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Improvement of the Thermo-Mechanical Position Stability of the Beam Position Monitor in the PLS-II

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In the storage ring of the Pohang Light Source-II (PLS-II), we reduced the mechanical displacement of the electron-beam position monitors (e-BPMs) that is caused by heating during e-beam storage. The BPM pickup itself must be kept stable to sub-micrometer precision in order for a stable photon beam to be provided to beamlines because the orbit feedback system is programmed to make the electron beam pass through the center of the BPM. Thermal deformation of the vacuum chambers on which the BPM pickups are mounted is inevitable when the electron beam current is changed by an unintended beam abort. We reduced this deformation by improving the vacuum chamber support and by enhancing the water cooling. We report a thermo-mechanical analysis and displacement measurements for the BPM pickups after improvements.

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I. INTRODUCTION

The Pohang Light Source upgraded machine (PLS-II) started user service after six months of commissioning in 2011 [1,2]. The PLS-II storage ring vacuum system was designed to maintain a pressure of 10^{-10} mbar to achieve a beam-gas scattering lifetime > 20 h. The vacuum components, especially photon absorbers and rf-shielded bellows were designed to endure 3-GeV and 400-mA beam operation [3]. The vacuum system design was also focused on providing a stable photon beam.

The electron beam size in the storage ring should be as small as possible for a bright photon beam to be provided to beamline. The designed electron beam size of the PLS-II in a short-straight section is 12 μm in the vertical direction, and the orbit must be stable to sub-micrometer precision because the beam-orbit instability should be $< 5 \sim 10\%$ of the beam size. One factor that has a strong influence on this requirement is the mechanical position stability of the e-BPMs that are mounted on the vacuum chambers. Because the orbit feedback system is programmed to make the electron beam pass through the center of the BPM, the mechanical stability of the BPM pickup itself is also important [4].

The PLS-II vacuum chamber support near the e-BPM pickup was designed to keep it immovable with respect to the reference plane of the beam-orbit. The support made of stainless-steel bars is bolted very tightly to the bottom of the vacuum chamber. This strong support was expected to prevent change in position of the BPM due to external force. During the design stage, thermo-mechanical deformations due to changes in the electron-beam current were not thought to be significant because the PLS-II was intended to operate in top-up mode, in which electrons are frequently injected into the storage ring to make up for decay of the stored beam and to give a constant electron-beam current.

However, the original design of the vacuum chamber and the support of the PLS-II had two flaws (Fig. 1). First, when the temperature increases, the vacuum chamber expands upward because the fixed support is mounted on the bottom of the chamber; as a result, the physical center of the BPM pickup moves. An unintended beam abort during operation can also cause thermo-mechanical deformation of the vacuum chamber because the electron-beam current is abruptly changed from 400 mA to 0 mA in < 1 s. Second, the position of the BPM pickup stabilizes slowly even though the beam current recovers quickly after a beam abort because the temperature of the vacuum chamber takes ∼3 h to equilibrate after the ring is re-filled.

II. DESIGN OF NEW THE VACUUM CHAMBER AND SUPPORT

In August of 2015, one sector of the storage ring was changed to a new vacuum system according to the plan

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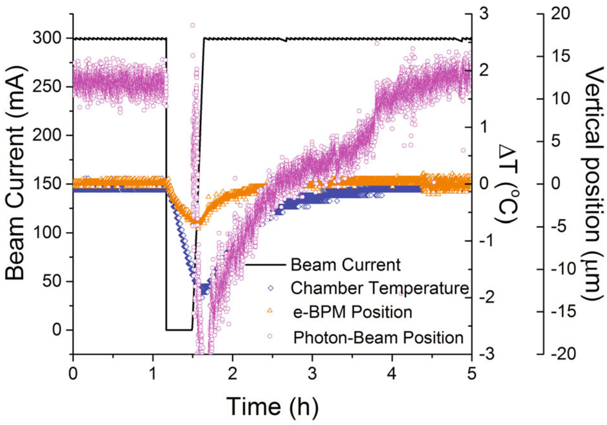

Fig. 1. (Color online) Typical behavior of the BPM pickup displacement on the bending magnet chamber after an abrupt beam abort. The beam current is recovered within half an hour, but the temperature or displacement of the BPM stabilizes only after 3 h, so the photon beam is unstable.

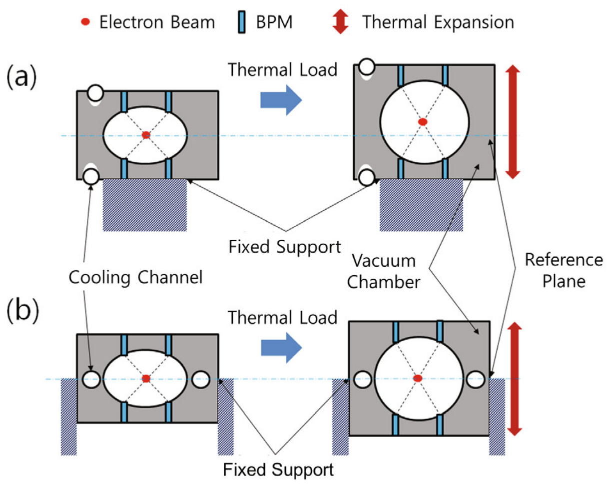

Fig. 2. (Color online) Schematics of the thermo-mechanical deformation of (a) the existing support design and (b) the new support design.

of the new elliptically polarized undulator (EPU) installation. The photon-beam size and flux from this new EPU are much larger than from the existing one, so the vacuum system (including the bending magnet chamber and the photon absorbers) located downstream of this insertion device were replaced with a new robust one. In addition to compatibility with the new EPU, plans were also made to improve the mechanical stability of this part.

The most important requirement for thermo-mechanical stability is good cooling efficiency for the vacuum chamber. The cooling channel for the existing chamber consists of a copper pipe mounted on the grooves of the vacuum chamber; this indirect cooling scheme has low efficiency. Another problem is the one-sided cooling with respect to the electron-beam

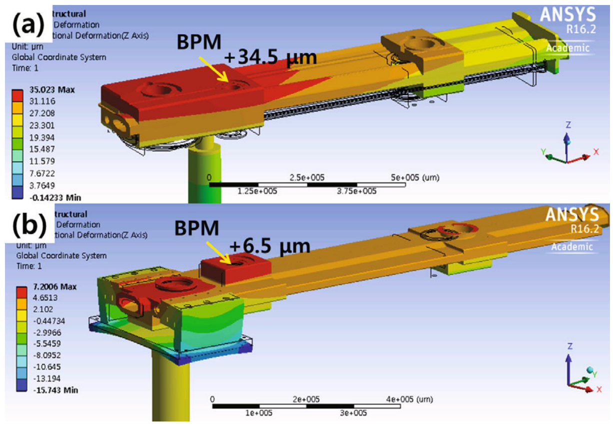

Fig. 3. (Color online) Thermo-mechanical analyses of the BPM pickup for (a) the existing chamber and support and (b) the new chamber and support for a multipole-II chamber of the PLS-II.

channel. The unbalanced heat dissipation by this cooling configuration can cause non-uniform deformation of the BPM chamber. We re-designed the vacuum chamber to include cooling channels on both sides of the beam channel for direct and uniform cooling; we also revised the support for the BPM chamber so that it would expand equally in the vertical direction when heated.

The new vacuum chamber and support system undergo much less thermo-mechanical expansion than the existing ones (Fig. 2). The center of the BPM in the existing vacuum chamber rises when heated (Fig. 2(a)) because the chamber can only expand upward due to the fixed support that holds up the chamber from the bottom. In contrast, the center of the BPM pickup in the new design stays in the original position, regardless of thermal load (Fig. 2(b)).

III. IMPROVEMENT IN THE MECHANICAL STABILITY OF THE BPM PICKUP

We calculated the thermo-mechanical effect for both types of vacuum chambers and supports, and then compared the thermal displacements and the times to thermal equilibrium. The storage ring vacuum chamber is heated mainly by synchrotron radiation that is reflected from the photon absorbers and by the electron-beam image current. The synchrotron radiation power from a bending magnet of the PLS-II storage ring is ∼ 17.5 kW when a 400-mA beam is stored; about 20% is reflected onto the vacuum chamber. For the Multipole-II chamber of the PLS-II, taking into account that the length ratio of this chamber is only 1.3 m/282 m, we assumed the uniform heat load of 26 W (16 W from the synchrotron radiation + 4 W from the image current + 6 W from the higher order mode (HOM) heating of the BPM pickups) to be dissipated on the inner surface of the electron

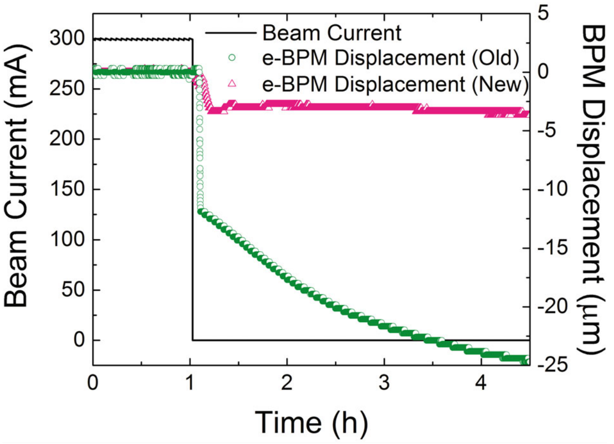

Fig. 4. (Color online) Measured BPM pickup displacement after an abrupt beam abort from 300 mA.

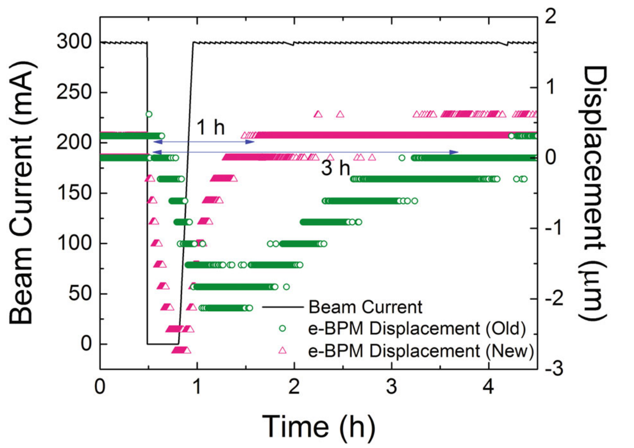

Fig. 5. (Color online) Required time to reach equilibrium after an abrupt beam abort followed by quick recovery of the beam current.

beam chamber. The boundary condition for cooling hole of the new chamber is set to 0.01 W/(mm^2·K), which is the typical convection coefficient of water, but for the existing chamber where the copper pipe is mounted on the outside groove of the chamber, the convection coefficient was assumed to be 10% that in the case with perfect contact. This assumption was based on the observation that the contact area between the cooling pipe and the chamber groove is $\leq$ 10% the groove area.

The thermo-mechanical analysis indicated that the displacements of the BPM pickup were smaller for the new designs than for the existing ones (Fig. 3). The BPM pickup in the old vacuum chamber moved about 34.5 μm vertically when heated (Fig. 3(a)), but that in the new vacuum chamber moved only about 6.5 μm (Fig. 3(b)). A linear variable differential transducer (LVDT) was used to measure the actual position of the top of the BPM. When the electron-beam current was abruptly decreased from 300 mA to 0 mA, the top of the existing chamber dropped 25 μm, but that of the new chamber dropped only 3.5 μm (Fig. 4). The difference between the simulated and the measured values is due to the difference in the stored current (400 mA or 300 mA), but the new chamber and support design is effective for both results.

This displacement can also be reduced by adjusting the location of the cooling channel and the contact between the chamber and the support. In the existing system, the contact points of the chamber and the support are just below the beam channel where heating is not negligible (Fig. 2), so a small amount of the heat is transmitted to the support and, therefore, the support itself also expands upward; this expansion amplifies the displacement. However, in the new chamber, the contacts between the chamber and the support are outside the cooling channel. In this arrangement, very little heat is transferred from the chamber to the support.

Due to its increased cooling efficiency, the new system reaches thermal equilibrium much faster than the old one after sudden change in thermal load (Fig. 5). When a beam was aborted suddenly due to a machine interlock from some reason and the beam current in the storage ring was recovered within 30 min, the new vacuum chamber took 1 h to reach thermal equilibrium whereas the old one took 3 h. During this time, the photon beam provided to the beamline also drifted for 3 h. This long transition time is due to the insufficient cooling efficiency of the system.

IV. SUMMARY

We improved the mechanical stability of the BPM in the PLS-II storage ring by modifying the vacuum chamber and the support. The new vacuum chamber was made of extruded aluminum with cooling channels on both sides of the electron-beam channel. The cooling efficiency of the new chamber was excellent, which reduced the time to reach thermal equilibrium to 1 h from 3 h. Thermal expansion in the new design is allowed in both upward and downward directions, so the new support also decreases BPM displacement during heating. The results of the thermo-mechanical analysis are in good agreement with the measured values. This design will be used in all vacuum chambers and supports in the storage ring of the PLS-II.

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