FEMTO-SECOND BUNCH LENGTH MEASUREMENT USING THE RF DEFLECTOR

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Abstract

The travelling wave type rf cavity operating in the dipole mode is being developed for a measurement of femto-second electron bunch length. Purpose of the femto-second electron bunch is used the pulse radiolysis experiments for the studies on radiation physics and chemistry with femto-second time resolution. The resonant frequency is tuned to the designing value 2856 MHz, which is same as accelerating frequency of the photo-injector linac at ISIR Osaka University. Further, we are planning to apply the design of the travelling wave rf deflector to X-band crab cavities for the Global Linear Collider (GLC) project. In this conference, we will report the design of the travelling wave rf deflector and the result of the cold test.

INTRODUCTION

The short electron bunches are very useful and powerful tools for various research fields. Especially, they play a critical role in experiments of coherent light source such as X-ray SASE-FEL [1] and the pulse radiolysis for investigating ultra-fast phenomena [2-4].

The pulse radiolysis experiment in sub-picosecond region is performed by using ultra-short radiation pulse of electron beam at the Institute of Scientific and Industrial Research (ISIR), Osaka University. In the pulse radiolysis experiment, the short-lived intermediates produced by an extreme short radiation pulse are detected by measuring the absorption of a short light pulse. The short radiation pulse of electron bunch is produced by a magnetic compression system, which able to compress the width of electron beam down to approximately 50 fs (rms) [4]. Time resolution of the stroboscopic pulse radiolysis is strongly depend on the length of the radiation pulse and that of the probe laser pulse. Therefore it is very important to determine the length of electron bunch to improve the quality of experiments.

The length of ultra-short electron bunches frequently are measured by using a streak camera in the time domain [5] and a coherent radiation technique in frequency domain [6]. The streak camera has recently succeeded to get sub-picosecond resolution, but it is expensive and need much effort for the installation. Other approach to measure the density-distribution in longitudinal phase space, by combining the tomography technique, the off-phase acceleration technique and the energy spectrum measurement, has been performed at the Stanford Picosecond FEL Centre [7] and BNL-ATF [8]. In their simple measurements, it is possible to transform the relative time coordinate of electron bunch within initial distribution to the relative energy coordinate of the final bunch. However the measurement using the tomography technique is not a single-shot measurement, it requires high stability of accelerator system.

The method of directly streaking the electron beam using an rf field can be apply to measure the length of electron beam. This concept has been used as beam separator in the 1960' at Stanford Linear Accelerator Center (SLAC) [9] and is investigated as a longitudinal diagnostic tool for future FEL experiment recently [10]. The high frequency time variation of rf field is used to deflect the electron bunch. The deflecting cavity is operated at zero-crossing phase of field, where the rf slope is maximum. The deflecting field makes a strong correlation between longitudinal position and transverse position of the electron bunch before and after the kick.

Taking the beam profile at downstream of the cavity, the absolute length of electron bunch can be obtained in a single-shot measurement as shown in Figure1. The resolution of measurement will be improved by using the higher operation frequency, since the large derivation of field gives a large spread on the profile monitor.

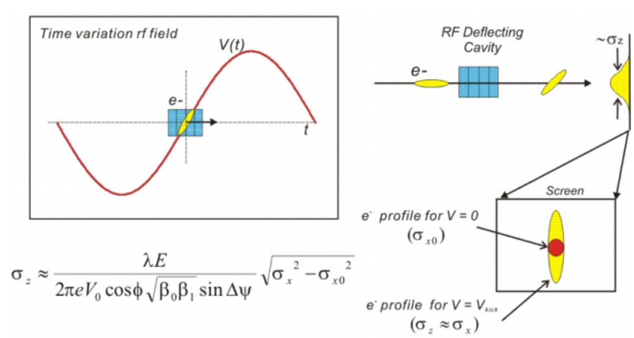

Figure 1: Principle of bunch length measurement using rf deflecting cavity.

DEFLECTING CAVITIES

The deflecting cavity gives to electron beam a time-depend transverse kick. The deflecting cavity or crab cavities were designed and tested in several laboratories and each of them has features [11,12]. The cavity is operated at the lowest dipole mode. In the case of cylindrical cavity, two dipole modes (TM_{11}) are degenerated. They have same operation frequency and different orientations in the cavity. Input coupler of the structure determines the polarization of the modes and a mode-locking hole has been used to prevent mode rotation in the deflecting cavity of SLAC [9]. In case of the crab cavity of KEK-B [11], the two-dipole modes are separated adopting non-cylindrical shape and frequencies of TE-like modes, which are also dipole-like mode for the beam coupling, can be made higher by shorten a cell length. A multi-cell structure will be chosen to get large transverse shunt impedance, however a large number of cells generates a large number of cavity modes and have a potential mode coupling. The design of deflecting cavity needs to compromise between the transverse shunt impedance and cell number of the deflector.

ISIR Photo-Injector Linac

Beam line of ISIR photo-injector linac consists of the S-band BNL-type rf-gun, a 3m-long accelerating structure and a magnetic compressor system. The deflecting cavity and a profile monitor for beam size measurement are installed at downstream of the magnetic compressor. The electron beam is generated by the photo-cathode rf-gun. The bunch length of the electron bunch at the exit of rf-gun cavity is approximately 10 ps in FWHM. By using magnetic compressor, the electron bunch can be compressed down to 50 ps. Maximum energy of electron beam is about 40 MeV. When the magnetic bunch compression is performed, the electron beam is accelerated at the off-phase in the accelerating structure to make a linear energy modulation along the longitudinal position of the bunch. Therefore, the energy of compressed bunch is much lower than maximum energy.

Design of the Deflecting Cavity at ISIR

To simplify the synchronizing system of the linac, the operation frequency of the deflecting cavity was chosen at 2856 MHz, is same as the operation frequency of the rf-gun and accelerator. On the other hand, we would like to distribute an rf power to deflecting cavity using a coaxial cable, because an rf distribution system using waveguide is complicate and expensive. The input rf power for the deflecting cavity is limited due to a withstand voltage of the coaxial cable. From this thing, a standing-wave structure is uncomfortable for our system, since only one-half of the rf power fed to structure contribute to deflect the electron bunch.

We designed a test multi-cell structure to get large deflecting field for the bunch length measurement of the short electron beam. The test structure has a $2\pi/3$ phase advance per cell with a period length 35 mm and the number of the cells of structure is 6. A transverse cross section of the cell is racetrack shape; it was chosen to separate the degenerated mode of two-dipole mode, TM_{210} and TM_{120} in rectangular coordinate system. Figure 2 shows a field distribution of the lowest dipole mode (TM_{120}) in the cell. This mode deflects the electron beam to vertical direction.

Figure 3 shows the electric field distribution in the deflecting structure, the field distribution was calculated using MAFIA code. In the case of that the cavity shape is the ideal pillbox cavity, there is no electric field of the TM dipole mode on the beam axis. However, the electron bunch passing through the deflecting cavity experiences the transverse kick from both magnetic and electric fields. For a practical cavity, beam iris introduces the TE-like mode and the mixed field of the TE-like and TM mode exist in the between cells.

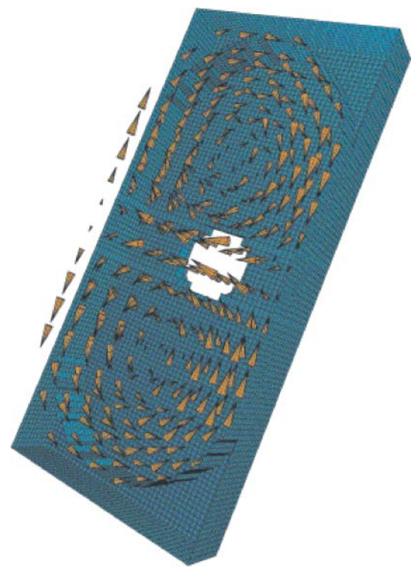

Figure 2: Magnetic field distribution of the lowest dipole mode of transverse deflection in a racetrack shape cavity. (Beam deflecting mode).

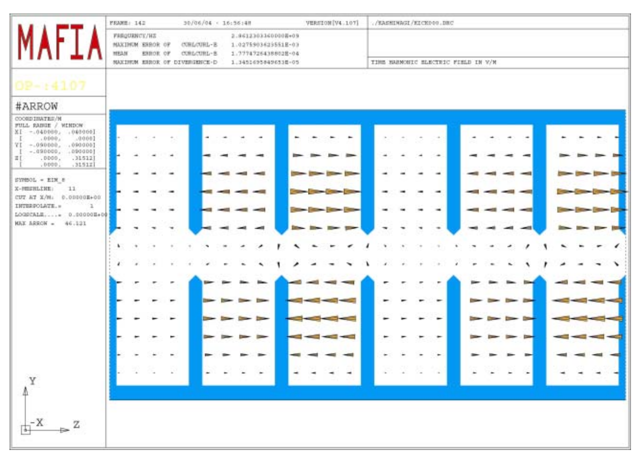

Figure 3: Electric field distribution of $2\pi/3$ mode in the deflecting cavity. (The field configuration of the TE-like and TM mode.).

RF Test of the Test Deflecting Cavities

The test cavity made by aluminium to study the deflecting cavity. Characteristic of the test deflecting cavities was measured using a network analyser (ADVANTEST R3770). As well known, the field profile can be determined by introducing a bead perturbation into rf cavity. The resonant frequency of cavity is shifted by a metal bead perturbation and the amount of frequency shift is proportional to the volume of the metal bead and the square of field strength at the bead position as shown in equation 1.

$$\frac{\Delta\omega}{\omega} = -\frac{\pi r_{bead}^{3}}{U}\left(\varepsilon_0 E_0^{2} - \frac{\mu_0}{2} H_0^{2}\right) \qquad (1)$$

where r_{bead} and U are radius of the bead and the stored energy in the cavity, respectively.

Figure 4 gives the result of an electric field perturbation measurement along the transverse direction in the deflecting cavity. The vertical size of the test deflection cavity is about 160 mm. In Figure 3, the red solid circles show the frequency perturbation on the centre vertical axis and the blue circles are that on an axis parallel and 10 mm away from the centre axis. There is no electric field on the beam axis, which corresponds to position zero in Figure 4.

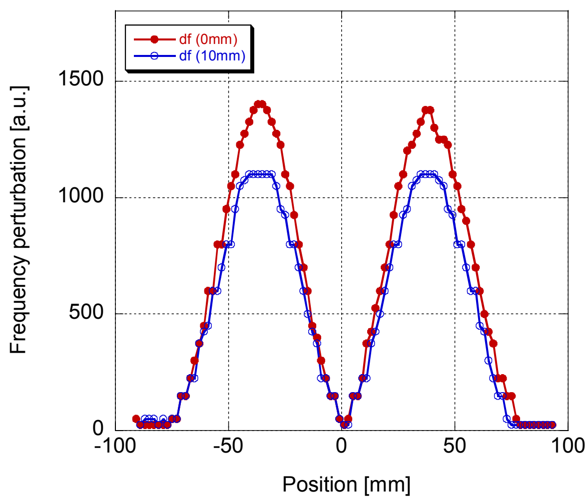

Figure 4: Square of electric field intensity in vertical direction of test cell as a function of vertical position.

The electric field perturbation measurement along the z direction (the axis of deflection cavity) was also performed. The bead was moved along z-direction, close to the disk iris, we couldn't observe a clear frequency perturbation of the deflecting cavity. Because the strength of electric field originally small around the beam axis and we used the small bead to improve a position resolution of the measurement.

CONCLUSION

The test cavity was made to study about the deflecting cavity for the bunch length measurement of the short electron bunch. We design the multi-cell deflection structure that has 2π/3 phase advance per cell and operation frequency is 2856 MHz. Using the bead perturbation technique, we measured the electric field of dipole mode in the transverse direction. We will continue a careful numerical analysis and rf measurement to know the rf characteristic of deflecting cavity. The hot model of deflecting cavity will be manufactured and the beam test for the deflecting cavity will be performed at ISIR. To apply the deflection cavity for multi-bunch beam, we will take account of multi-bunch beam loading in design of the deflecting cavity.

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