BPM SIMULATION OF BEPCII

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Abstract

Considering the effect of photoelectron, BEPCII's beam vacuum pipe will adopt antechamber structure. Because of the slot effect, the cutoff frequency of TE_{10} mode is maybe lower than the BPM signal processing frequency of 500MHz. The power of TE_{10} mode around 500MHz will propagate in the vacuum chamber and penetrate the electrodes of BPM. So the beam position measurement error will be generated. Simulating the problem with MAFIA program, we found that the error is beyond the acceptance when the cutoff frequency of TE_{10} mode is lower than 500MHz. When the cutoff frequency is higher than 500MHz, the error can be accepted. In this paper, the simulation for the effect of the wakefield to the beam and calculation for the longitudinal impedance will also be described in detail.

INTRODUCTION

In the upgrade plan of Beijing Electron Position Collider, the beam vacuum pipe will adopt an antechamber structure, which has a slot for absorbing photoelectron. Considering the absorbing to photoelectron, the slot length is hopeful long enough. But increasing the slot length will decrease the cutoff frequency of TE_{10}-like mode. When the TE_{10} mode's cutoff frequency is lower than the BPM signal processing frequency of 500MHz, the TE_{10} mode power that penetrates the BPM's electrodes will cause an obvious beam position measurement error. We simulated this problem with Mafia program and given an optimized slot length that is taken into account the balance between absorbing photoelectron and reducing the measurement error.

SIMULATION OF TE MODE POWER

BEPCII's BPM antechamber structure is shown in Fig. 1. Each BPM has four electrodes located on the top and bottom of the chamber. The diameter of electrode is 15mm. There is a gap between the electrode and feed through housing. The gap width is 1mm. The BPM button gaps, which break the continuity of the vacuum chamber, will cause beam losing energy in this structure. The TE_{10} mode will be excited when the beam is off axis. When the slot length is 200mm, the TE_{10} mode cutoff frequency is 416MHz which is lower than the signal processing frequency 500MHz. The first TE mode (TE_{10}-like mode) at the frequency 500MHz is transfer mode with $\beta=5.8m^{-1}$ and the other is not. So we mainly consider the TE_{10}-like mode's effect of generating beam position measurement error.

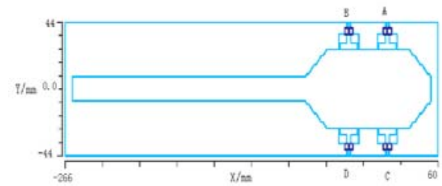

Figure 1: Transverse structure of BEPCII's BPM.

The TE power generated by the BPM can be calculated using Mafia program by driving beam off axis [1]. Considering the convenience of calculation with Mafia, we use a line current source to replace the beam source. The line current source has a Gauss distribution with pulse width σ_z=1.5cm as the beam does. By driving the line current source off axis 1cm both the x and y directions, we simulate the TE mode power generation in the BPM vacuum chamber. The fields generating and propagating in the vacuum chamber can be decomposed into the waveguide eigenmodes. In particular, we monitor the amplitude of the TE_{10} mode as a function of time. At the same time, we should monitor the signal amplitude as a function of time which produced on the output port of the coaxial cable connected with the BPM's electrodes. Because the electronics of signal processing work on a narrowband mode, the useful information in interested spectrum can be obtained from the Fourier transform of the time variation.

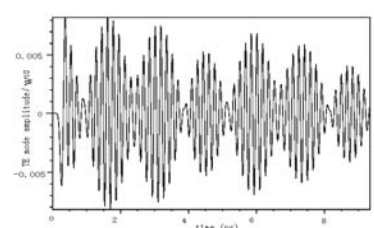

Figure 2: TE_{10} mode amplitude.

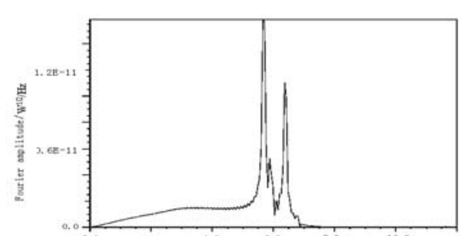

Figure 3: Spectrum of the TE_{10} mode.

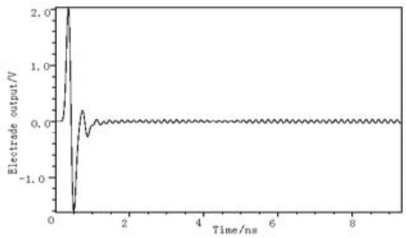

Figure 4: Signal amplitude on the output port.

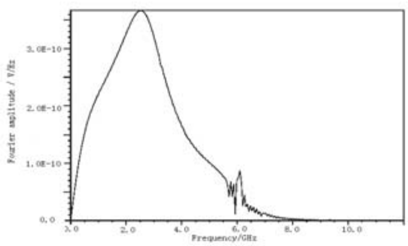

Figure 5: Spectrum of the output signal.

The power of TE_{10} mode or useful signal on output port can be obtained by integrating the spectrum within the interested frequency range, see Fig.2 to Fig.5. Because the electronics processes the signal at 500MHz with bandwidth 20MHz, the power can be given by

$$p = \Delta f \cdot \left| F(f_0) \right|^2 \cdot q^2 \Big/ 2\pi \cdot \sigma_t^{\,2} \cdot t_b \qquad (1)$$

where f_0 is the central frequency, Δf is the bandwidth of the signal processing frequency, q is the bunch charge, σ_t is the bunch length in unit of time and t_b is the bunch spacing in time. In the stance of BEPCII, q=4.85×10^{10}e, t_b=8ns and σ_t=0.05ns. So the power of TE_{10} mode in the chamber is 0.219μW. Consequently, the output power of electrodes A, B, C, D is 4498μW, 326μW, 414μW and 123μW respectively. The corresponding to the voltage on the coaxial cable connected with electrodes A, B, C, D is 474mV, 127mV, 143mV and 78mV, respectively.

TE POWER TRANSMISSION

TE_{10} mode propagates in the chamber, and couples to the electrodes when passing the button. It's not all TE_{10} mode power coupling to the electrodes of the BPM. So we should calculate the efficiency of power coupling. The TE modes have a certain electric field distribution, as shown in Fig.6. It can be seen that the TE_{10} mode's electric field centralized in the slot. We calculate the transmission coefficient to determine how much TE_{10} mode power penetrates to the electrodes of BPM. All of the four output signals should be monitored when the TE_{10} mode at 500MHz is driven in the BPM vacuum chamber. The transmission coefficients at electrodes A, B, C and D are found to be 2.0×10^{-3}, 3.75×10^{-3}, 2.0×10^{-3} and 3.75×10^{-3}, which correspond to power transmissions of 4.0×10^{-6}, 1.406×10^{-5}, 4.0×10^{-6}, 1.406×10^{-5} respectively.

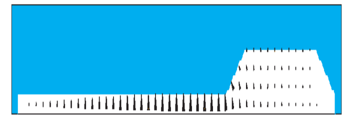

Figure 6: Electric field pattern of TE_{10} mode.

TE_{10} mode is a transmission mode at 500MHz in the BPM vacuum chamber. Considering the surface impedance of vacuum chamber, the attenuation constant of TE_{10} mode is about 3.28×10^{-3}m^{-1}. Because the reflection coefficient at the boundary of BPM vacuum chamber is very large and the length of BPM vacuum chamber is 3m, the times of TE_{10} mode power passing the BPM is equal to 101 times. In the stance of BEPCII, all the power of TE_{10} mode at 500MHz coupling to the electrodes A, B, C and D are 8.94×10^{-5}μW, 3.14×10^{-4}μW, 8.94×10^{-5}μW and 3.14×10^{-4}μW, which correspond to voltage output 0.0669mV, 0.125mV, 0.0669mV and 0.125mV, respectively.

The y-vector of electric field radiated by the bunch has the same phase to any of the electrodes of the BPM. But the phase of TE_{10} mode to the top electrodes has the opposite sign relative to the phase to the bottom electrodes. Considering the method of calculating x and y position [2], the TE_{10} power does not cause beam position measurement error in x direction. The error of y direction can be given by

$$\sigma = \frac{2 \cdot (PT_A^{\,1/2} + PT_B^{\,1/2}) \cdot y_R}{PB_A^{\,1/2} + PB_B^{\,1/2} - PB_C^{\,1/2} - PB_D^{\,1/2}} \qquad (2)$$

where PT is the power of TE_{10} mode coupling to the electrodes, PB is the output power of electrode, and y_R is the beam displacement in y direction. In the stance of slot length L=200mm, the position measurement error caused by coupling of TE_{10} mode power is 10.1μm. The error is beyond the acceptance. Finally, we change the slot length to 75mm. In this stance, the cutoff frequency is 868.8MHz and the TE_{10} mode power passes the BPM only one times. The output power of electrodes does not change and the TE_{10} mode power generated in the chamber is 0.568μW. The transmission coefficients at electrodes A and B are 2.0×10^{-3} and 3.75×10^{-3}. So the position measurement error caused by coupling of TE_{10} mode power is 2.1μm. The error can be accepted. Considering the position measurement error caused by TE_{10} mode and absorbing photoelectron, the BPM's structure is like Fig.1, but the slot length is 75mm.

WAKEFIELD AND IMPEDANCE

At last, we simulate the effect of wakefield, and calculate the longitudinal impedance and loss parameter of the structure [3], as shown in Fig.7 and Fig.8.

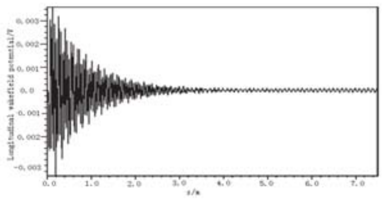

Figure 7: Longitudinal wakefield vs. particle position.

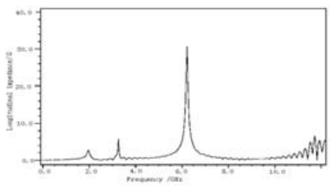

Figure 8: Longitudinal impedance spectrum.

It can be seen that there is a narrowband impedance peak of 30Ω at frequency of 6.4GHz. It should be generated by the BPM electrode, and be related with the TE_{11} cutoff frequency of 5.96GHz of the waveguide port, which is composed of electrode and the aperture for fitting it. But we should have more detailed research of the question. From the longitudinal wakefield, the inductance of a BPM is estimated to be 0.026nH or the broadband impedance to be $2.06\times10^{-4}\Omega$. Because the beam passes the chamber in the longitudinal wakefield, particles of the beam lose energy in the chamber. By integrating the lost energy, the loss parameter of a BPM is 9.21×10^{-4}V/pC. For the stance of BEPCII, power loss of a BPM is 6.95 W.

SUMMARY

Because the antechamber structure reduces the cutoff frequency of TE_{10} mode, the power of TE_{10} mode coupling to the electrodes causes beam position measurement error. We simulated this problem with Mafia program. The error is 10.1μm and beyond the acceptance when the slot length is 200mm and the cutoff frequency of TE_{10} mode is lower than 500MHz. The error can be accepted when the cutoff frequency is higher than 500MHz. At last, we simulated the longitudinal wakefield effect to the beam.

REFERENCE

[1] J. Corlett, C.-K. Ng et al., Effect of TE Mode Power on the PEPII LER BPM System, Proc. of PAC97 p2116-2118, Vancouver, 1997.

[2] Ma Li, Shi Ping, Ye Kai-Rong. HEP&NP, 1998, 22(5): 475-480.

[3] C.-K. Ng, T. Weiland, D. Martin D et al., Simulation of PEP-II Beam Position Monitors, Proc. of PAC95, p2485-2487, Dallas, 1995.