CALCULATION OF WAKEFIELDS IN 17 GHz BEAM-DRIVEN PHOTONIC BANDGAP ACCELERATOR STRUCTURE*

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Abstract

We present computer simulations of the wakefields in a Photonic Band Gap (PBG) structure. Using the commercial code CST Particle Studio, the fundamental accelerating mode and dipole modes are excited by passing an 18 MeV electron beam through the structure. Three dipole modes (TM_{11}-like, TM_{12}-like and TM_{13}-like) are excited with the same order of amplitude, and all of these modes are damped quickly due to the lower quality factors. The comparisons of the wakefields in a round-rod PBG structure and disc-loaded waveguide (DLW) structure are carried out and verify that the PBG structure has advantages to damp the unexpected dipole modes. All of the simulation results will guide the design of next generation high gradient accelerator PBG structures.

INTRODUCTION

In accelerator structure design, wakefield damping, especially transverse wakefield damping is a significant consideration. The transverse wakepotential can be described as [1]:

$$W_{\perp}(s) = \sum_{n} k_{mn} \sin\left(\frac{\omega_{mn} s}{c}\right) e^{-\frac{\omega_{mn} s}{Q_{mn} c}}$$

where k_{mn} is the kick factor, ω_{mn} is the frequency and Q_{mn} is the quality factor of TM_{mn} mode.

All kinds of structures have been built to provide sufficient wake potential damping. Due to the band gap property, photonic crystals have become an attractive field of research in accelerator science. Photonic Band Gap (PBG) structure using in accelerator has been intensively researched theoretically and experimentally [2-3]. The designed PBG structure with a defect can confine the fundamental mode (TM_{01}) at the center and let higher frequency modes leak out. A 17 GHz PBG accelerator structure has been designed, simulated and tested at PSFC MIT [4-5] and has demonstrated sufficient damping effect of the dipole modes.

In this paper, we report the PIC (particle in cell) code simulations of the wakepotential in the MIT 17 GHz PBG structure. Early theoretical calculations indicated that there is only a single mode (TM_{11}) considered as dipole mode involving the transverse wakepotential. The results from CST Particle Studio show that there are three dipole-like modes: TM_{11}-like, TM_{12}-like and TM_{13}-like that are excited by an off-axis electron beam. The characteristics of each dipole mode including the amplitude, damping time and quality (Q) value are analyzed. The comparison of the PBG structure and the disk-loaded waveguide (DLW) structure is carried out.

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WAKEPOTENTIAL CALCULATION

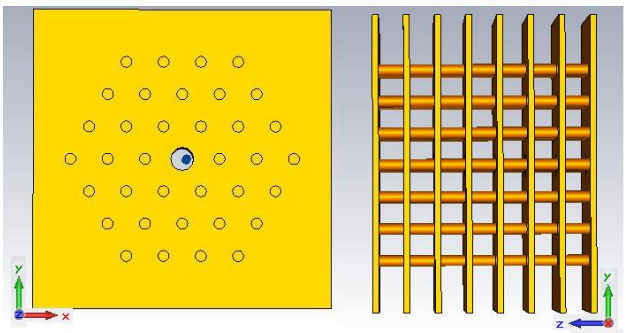

Figure 1: Schematic of seven cells PBG structure. The structure is formed by three layers of triangular lattice of metallic cylindrical rods. The central rod is removed to form a defect region to confine the fundamental TM_{01} mode. The dimensions are given in Table 1.

Table 1: Dimensions of the PBG structure

Geometric parameters	Value
Rod radius a	1.04mm
Rod spacing b	6.97mm
Iris thickness t	1.14mm
Iris diameter d	4.32mm
Cavity length L	5.83mm
TM_{01} mode frequency	17.14GHz
Accelerating mode	2π/3 mode
Electron beam diameter	1mm
Beam Displacement	0.8mm
Number of cells	7

The 17 GHz PBG structure is shown in Fig. 1 for the simulation. Wakefield Solver in CST Particle Studio is used to calculate the longitudinal and transverse wakepotential and wake impedance. A seven cell structure is used. One bunch of an electron beam is injected into the beam tunnel with a 1 mm Gaussian width and a 0.8 mm displacement in the X direction. The geometric parameters of the PBG structure are shown in Table1. The metallic rods and plates are lossy copper. The boundary around the structure is PML.

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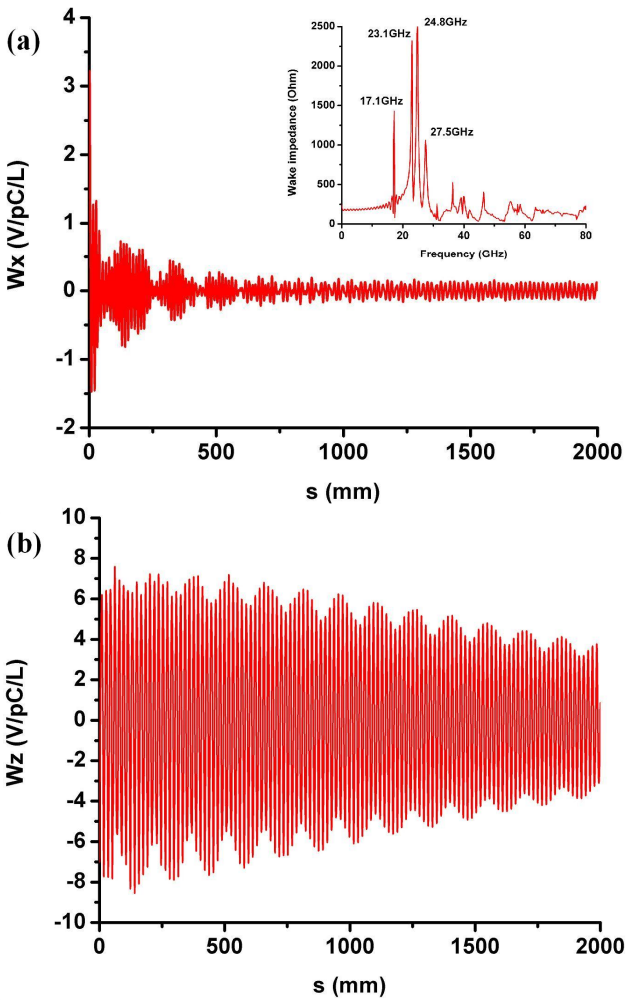

Figure 2: Calculation of Wake potentials. (a) Transverse wake potential measured on the beam axis and normalized by the cavity period L; the top right graph is the frequency spectrum of the transverse wakepotential. (b) Longitudinal wakepotential measured on the beam axis.

Figure 2 demonstrates the calculated transverse and longitudinal wakepotentials vs. distance from CST PS wakefield solver. Fig.2 (a) is the calculated transverse wake potential which damps quickly along the distance. The spectrum of the transverse impedance is obtained on the top right of Fig.2 (a). The component of transverse wakepotential at the fundamental mode frequency 17.1 GHz is identified, which is formed due to the irises and is confined at the defect area. Shown in the spectrum, three modes are excited ranging from 23.0 GHz to 27.5 GHz with the same order of amplitudes. The field distributions of these modes are shown in Figure 3. The three modes are distinguished as TM_{11}-like, TM_{12}-like and TM_{13}-like modes separately and all of these modes are not confined but radiate away from the center to the outer boundary. The longitudinal wake potential in Fig.2 (b) decays slowly at the fundamental frequency 17.1 GHz.

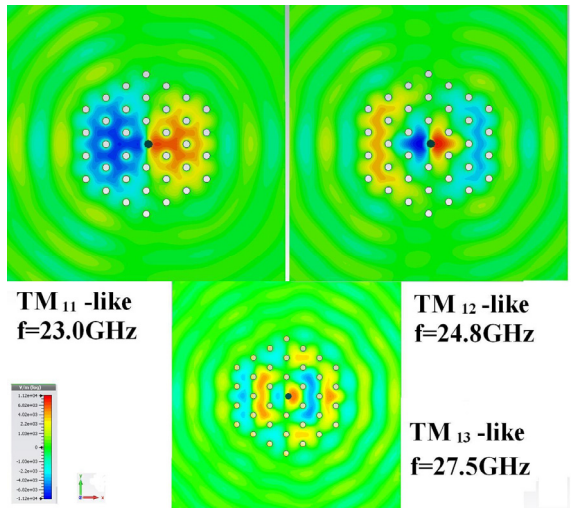

Figure 3: Field distribution of three dipole modes, identified as TM_{11}-like mode at 23.0 GHz, TM_{12}-like mode at 24.8 GHz and TM_{13}-like mode at 27.5 GHz.

DIPOLE MODE ANALYSIS

Figure 2 (a) shows that the transverse wake potential in the PBG structure is quickly damped. However, the first three dipole modes that are close in frequency and approximate intensity are excited. The whole effect of all these dipole modes may be dangerous. Then we use numerical filtering to separate the components of each mode in the transverse wakepotential to study the damping in detail.

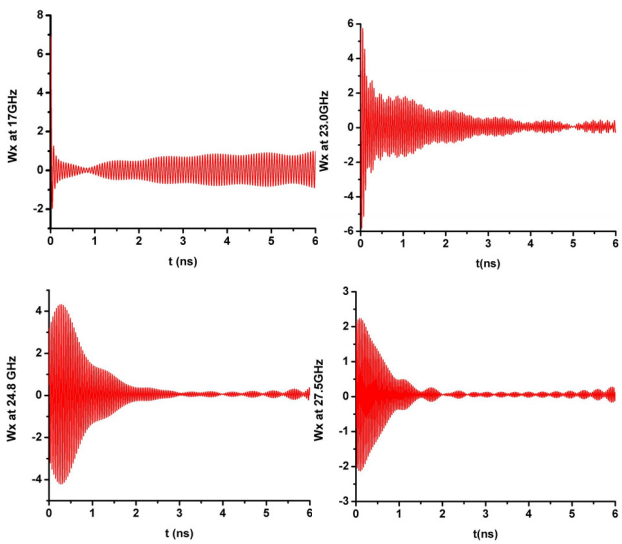

Figure 4: The transverse wakepotential components at the fundamental TM_{01} mode 17 GHz, First dipole TM_{11} mode 23.0 GHz, Second dipole TM_{12} mode 24.8 GHz and Third dipole TM_{13} mode 27.5 GHz.

Figure 4 shows the filtered main components of the transverse wakepotential. The amplitudes of these components are coincident with the peaks in the spectrum. The components at the fundamental mode frequency 17 GHz last for a long time at an almost constant intensity. This part of the transverse wakepotential is caused by the irises and does not decay due to the confined TM_{01} mode.

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The first dipole mode, the TM_{11}-like mode, decays more slowly than the two other dipole modes and has higher amplitude at the beginning part. The second dipole mode is excited with a short time delay and lasts a shorter time. The third dipole mode is lower than half intensity of the previous dipole modes and decays faster.

To study the diffractive quality factor of each mode, HFSS simulations are run with the same simulation environment as in CST PS. The ohmic loss and irises are included. The phase differences between cells are set as $2\pi/3$ for the fundamental mode and π for the dipole modes which comes from the calculation of CST PS results.

Table 2: HFSS simulation results

Modes	Eigenmode frequency	Q values
TM_{01}-like	17.1 GHz	3955
TM_{11}-like	23.2 GHz	71
TM_{12}-like	24.7 GHz	57
TM_{13}-like	27.0 GHz	45

The results of eigenmode calculations in HFSS are shown in Table 2. The quality factors in Table 2 contain both the ohmic losses and diffractive losses in the structure. The HFSS simulation results agree well with the CST simulations.

COMPARISON OF PBG AND DLW

The previous results display an expected damping effect on the dipole modes of the PBG structure. The comparison of the PBG structure and the DLW structure should be carried out. We ran CST PS to simulate the DLW structure with the same fundamental mode frequency, the same dimension of period, irises and beam tunnel and the coincident beam parameters. The wake potentials from the two structures are both normalized by unit beam and cavity period.

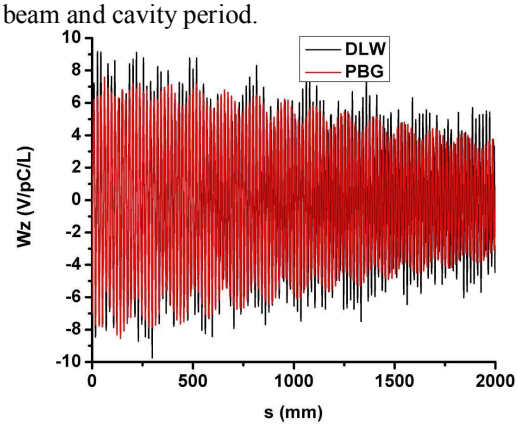

Figure 5: Comparison of longitudinal wake potential between DLW and PBG structure.

Figure 5 shows that the longitudinal wake potentials decay because of the ohmic losses of copper in both structures. The small difference between the amplitudes reveals that the TM_{01} mode is strongly confined.

Figure 6 certifies that the transverse wake potential in the PBG structure damps much more quickly than in the DLW structure.

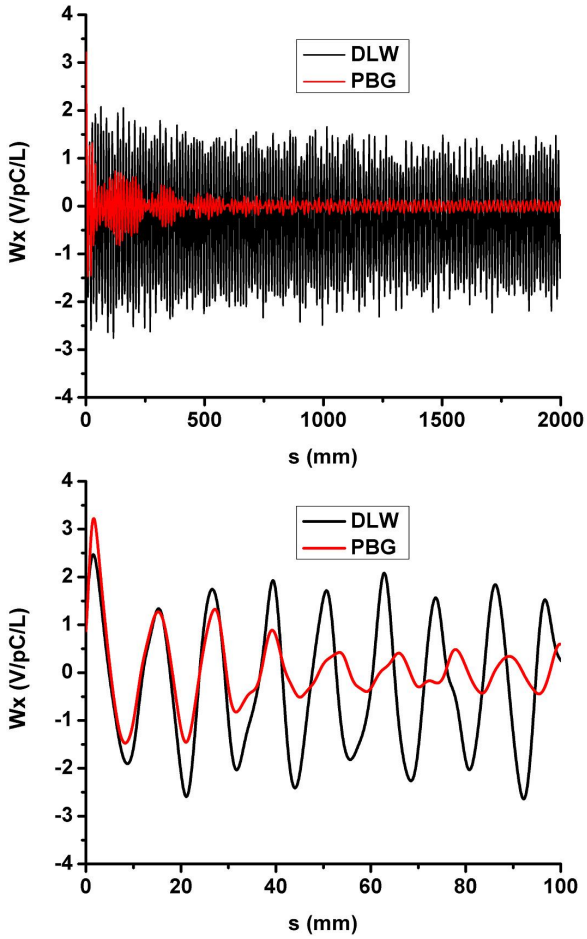

Figure 6: Comparison of transverse wake potential between DLW and PBG structure.

In conclusion, PIC simulations demonstrate the effective damping in PBG structures for accelerator applications.

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