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Measurement of resonance modes causative of beam position monitor signal noise in vacuum chamber of storage ring

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ABSTRACT

It is known that the position reading obtained from the beam position monitor (BPM) mounted at the storage ring can be corrupted by the resonance mode. We carried out a three dimensional finite-difference time-domain (FDTD) simulation of vacuum chambers of the storage ring of the Pohang Light Source (PLS) without simplified modeling to measure the frequencies of resonance modes excited in the vacuum chamber. The frequencies of resonance modes obtained by the eigenmode simulation are well matched with the peak frequencies of RF transmission scattering matrix (S_{21}) graph of sector vacuum chamber measured using a network analyzer. It is found that a transverse electric (TE) resonance mode exists in the operation frequency band of BPM and the vertically oriented electric field of TE resonance mode is linked to the BPM position reading noise. Based on this study, we can easily design a vacuum chamber free from the BPM position reading noise caused by the TE resonance mode.

1. Introduction

A storage ring is a type of circular particle accelerator in which a continuous or pulsed particle beam may be kept circulating for a long period of time, up to many hours. It consists of many vacuum chambers where charged particle beam travel under the influence of magnets positioned around the circumference of the circle. The magnetic fields must be controlled in order to keep the particles on the constant radius path. Therefore a beam position monitor (BPM) [1,2] to detect the position of the particle beam is required. A BPM mounted at vacuum chambers in the storage ring usually consists of four pickup electrodes that are coupled to the particle beam in a capacitive manner. When the charged particle beam passes through the storage ring the electric field of the beam couples to that of the electrode, which leads to a measurable output voltage. The horizontal and vertical positions of the particle beam are then calculated from the voltage difference between the electrodes and are used for a feedback loop to correct the beam orbit.

However, the position reading obtained from the BPMs in vacuum chamber can be corrupted by the noise caused by various reasons. For example, the transverse electric (TE) resonance modes excited in the vacuum chamber with the resonance frequency near storage ring RF frequency can cause BPM noise. The electric field for the TE resonance mode is oriented vertically with propagating particle beam and mixed with vertical BPM position reading signal.

Therefore, there have been many analytical and experimental works to measure the frequency distribution of resonance mode in the vacuum chamber. The storage ring vacuum chamber was simplified to a wedged waveguide and simulated to find the resonance modes [3]. A network analyzer was also used to measure the transmission of RF power from one end of the vacuum chamber to the other using the BPM pickup electrode mounted at opposite ends of the vacuum chamber [4–6].

In this study, we carried out full three dimensional finite-difference time-domain (FDTD) simulation of the vacuum chambers of the storage ring of the Pohang Light Source (PLS). In this eigenmode simulation, the complex structures that cannot be dealt with in simplified wedged waveguide model like photon absorbers, non-evaporate getter (NEG) support structures, and arc section of vacuum chamber are included. The eigenmode resonance frequencies are compared with the peak frequencies of RF transmission scattering matrix (S_{21}) through the pickup electrode of BPMs mounted at both the ends of the sector vacuum chamber. Furthermore, we obtained the electric field distribution in the vacuum chamber and found the relationship between the electric field and the BPM position reading noise.

2. BPM position reading noise in PLS storage ring

The storage ring of the PLS has 12 cells of the same shape and each cell is divided into two sector vacuum chambers; however,

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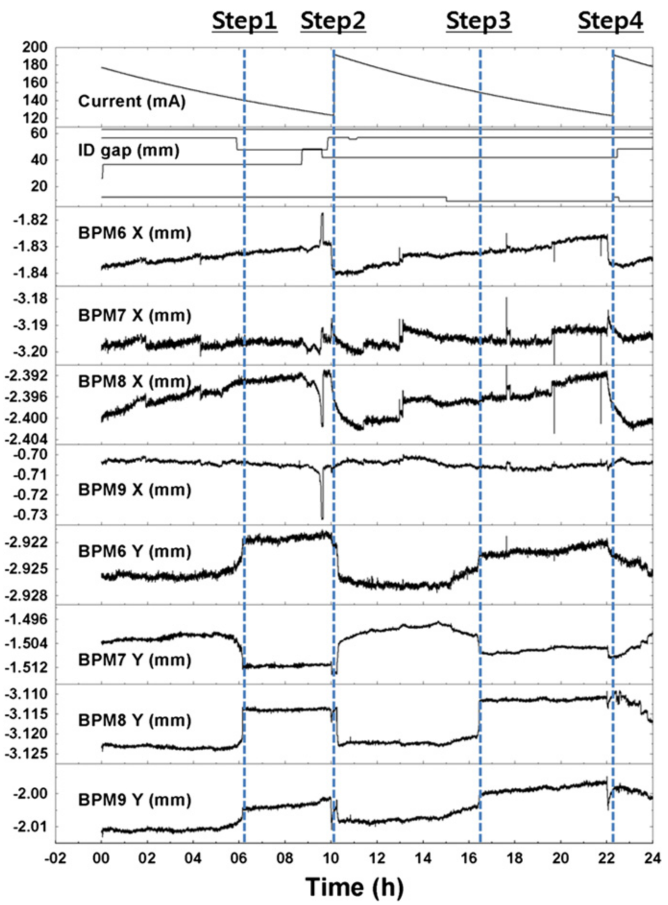

Fig. 1. Temporal variations of beam current, insertion device gap, and horizontal (*X*) and vertical (*Y*) BPM position readings of cell 9 on March 21, 2009.

there are sudden step changes in the vertical position readings of the BPMs mounted in only some of the sector vacuum chambers.

For instance, the time-varying profiles of the beam current, insertion device gap, and horizontal and vertical position readings of BPM 6–9 in cell 9 on March 21, 2009 are shown in Fig. 1. The positions of BPMs and the shape of the sector vacuum chamber of the PLS storage ring are illustrated in Fig. 2(a). Fig. 1 shows four step changes in the position readings of the BPMs. Steps 2 and 4 correspond to beam injection into the storage ring, during which both the horizontal and vertical BPM position readings change. However, the origins of steps 1 and 3, in which only the vertical position reading changes, are not clear. Many possible causes were considered, for instance, ground motion of the storage ring, irregular current from the magnet power supply, and electrical problems with the BPM boards. Finally, it was suspected that the sudden step change in the vertical BPM position reading is linked to excitation of the TE resonance modes inside the sector vacuum chamber because the offset signs of the vertical position readings are not uniform in the different BPMs and the horizontal position readings are relatively quiet.

A large horizontal width of sector vacuum chambers of the PLS is required to extract synchrotron radiation out to the beam port and install vacuum components as shown in Fig. 2(a). Therefore, the beam chamber is connected to the antechamber by a neck of small height as shown in Fig. 2(b). The extended width of the sector vacuum chamber at the neck and antechamber reduces the cut-off frequency of the transverse electric (TE) mode to less than the BPM operation frequency of 500 MHz. Furthermore, the neck introduces a large capacitive loading that lowers the cut-off frequency for TE modes of the chamber in comparison with a rectangular waveguide of the same width. The dominant TE mode in the PLS vacuum chamber is calculated to be at a frequency of 211.2 MHz. Therefore, it is possible for one of the longitudinal harmonics of the TE mode to be excited near the operation frequency of the BPM.

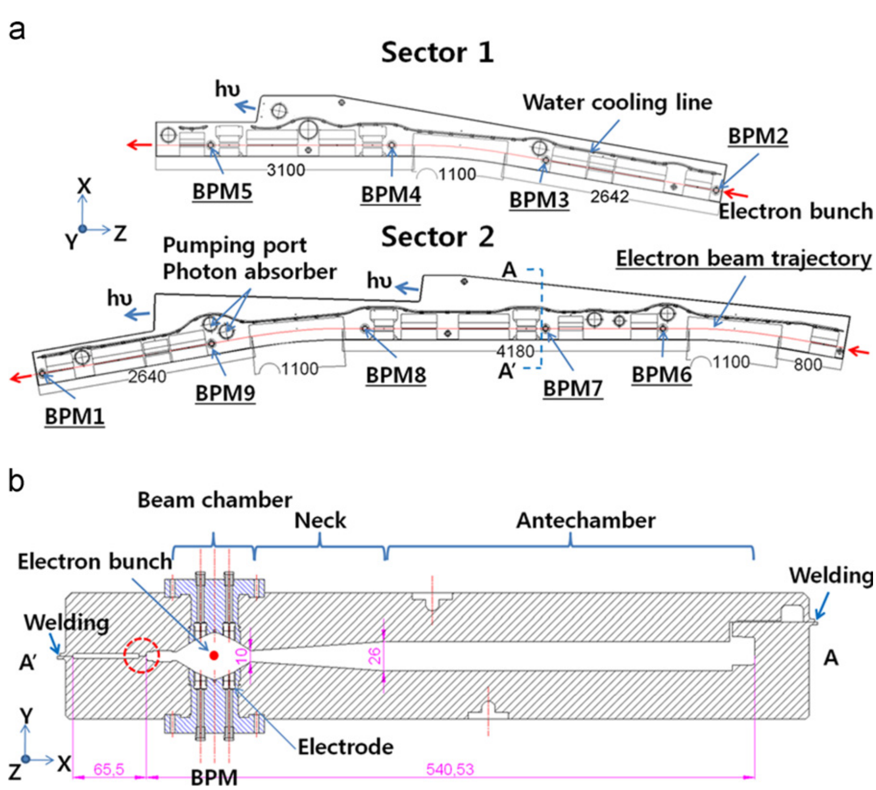

Fig. 2. (a) Top view of sector vacuum chambers of a cell of PLS storage ring with positions of BPMs. (b) Cross-section of normal vacuum chamber of PLS storage ring along line A–A′. The arrows indicate welding points.