A New Estimate Method of Micro-pulse Width Using Standing Wave Measurement

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Abstract

A new method for estimating the micro-pulse width of electron beam using the measurement of the standing wave distribution is discussed. When a conducting plate is set transversely in the vicinity to an electron beam's path, the standing wave distribution is formed by interference between two waves. One is an incident wave radiated directly from electron beam. Another is a reflected wave returned from the conducting plate. Further the wave radiated from the edge of plate exists. This radiated wave propagates spherically and affects the above standing wave distribution. We measured the standing wave distributions by using Hokkaido University 45MeV Linac. The micro-pulse width was estimated by using this new method, i.e. using the ratio and width of each dip of the standing wave distribution. The estimated values showed well agreement with the expected pulse width of this linac.

1 Introduction

As a measurement method of the micro-pulse width without distorting the electron beam, we have proposed a measurement method using the standing wave distribution created by electric fields radiated from electron beam. It is easy to measure a standing wave distribution, because it only measure the rectified voltages of the spatial distribution. On the other hand, real time direct measuring[1, 2] of an electric field radiated from ultra short micro-pulse electron beam requires a wide frequency range measurement equipments.

Thus far, we placed two conducting plates in a cylindrical waveguide, and we measured the standing wave distributions. Further, on an analytical model analogous to this experimental system we calculated the standing wave distributions using the finite difference time domain (FD-TD) method[3]. We investigated in frequency domain the experimental and analytical results[4]. Correlation for frequency spectra between the standing wave distributions and electron beam micro-pulses have been studied, however, it was not easy to estimate the micro-pulse width from frequency spectra, because the spectra of standing wave distributions are affected by the modes of electromagnetic fields in a cylindrical waveguide, size of the waveguide, the positon of antenna and so on.

In this paper we placed only one conducting plate transversely in the vicinity to the electron beam surrounded by microwave absorbers, and we measured the standing wave distributions. In this experimental system, the reflection on the plate is done only once, and the standing wave distribution is formed by discrete interferences. When electron beam passed near a conducting plate at a speed close to light velocity, two waves are radiated in an opposite direction of beam. One is a reflected wave from the conducting plate, which has the inverse phase to an incident wave. The standing wave distribution is formed by interference between incident waves and the reflected waves. Another is a radiated wave from the edge of a conducting plate, which is created by interaction between electron beams and positive image charges induced on the edge of a plate. Radiated waves affect the above standing wave distribution. In this paper we describe a new estimate method of the micro-pulse width using this standing wave measurement and the result of measurement.

2 Standing Wave Measurement

Standing wave distributions were measured using 45MeV Linac at Hokkaido University. The FWHM of a macro-pulse was 10ns, and the average current was 45nA.

Fig. 1 shows the experimental system. we set a conducting plate transversely near to the electron beam and we measured the spatial distribution by moving the stage in 0.5mm steps along the z axis using the stepping motor. The edge of a plate was at a distance 25mm apart from beam center. In this experiment a quarter-wavelength monopole antenna was used. It was made of coaxial cable of Semi-Rigid type, and center wire of 2.9mm long. The tip of antenna was at a distance 103mm apart from beam center. Rectified voltages of antenna were observed on oscilloscope through a crystal detector (HP423B: 10MHz$\sim$12.4GHz). And the maximum output voltage (ground to peak) was plotted at each point.

3 Experimental Result

Fig. 2 shows the measured standing wave distribution. The axis of abscissa denotes the relative position of antenna with respect to the position of a conducting plate, considering $z = 0$mm, and the axis of ordinate denotes rectified voltages (ground to peak) on oscilloscope through a crystal detector HP423B.

Large dips were observed at intervals of 53mm because the spatial interval of micro-pulses was about 105mm. Therefore dips are the result of interference between pulsed incident waves and the reflected waves. Minimum values of the dip changed as antenna became further from the plate because the amplitude of micro-pulses change according to the macro-pulse shape.

On the other side, the maximum values of distributions resulted from the interference between incident waves and radiated waves from the edge of a plate. While reflected waves have inverse phase to incident waves, but radiated waves have same phase, and so out-

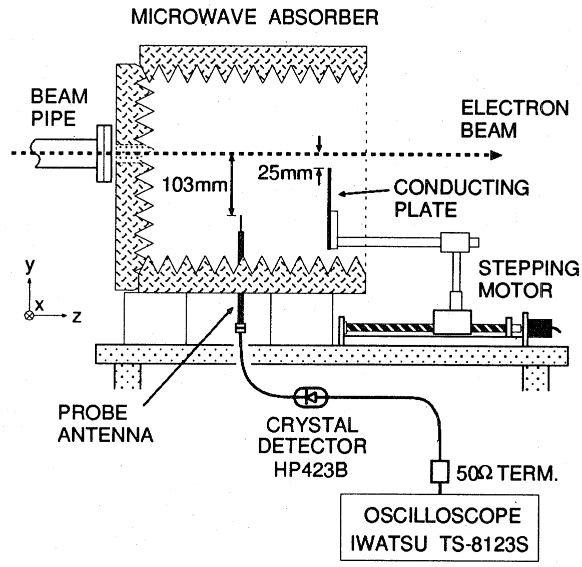

Fig. 1 Schematic of the experimental system.

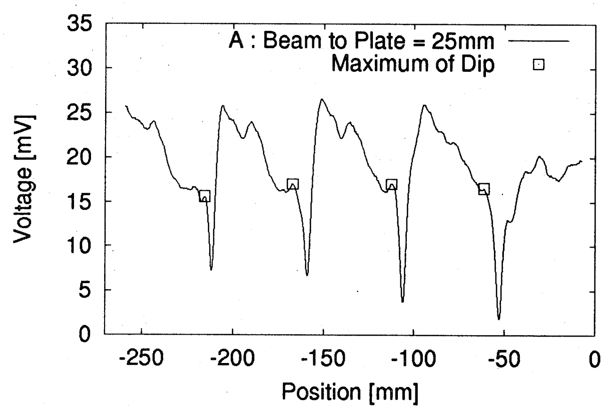

Fig. 2 Measured standing wave distribution.

put voltages at this points of interference were larger than only incident waves. This results shows that incident waves interfered with reflected waves and radiated waves at different positions. Furthermore it was found that radiated waves propagated in retard from reflected waves because the positions of maximum values were more or less away from the dip to the side of the conducting plate.

The micro-pulse width is estimated using the voltage standing wave ratio and the width of each dip. This estimate method of the micro-pulse width is explained at next section. In obtaining the voltage standing wave ratio, as the maximum value of each dip, the points (where the squares were marked in Fig. 2) were picked out so as to minimize the effect of radiated wave from the edge of a plate.

Relation between the standing wave ratio and the dip width at each dip is shown in Fig. 3. It is considered that the dip width is linearly dependent on the standing wave ratio. A regression line approximated by the least squares method for this result is also shown in Fig. 3. The micro-pulse width can be estimated from the dip width at the ratio is unity. The result width estimated from the dip width was 5.996mm and so the FWHM of micro-pulse was estimated as 26.03ps. At 45MeV Linac of Hokkaido University, it is assumed that the micro-pulse width is about 20ps in FWHM, but changes dependent on the condition of adjustment on the accelerator. Therefore it is considered that the pulse width estimated from this measured distribution gives the valid result, and radiated waves are not so affected for estimating the pulse width.

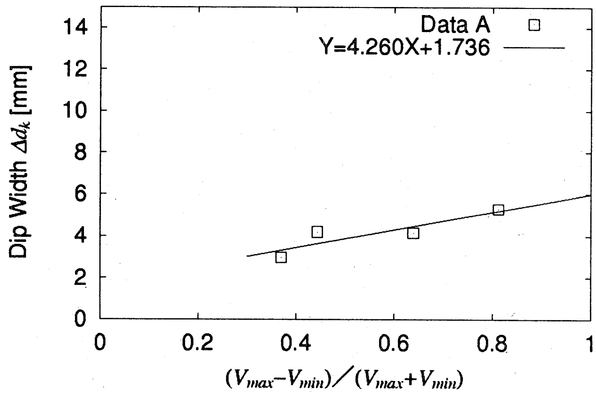

Fig. 3 Relation between the dip width and measured voltage standing wave ratio.

4 Estimate Method of Micro-pulse Width

Incident waves interfere with reflected waves and radiated waves at different positions. Therefore we can also separate the standing wave distribution in two interferences. One is the interference between incident waves and reflected waves. Another is the interference between incident waves and radiated waves. So in this paper we analyzed the standing wave distribution formed by incident waves and reflected waves using a one-dimensional model.

When incident waves are electric fields radiated from micro-pulses of electron linac whose amplitudes are constant, the maximum value of this distribution is equal to the rectified output dependent on incident waves only, and its minimum value is zero. Therefore the standing wave ratio of this distribution is unity. It was found that the dip width at the level of 55.88% of maximum is equivalent to the spatial bunch length of micro-pulse. Further it was found that the dip width of the rectified voltages extends 1.809 times by taking into account the square law characteristics of the crystal detector and the rise time of oscilloscope.

On the other side, when micro-pulses amplitudes change according to the Gaussian macro-pulse, the standing wave distribution formed by the electric fields is shown in Fig. 4. The FWHM of micro-pulse was 20ps, and the FWHM of macro-pulse was 10ns.

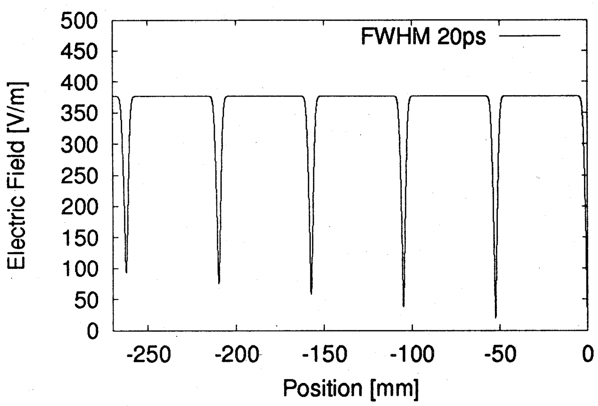

Fig. 4 Calculated electric fields of standing waves excited by the Gaussian macro-pulse.

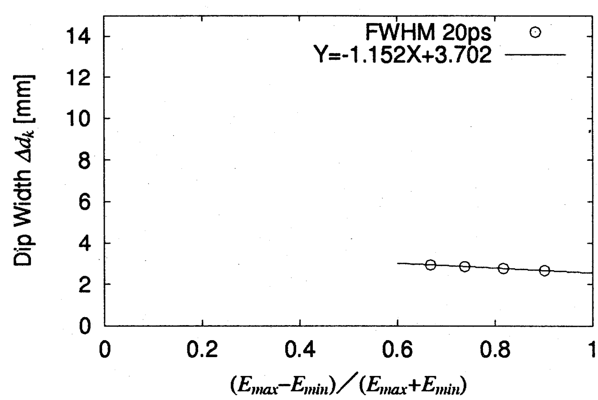

Fig. 6 Relation between the dip width Δd_k and the standing wave ratio of the electric fields.

In this case, minimum values of the dip change dependent on the positions, so the dip height H_k is calculated by the following equation,

$$H_k = 0.5588\,(E_{max} - E_{min,k}) + E_{min,k} \tag{1}$$

where E_{max} denotes the maximum value of electric field of the standing wave distribution, and $E_{min,k}$ denotes the minimum value of the k-th dip D_k from the plate. This is illustrated schematically in Fig. 5. Furthermore

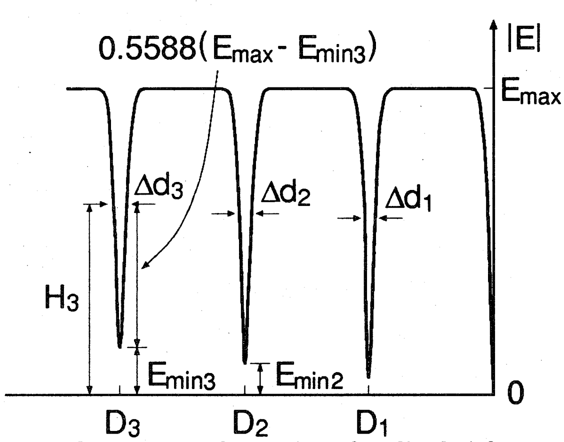

Fig. 5 The way to determine the dip height H_k to obtain the dip width Δd_k.

relation between the dip width Δd_k and the standing wave ratio of the discrete standing wave distribution, defined by $(E_{max} - E_{min,k})/(E_{max} + E_{min,k})$, is shown in Fig. 6. It is considered that the dip width is linearly dependent on the standing wave ratio. A regression line estimated by the least squares method is also shown in Fig. 6.

Since the dip width, at the ratio is unity, corresponds to one of constant amplitude, the estimated value is equivalent to the spatial bunch length of micro-pulse. The result obtained by the regression line was 2.550mm, and so the FWHM of micro-pulse was estimated as 20.03ps. Further, considering characteristics of a crystal detector and oscilloscope, the dip width extends 1.809 times in the same manner.

5 Conclusion

We proposed a new method for estimating the micro-pulse width of electron beam using the standing wave distribution. The standing wave distribution was measured in the experimental system where a conducting plate set surrounded by microwave absorbers. In this method the estimated micro-pulse width of electron beam agreed well with the expected value, though the radiated waves from the edge of a conducting plate affected this standing wave distribution. It is advisable to use simultaneously other instruments as well to show the validity of this method.

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