FD-TD ANALYSIS OF SLOT ANTENNAS FOR LINAC BEAM POSITION MONITOR

Shusuke NISIYAMA, Satoshi TOMIOKA and Takeaki ENOTO
Division of Quantum Energy Engineering, Graduate School of Engineering, Hokkaido University
Kita 13, Nishi 8, Kita-ku, Sapporo, Hokkaido 060-8628, Japan

Abstract

In this report, simplified slot antennas for beam position monitor were analyzed numerically to determine the antenna structure. Generally, a slot antenna is the antenna where a narrow slot was installed on a large conductor surface. However, to use a slot antenna for a beam position monitor, the conductor should be small to avoid the beam trajectory. Therefore, the conductor dimension and the slot configuration should be considered to get the suitable characteristics. By this study, it was found that the sensitivity and the frequency characteristics of the slot antenna are mainly influenced by the slot length and the slot position on the conductor surface.

1 INTRODUCTION

We have studied on the slot antenna characteristics for a non-destructive beam position monitor[1]. In general, a slot antenna is composed of a narrow slot on a conductor surface. An incident electromagnetic field induces currents on the conductor surface and the surface current across the slot makes electric potential difference between the slot edges. Therefore, incident electric field across the slot can be detected by the slot antenna. To use slot antennas for a beam position monitor, the conductor surface should be placed perpendicularly adjacent to the beam trajectory. This is because the electric field of a relativistic charged beam is concentrated to perpendicular direction of the trajectory. Therefore, the conductor should be small to avoid the beam trajectory.

In our recent experimental studies[2][3], slot antennas were made on H-wall of small and thin rectangular waveguide resonators. The detected signal power was almost inversely proportional to the square of the distance between the beam and the slot. The beam position between two slot antennas was calculated by the ratio of the sum and the difference of the detected signals. However, the sensitivity and the frequency characteristics of these slot antennas were influenced by the resonator dimension, the slot length, and the feed point structure. It was difficult to characterize the slot antennas by the experiments using S-band multi-bunch LINAC because of the discrete electromagnetic field spectrum.

In this report, to determine the suitable conductor dimension, slot position, and slot size for a beam monitor, the current density on the conductor surface of a simple model is calculated by the finite-difference time-domain (FD-TD) method[4].

2 INDUCED CURRENT ANALYSIS

2.1 Analysis System

First, the induced current on the conductor surface was calculated numerically. The numerical analysis system is shown in Fig. 1. A thin perfect conductor plate was placed perpendicularly adjacent to the beam trajectory. The plate dimension was 30 mm × 30 mm and the thickness was infinitely small. The beam was a single bunch 45 MeV electron beam. The distance between the beam trajectory and the nearest plate edge was 15 mm.

This analysis was carried out by the scattered field FD-TD method using point charge responses[5]. The analysis space consisted of 1 mm cubical unit cells and the discrete time step was 1.9 ps. With these space and time resolution, the electromagnetic field could be calculated with enough accuracy up to 30 GHz frequency. To simulate free space, all outer 12 cells of the analysis space were the Berenger's perfectly matched layer (PML) absorbing boundary[6].

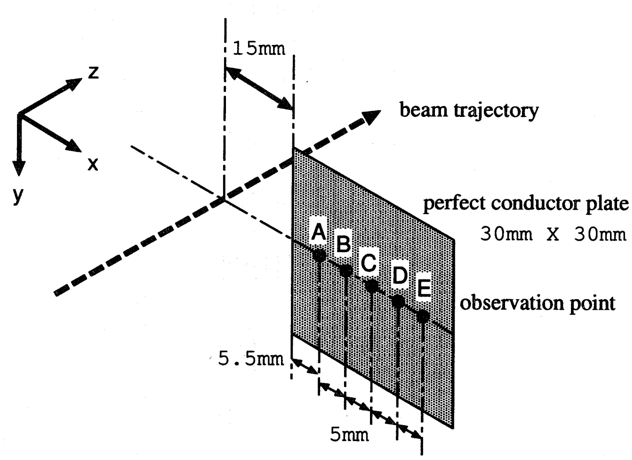

Figure 1: Schematic of the numerical system for induced current analysis.

2.2 Numerical result

Fig. 2 shows the surface current waveforms at observation points, A-E. Because of the system symmetry, the surface currents at these observation points had x direction components only. The beam bunch FWHM was 10 ps.

At t = 105 ps, the beam bunch passed the side of the conductor plate and the incident electric field induced surface current directed to the beam all over the upstream side surface simultaneously. The surface current density was inversely proportional to the distance to the beam trajectory.

Positive charges were concentrated at the nearest point to the beam on the conductor plate by the induced current. Then the positive charges moved to the opposite edge. At the observation point A, the moving charges made current peak at 23.5 ps after passing the beam. The 23.5 ps delay is equivalent to 7.0 mm distance with the velocity of light. However, the distance of the point A and the edge was 5.5 mm. The peak time difference at point A and B was 17 ps. It is equivalent to 5 mm, that is the distance between these points. The excess 1.5 mm (5 ps), therefore, seems the capacitance effect of the edge. The positive charges passed at the observation point from A to E sequentially with 17 ps interval and the peak current density decreased exponentially with the distance from the edge.

Since the second current peak was opposite polarity with the first peak, current spectrum was enhanced at the frequency that the cycle time was twice of the time difference between these peaks. Fig. 3 shows the contour map of the surface current spectrum on the center of the conductor surface. The abscissa is distance from the beam side edge of the plate and the ordinate is frequency. At 10 GHz or higher frequency, the large current density area was found at 3-8 mm away from the edge. The distance, however, was smaller than a half of the wavelength. It was nearly a quarter of the wavelength. Because of the capacitance effect of the edge, and because at closer position to the beam the surface current was greater, the large current density area shifted to the beam side. At 4 GHz, the half wavelength resonant occurred and at lower frequency the current density was small. In other analyses with different conductor plate dimension, similar results were obtained.

3 SLOT VOLTAGE ANALYSIS

Next, a slot was placed on the perfect conductor plate and electric potential difference between the slot edges was calculated. The numerical analysis system is shown in Fig. 4. A 20 mm, a 10 mm, and a 6 mm length slots were analyzed, respectively. These slots were 2 mm width and were placed on the plate 5 mm away from the beam side edge. At the slot position, the surface current spectrum intensity variation was small in 10 GHz or higher frequency range. The slot voltage spectra are shown in Fig. 5. Each spectrum made a peak at half wavelength resonant frequency. The peak intensity of the spectrum was almost proportional to the slot length. Since these slots were relatively wide, each slot length was about 0.45 wavelength at the resonant frequency.

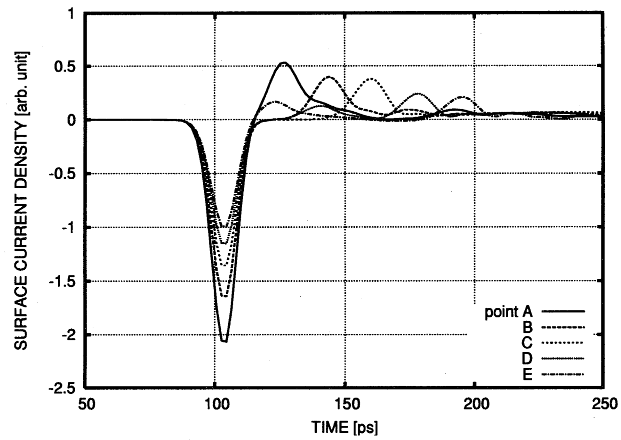

Figure 2: Surface current density at each observation point.

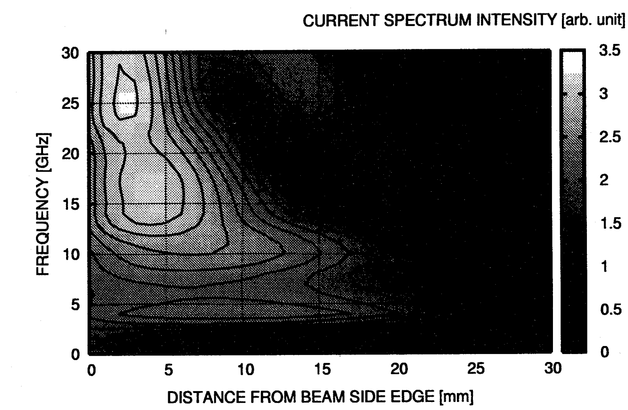

Figure 3: Contour map of surface current density spectrum.

Fig. 6 shows spectra of same 6 mm length slot at different slot positions. Each distance between the slot and the beam side edge of the plate was (a) 5 mm, (b) 10 mm, and (c) 15 mm, respectively. In Fig. 3, the surface current spectrum contour map, it is found that at 22 GHz or higher frequency current spectrum decreased at position (b). The slot voltage spectrum at position (b) also decreased at 22 GHz or higher frequency. At position (c), the surface current spectrum was decreased at 12-22 GHz, and the slot voltage spectrum was also decreased in the same frequency range. Consequently, the slot position should be determined with considering the surface current distribution at the signal frequency.

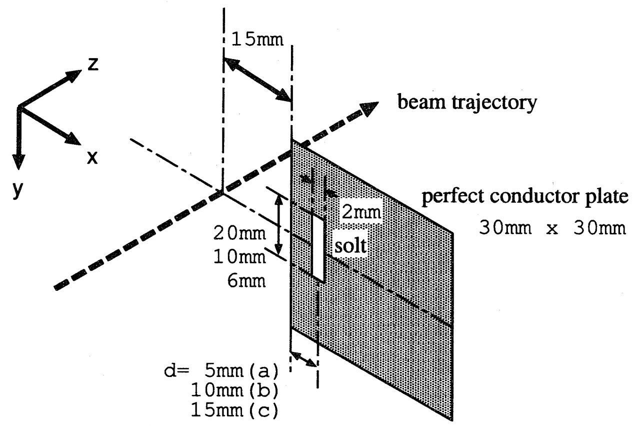

Figure 4: Schematic of the numerical system for slot voltage analysis.

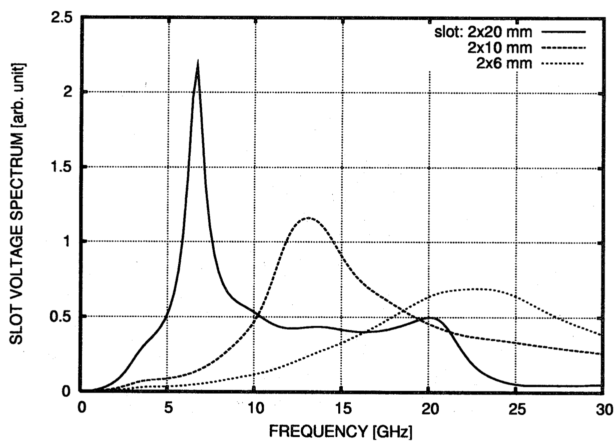

Figure 5: Slot voltage spectrum. Each slot length was 20mm, 10mm, 6mm, respectively.

4 CONCLUSION

In this report, simple slot antenna models were analyzed numerically with the scattered field FD-TD method. It was found that the slot antenna has good sensitivity at the half wavelength resonant frequency even if the electromagnetic field is not a plane wave but is generated by an adjacently passing beam. The sensitivity is almost proportional to the slot length. The slot position on the conductor surface affects the sensitivity. The sensitivity is enhanced at the frequency that the distance between the slot and the beam side edge of the plate corresponds to a quarter of the wavelength.

For more exact analysis, the feed point structure and the impedance of the antenna should be considered.

5 REFERENCES

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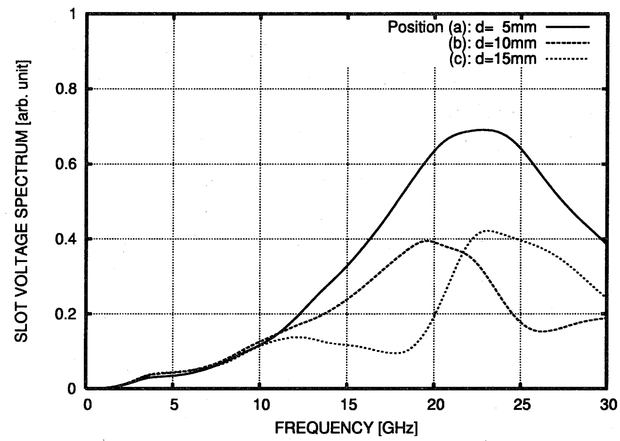

Figure 6: Slot voltage spectrum at various position.