Experimental and Theoretical Analysis of the Spectrum of Transient Electromagnetic Field Created by Linac Electron Beam

Hiroyasu Itoh, Satoshi Tomioka, Takeaki Enoto
Department of Nuclear Engineering, Hokkaido University
Kita13 Nishi8 Kita-ku Sapporo 060 Japan

Abstract

Wave information about micro-pulses of electron beams is required in order to control an electron beam precisely, and it may be possible to obtain such information by analyzing the spectrum of the electromagnetic field created by a linac electron beam. In order to derive the spectrum, we measured the spatial distribution generated by a standing wave. Furthermore we caluculated the transient electromagnetic field excited by a bunched electron beam, using the finite-difference time-domain (FD-TD) method, and compared two spectra in the frequency domain, into which the calculated value in time variation and the measured values in spatial variation are transformed by using the fast Fourier transform (FFT) respectively.

I. INTRODUCTION

Wave information about micro-pulses of electron beams, half width, peak value, energy distribution of bunches, etc., are required in order to control an electron beam precisely. It may be possible to obtain this information by analyzing the spectrum of the electromagnetic field created by a linac electron beam. However, it is difficult to measure the time variation of a bunch, whose half width is only several tens of psec.

In this case, it is effective to measure not time variation of a bunch, but rather spatial variation generated by a standing wave, which is created by interference between a progressive wave and a reflective wave both generated with an electron beam and two reflective plates. Furthermore the wavenumber spectrum is estimated by using the FFT for measured values. This method enables measurement of the half width of a bunch easily even by using an osciloscope with a lower frequency bandwidth limit of, for example, 100MHz.

II. MEASUREMENT

We placed two reflective plates, spaced 355mm apart, perpendicular to the axis in the cylindrical waveguide, and measured the spatial distribution, by moving the stepping motor controlled stage in 1mm steps along the axis. Measurement system is shown in Fig.1. In the experiment reported here, dipole antennas used are made of coaxial cable of Semi-Rigid type, and antenna lengths are 3mm and 5mm, such that resonance frequencies correspond to 25GHz and 15GHz respectively.

Fig.2 shows the spatial variation of electrical fields along the axis in a cylindrical waveguide. The maximum output voltage (ground to peak) is plotted. After the measured values (256 points) were windowed by the hanning window, we transformed them into the wavenumber spectrum by applying the FFT. The expected distribution of the spectrum is equal to the convolution of the true power spectrum with the transform of the window function.

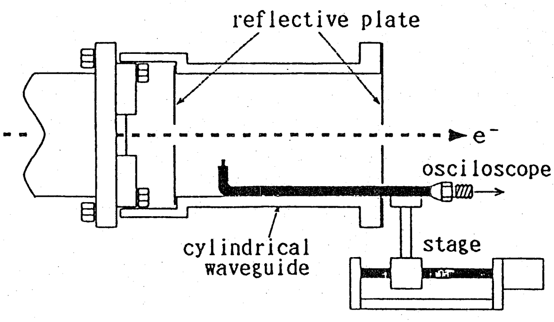

Figure 1. Measurement of a standing wave.

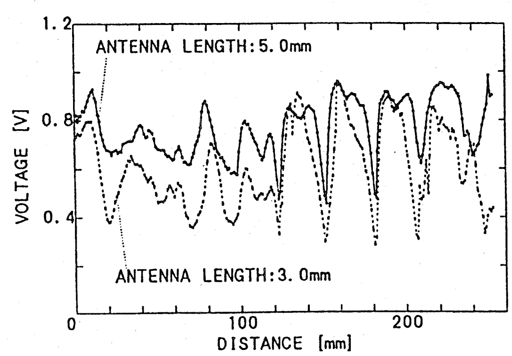

Figure 2. Spatial variation in the waveguide.

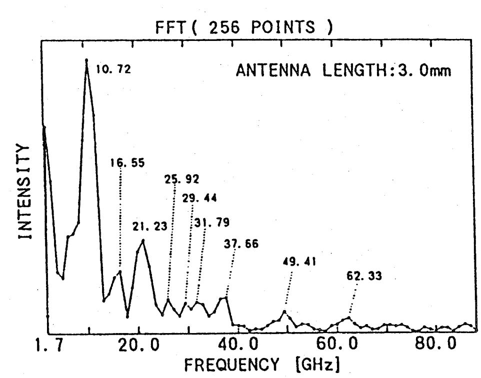

Figure 3. Frequency spectrum (antenna length is 3mm).

Fig.3 and Fig.4 show the frequency spectrum into which the wavenumber spectrum is converted, taking into account the dispersion of TM_{01} mode in the cylindrical waveguide. It is confirmed in Fig.3 and Fig.4 that the resonance frequency and their higher harmonics exist.

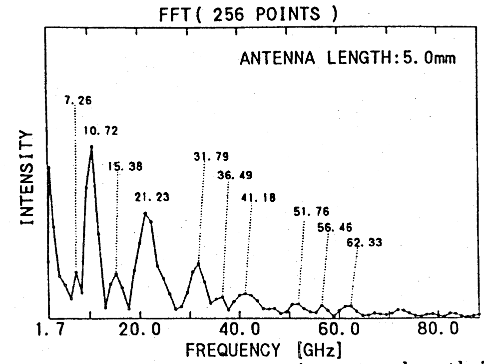

Figure 4. Frequency spectrum (antenna length is 5mm).

III. Numerical Analysis

A. Analytical Model

The finite-difference time-domain(FD-TD) method was proposed for the solution of Maxwell's equations by Yee [1]. It is a popular technique to calculate the transient electromagnetic fields [2]. In applying FD-TD techniqes, Maxwell's curl equations are solved by replacing them with difference equations in the solution domain, which is divided by a finite-difference grid. Electric and magnetic fields are calculated at alternative half-time steps.

We considered an electron beam passing along the axis of a cylindrical waveguide at almost the speed of light, and solved the difference equations in cylindrical coodinates for this analytical model [3]. The Solution domain is the axial cross-section of the cylindrical waveguide used in the measurement of the standing wave.

We assumed that the electron beam has the uniform diameter of 6mmϕ, and is a Gaussian pulse with the half width of 20psec in the direction of propagation, also injects periodically (every 350psec) according to the acceleration period of the clystron.

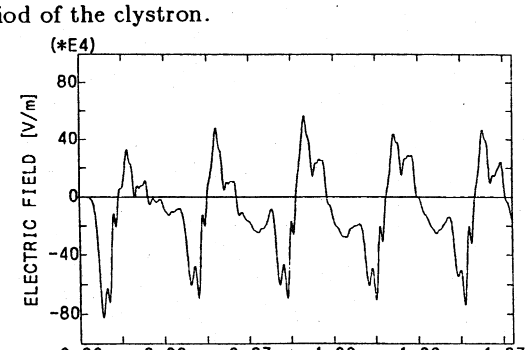

Figure 5. Time variation of the electric field E_r at point (r,z)=(47,400),and $\Delta t = 1.668$psec, $\Delta r = \Delta z = 1.0$mm.

B. Numerical Result

Fig.5 shows time variation of electric field in the cylindrical waveguide. After the calculated values were windowed by the hanning window, we transformed them into the frequency spectrum by using the FFT as shown in Fig.6.

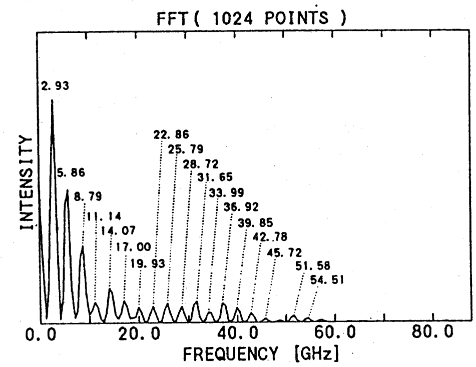

Figure 6. Frequency spectrum by FD-TD method.

IV. Conclusion

To obtain the wave information about pulses, we measured a standing wave and calculated the transient electromagnetic field. As a result of comparing the frequency spectrum of them, we found that several frequencies corresponded, specifically for 25.92GHz, 31.79GHz etc.. These frequencies also depended on the resonance frequency and their higher harmonics of the antenna. Therefore it is necessary to measure standing waves for a lot of antennas, which have diferent resonance frequencies, in order to obtain the true power spectrum. This technique potentially is effective to analyze the spectrum of the electromagnetic field created by linac electron beam.

V. References

[1] K. S.Yee, "Numerical solution of inital boundary value problems involving Maxwell's equations in isotropic media," *IEEE Trans. on Antennas and Propagation*, vol.AP-14,pp.302-307,May 1966.

[2] A. Taflove and M. E. Brodwin, "Numerical solution of steady-state electromagnetic scattering problems using the time-dependent Maxwell's equations," *IEEE Trans. Microwave Theory Tech.*,vol.23,pp.623-630, Aug. 1975.

[3] T.Weiland, "On the numerical solution of Maxwell's equations and applications in the field of accelerator physics," *Particle Accelerators*,vol.15,pp.245-292, 1984.