ELECTRON BUNCH LENGTH MEASUREMENT USING RF DEFLECTING CAVITY

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Abstract

Recently, the RF photogun based-ultrafast electron diffraction (UED) system has been developed in KAERI. In the system, the emitted electron bunches are experimentally confirmed to be accelerated up to 3 MeV at 5 MW of RF power. And the time duration of the each bunch is initially designed to be less than 50 fs at the sample position. To analyses the performance of the system and to measure exactly the length of the electron bunches, we developed a rectangular type of S-band deflecting cavity working on TM_{120} mode. The principle of electron deflecting in the cavity, design & mechanical fabrication process and test results will be present in the conference.

INTRODUCTION

To understand the ultrafast dynamics of atoms or molecules, we use the X-FEL or ultrafast electron diffraction (UED) system. Those systems can provide the pulses with high temporal and spatial resolution. UED system using electron bunches with a few MeV has compact size compared with X-FEL, while it still can make the femtosecond time resolution or over sub nanometers of atomic spatial dimension [1].

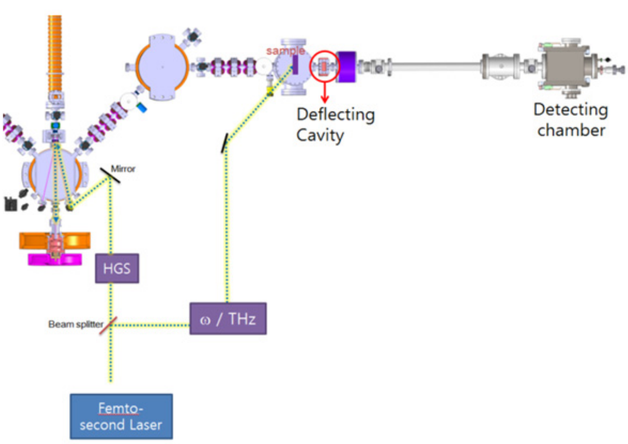

Figure 1: Schematic of the Korea Atomic Energy Research Institute (KAERI) UED system.

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Figure 1 shows schematics of the KAERI UED system. The RF photocathode gun is equipped at the system for the electron generation. The electron beam emitted from photocathode by fs laser is accelerated to 3 MeV by input RF power to reduce the space charge effect. After the gun, the electron beam is focused by several magnets, and the electron bunch length would be less than 50 fs. To measure the longitudinal distribution of the electron bunch, we are going to use an RF deflecting cavity working on TM_{120} mode. A strong transverse magnetic field deflects the beam passing through the cavity. After that the transverse beam size at the screen located downstream at the cavity is related to the bunch length at the deflector position.

The temporal resolution of deflecting cavity can be calculated by using following equation:

$$\Delta t = \Delta x \frac{U/e}{L\pi f V_t} .$$

To get the temporal resolution less than 20 fs, the RF input power at the cavity is estimated to be 2 MW. To improve the resolution of measurement, the 10 um slit would be used at upstream of the deflecting cavity.

RF DESIGN

We design the RF deflecting cavity similar to a rectangular cavity which drives 2.856 GHz working on TM_{120} mode [2]. The distribution of electromagnetic field in the cavity is shown in Figure 2.

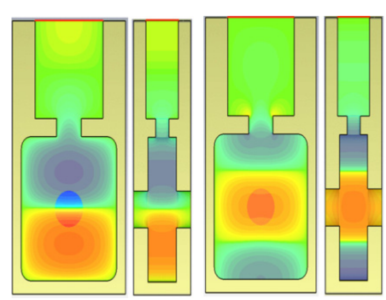

Figure 2: Electric field (left) and magnetic field (right) distribution of TM_{120} mode in the deflecting cavity.

Figure 3 shows the simulation results of the RF deflecting cavity. The resonance frequency of the results is higher than expected value because of error at the simulation.

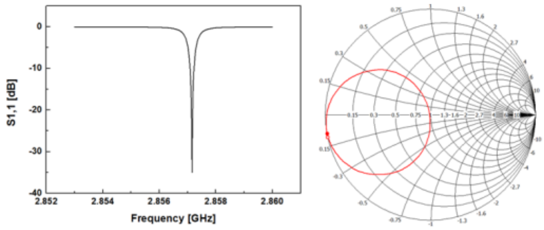

Figure 3: S11 parameter (left) and Smith chart (right) of the simulation of the deflecting cavity.

The measured results of fabricated deflecting cavity are shown in Figure 4 below.

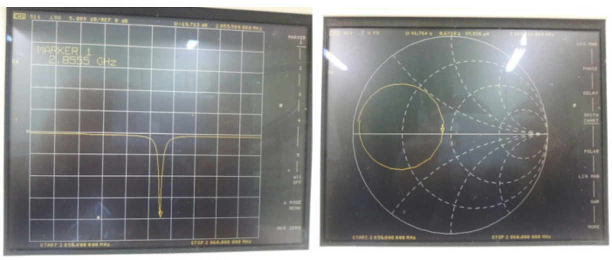

Figure 4: Cold test results of S11 parameter (left) and smith chart (right) of the deflecting cavity.

The resonance frequency and Q-value of cavity is 2.8555 GHz and 12326 respectively. Table 1 below shows the simulation and measured results of the cavity.

Table 1: DeflectingCavity Parameters

Parameter	Simulation	Real
Resonance frequency	2.8572 GHz	2.8555 GHz
Loaded Q-factor Q_L	6968	7103
Coupling constant β	0.96	0.73
Unloaded Q-factor Q_0	13332	12326

BEAM DYNAMICS

The electron beam deflected vertically after a drift space, and the vertical beam size would be related to the bunch length. The force in the deflecting cavity is given by

$$F_y(z) = q\left[\widetilde{E_y}(z) + c\widetilde{B_x}(z)\right],$$

where

$$\widetilde{E_y}(z) = E_y(z)e^{-j(\omega t+\varphi)},$$
$$\widetilde{B_x}(z) = B_x(z)e^{-j(\omega t+\varphi-\pi/2)}.$$

The maximum deflecting voltage, V_{def}, is defined when the RF phase in the cavity is 90 degree:

$$V_{\mathrm{def}} = -\int_{-L/2}^{L/2}\left[E_y(z)\sin(kz) + cB_x(z)\cos(kz)\right]dz,$$

and the change in the angular divergence of the electron beam is given by

$$y_f' = \frac{1}{E_0}\int F_y dl = \frac{q}{E_0}\int E_y dl = \frac{-qV_y}{E_0}$$
$$= \frac{-qV_{def}\sin(\varphi - ks)}{E_0}.$$

Using those equations, the vertical electron beam size can be calculated [3, 4].

$$\sigma_y^2 = \sigma_{y,0}^2 + \left(\frac{kqV_{def}}{E_0}\sigma_z D\right)^2.$$

Beam simulation has been progressed for the deflecting cavity. We used particle tracking code of ASTRA to consider the space charge effect. The energy of electron beam is 3 MeV and the horizontal and vertical rms beam sizes are 1.2 mm and 1.4 mm respectively. The electron bunch length at the deflecting cavity is about 50 fs. The electron beam would be transferred to the screen located after 2 meters downstream from the deflecting cavity. Figure 5 shows the simulation results. We measured the electron beam sizes after the drift space without RF field and with RF field in the deflecting cavity to obtain the electron bunch length.

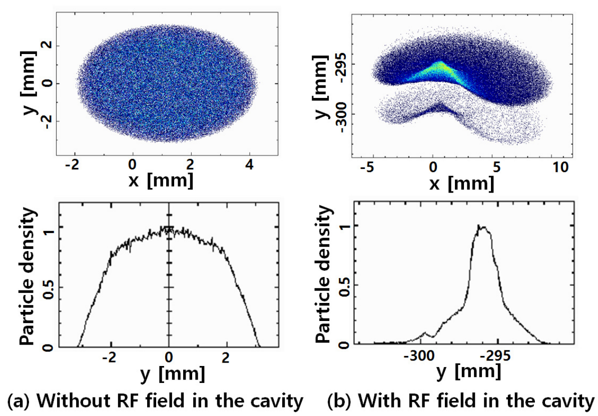

Figure 5: ASTRA simulation results. (a) is the beam distribution after the deflecting cavity without RF field in the cavity, (b) is the beam distribution after the deflecting cavity with RF field in the cavity.

The calculated bunch length is about 58 fs. We applied the 10-µm slit at the simulation to compensation of vertical beam effect for the electron bunch length measurement.

SUMMARY

The KAERI UED will use ultrafast electron bunches with a bunch duration less than 50 fs at the sample position. To measure the longitudinal distribution of the electron bunch, we will use an RF deflecting cavity working at TM_{120}-like mode. We studied beam dynamics in the deflecting cavity using code ASTRA. The beam optimization should be needed. According to the results of simulation and cold test, the deflecting cavity would be used for bunch-length measurement at KAERI UED system.

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