focal length of these mirrors is 200 mm and the diameter is 100 mm.

Roof Mirrors

The roof mirror is the key element of the MPI. It consists of two plane mirrors which are perpendicular to each other. The most important property of the roof mirror is that it changes the polarization direction of the incident radiation. Suppose the incident radiation is linearly polarized and the electric field can be split to parallel and perpendicular components. Since the boundary conditions of the mirror surface, the vertical component of the electric field change for 180° on the surface and it change again at the second surface of the roof mirror. So the vertical component keeps the same direction. The horizontal component of the electric field, however, rotates 90° at each surface so that the horizontal component rotates 180° after the roof mirror. Therefore, the function of a roof mirror can be described as changing the radiation direction by 180° while preserving its polarization state.

Detectors

There are three kinds of detector, liquid-helium-cool bolometer, pyroelectric detector and Golay cell, can be used to measure the radiation pulse. In this design, we chose the pyroelectric detector for the low price and convenience.

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To enlarge the effective active area of the detectors, radiation is collected using copper cones. Although the cones lead to an angle dependence to the detector acceptance, they are conducive to increase the signal-noise ratio.

Translation Stage and Controller

The right mirror is mounted on a moveable stage which is driven by a step motor. The step motor type, shown in Fig. 4, is 56BYG250D [7].

Figure 4: Photograph of the step motor.

The minimum step size of the stage is 1 μm. The step motor is computer controlled via the local Area Network. The two signals from the pyroelectric detector are extracted by ADCs with differential inputs. The ADCs are PCI card based and are installed in a computer. The bunch length measurements with the MPI were automated. The control software will be written in LabVIEW.

SUMMARY

The measurement system of the bunch length is designed. The main components of the MPI is described and the parameter is given. All these components will be purchased and assembled to optimize the parameters in the near future.

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