The 12th Symposium on Accelerator Science and Technology, Wako, Japan 1999

Numerical Analysis of the Electron Beam Micro-Pulses Width Measurement Method Using Standing Waves

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Abstract

In this paper, we have examined new micro-pulse width estimation method that we proposed in previous reports. This method was based on standing wave distribution measurement. However, to estimate properly was difficult because of the complex standing wave distribution. With the numerical analysis, it has been cleared that our estimation method is able to estimate validly the pulse width.

1 Introduction

We proposed a new measurement method of micro-pulse width of a multibunch electron beam [1][2]. This method does not use equipment with pico-second order time resolution. The micro-pulse width is estimated by standing wave distribution that is measured with a probe antenna and a crystal detector for microwave. However, it is difficult to estimate properly because the reflector that generates standing wave is also generates "radiated field." Therefore, we used the part of the standing wave distribution that is seemed to be small influenced by the radiated field.

In this paper, we have simulated the measurement system by numerical analysis and have examined this estimate method considering the influence of the radiation field.

2 Principle of our method

The experimental system is shown in Fig.1. The standing wave is generated by the incident field that is radiated directly from a micro-pulse of the electron beam and the reflected field that is radiated from former micro-pulse and reflected by the reflector. The distribution of this standing wave along the beam trajectory is measured with a probe antenna and a crystal detector. In Fig.1, the reflector is moved along the beam trajectory instead of moving the probe antenna.

If the electron beam consists of infinite uniform micro-pulse train, the incident field and the reflected field reach simultaneously where the distance from the reflector is one or several times of a half of the micro-pulse interval. At these points, the incident field and the reflected field cancel each other, and the standing wave is not detected. In the position with a time difference in arrival of the incident field and arrival of the reflected field, these fields partially cancel each other, and it is detected as a standing wave. The intensity of the standing wave depends on the micro-pulse waveform and the time difference of arrival of the fields. In the position where arrival time difference is sufficiently larger than the micro-pulse width, moreover, the output of the crystal detector is sum of the power of the incident field and the power of the reflected field. Therefore, ideal standing wave distribution has dips with uniform interval on constant level, like Fig.2. If the micro-pulse has Gaussian waveform, the dip width of 55.88% depth is agree with 1.809 times of FWHM of the micro-pulse.

In Fig.3, a measured standing wave distribution is shown. In different from the ideal case, it is difficult to determine the dip width properly since the dips have different shapes and flat level is not found. The main reason of this complex standing wave distribution is radiated field that is radiated spherically from the nearest point to the beam on the reflector. Since the radiated field arrives later than the reflected field, and has same direction component of electric field as the incident field, the standing wave distribution has peaks at points nearer for the reflector than each dips.

In our previous reports [1][2], therefore, we defined the dip depth by the bottom and far side edge of the dip (square marks in Fig.3), determined the width of the dip, and estimated the micro-pulse width. In the latter section, the validity of this estimate method is examined using numerical analysis.

3 Numerical analysis method

We use the finite difference time domain (FD-TD) method [3] for this numerical analysis. The FD-TD method solves the Maxwell's curl equations in discrete time and space.

In the FD-TD method, an electron beam is represented as a traveling free current and is distributed into discrete spatial points. However, it is difficult to satisfy the conservation of charge completely for any beam trajectory. Moreover, absorbing boundaries radiate spurious fields when a beam passes near the boundaries.

To avoid these difficulties, we use the scattered field FD-TD method [5] that calculates numerically only scattered fields. Scattering objects are illuminated by field of a point charge that has same energy and trajectory as the electron beam [6]. Convolution of the calculated electromagnetic field and the beam waveform is the field excited by the beam.

The numerical analysis system is shown in Fig.4. The analysis space consists of 200 × 200 × 200 cells of 1mm cubic unit cell. All the outer 8 cells are PML absorbing boundary layers [4] to simulate free space. The reflector is a 180mm square perfect conductor plate. The electron beam is an infinite uniform micro-pulse train. This beam has 45MeV energy and moves to +z direction

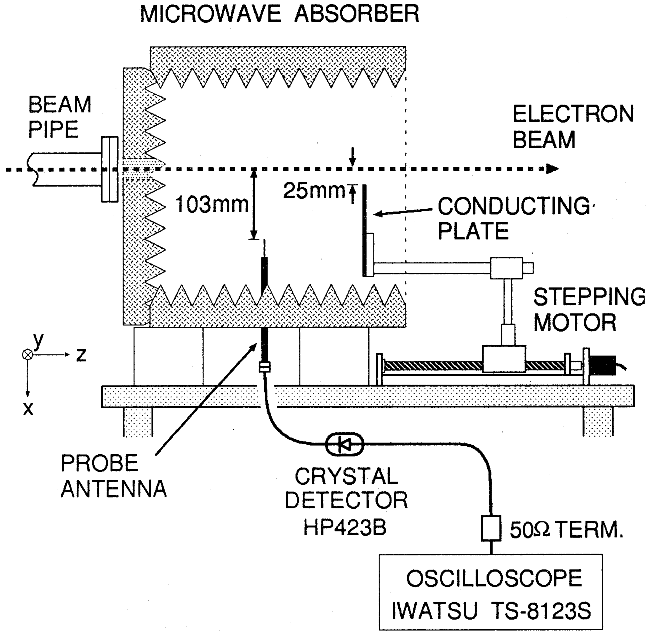

Fig. 1 Schematic of the experimental system.

at 10mm apart from the edge of reflector. The micropulse has Gaussian waveform of 40ps FWHM, and the interval of two micro-pulses is 353.7ps (106.1mm).

4 Numerical result

In Fig.5, it is shown that a distribution of radial component of electric field E_x along the field observation line in Fig.4. This line lies perpendicularly to the reflector and reaches to the center of the reflector. The beam trajectory runs parallel to this line. The axis of abscissa denotes distance from the reflector, and time is a parameter. The incident field and the radiated field make negative amplitude; the reflected field makes positive one.

In Fig.5, the positive side envelope has clear dips every 53mm that is a half of micro-pulse interval. On the other hand, dips of the negative side envelope do not reach to zero because of the radiated field. At the positions nearer for the reflector than dips, the negative side envelope has peaks since the incident field and radiated field arrived simultaneously.

The experimental result of the standing wave distribution is power distribution using a crystal detector. To compare the experimental and numerical results, square of E_x is integrated over one cycle of micro-pulse (353.7ps) at each position and is shown in Fig.6. The dashed line in Fig.6 is power distribution of positive side electric field in Fig.5. Since the radiated field does not influence the positive side, it is easy to determine the dip width. However, the actual output voltage of the crystal detector (Fig.3) is similar to the solid line of Fig.6. The solid line is a distribution of the total power of the radial direction electric field. In this case, it is difficult to determine the dip width because the radiated field makes a complex standing wave distribution.

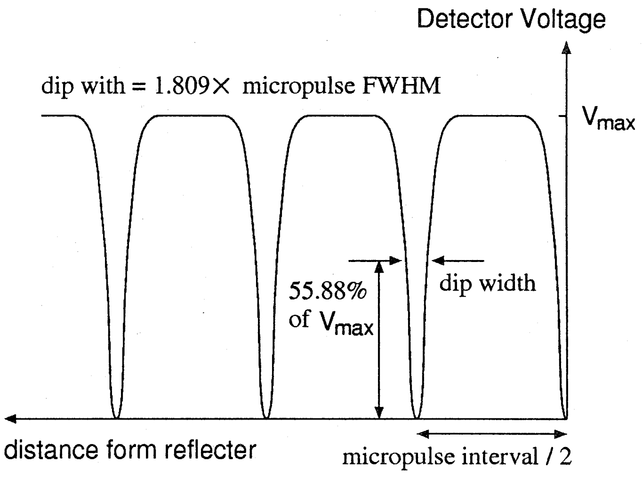

Fig. 2 Ideal standing wave distribution.

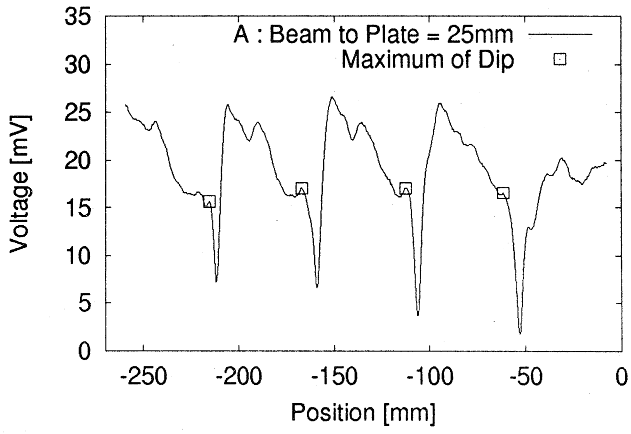

Fig. 3 Measured standing wave distribution. Axis of ordinate denotes output voltage of crystal detector.

Nevertheless, the radiated field power is added simply where the radiated field pulse does not overlap the incident field pulse. The power distribution has peaks where the incident and the radiated field pulses overlap. Therefore, it is able to determine the dip width and to estimate the micro-pulse width properly by subtracting the radiated field power if the dip of the power distribution is apart enough from the peaks.

In our previous reports [1][2], the dip width was determined by the power at the bottom and the far side edge from the reflector. It is equivalent to determine the dip width by subtracting the constant radiated field power. Since the radiated field propagates spherically from the edge of the reflector, the radial component power of the radiated field increases with the distance from the reflector and approaches to constant level. Therefore, at the dip near the reflector, the width is estimated larger because the dip depth is over esti-

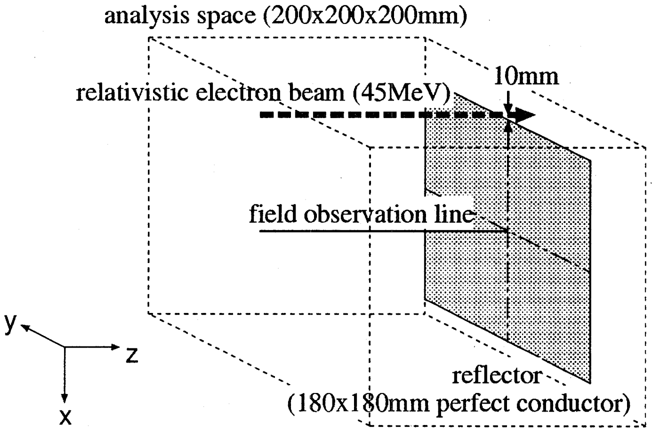

Fig. 4 Schematic of the numerical analysis system.

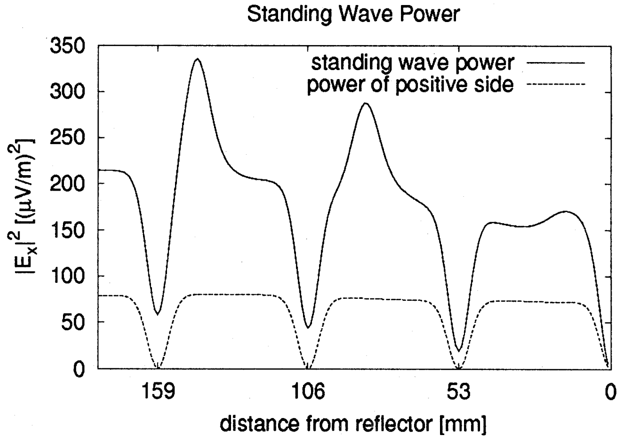

Fig. 6 Distribution of standing wave power.

mated. In contrast, at the dip far from the reflector, the width is estimated smaller because the radiated field pulse overlaps the incident pulse near the dip. Consequently, by selecting dips for estimation under the consideration of these error factors, it is able to estimate validly the micro-pulse width with this method.

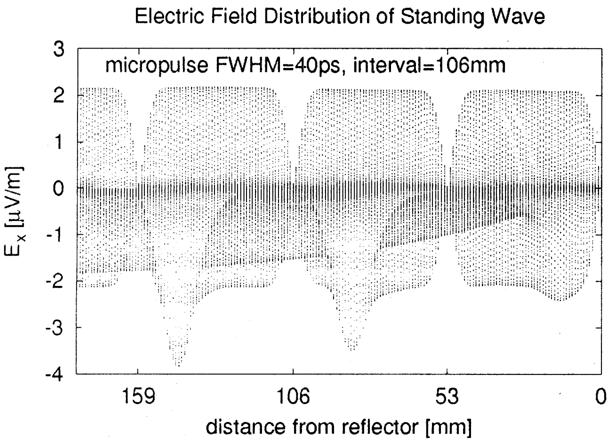

Fig. 5 Spatial envelope of standing wave.

5 Conclusion

The electron beam micro-pulses width measurement method using standing waves that we proposed in previous reports has examined by numerical analysis. The radiated field from the reflector edge makes complex standing wave distribution. It has been cleared that the micro-pulse width estimate method presented in our previous reports is able to estimate validly decreasing the radiated field influence.

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