Effect of Environmental Factors on Electron Beam Orbit Stability at PLS Storage Ring

C. W. Chung, Y. C. Kim, K. R. Kim and M. H. Yoon

Pohang Accelerator Laboratory, POSTECH, Pohang, Korea, 790-784
Phone: (82)54- 279-1008, Fax: (82)54- 279-1799
E-mail: cwchung@postech.ac.kr

Abstract

The investigation on the beam orbit stability in the PLS storage ring has been conducted to enhance ID beamline performances. We have performed the measurement on the thermal deformation of machine components comprising magnets and girders during the user service beam time with 2 GeV beam injections and the period of machine study with 2.5 GeV beam injections. The measurements were especially focused on local sector #4 in PLS storage ring. The large deformations of the magnets recorded during 2 GeV injections have disappeared during the full energy injection. The relative vertical movements of magnets in the time span of 2 and half days of full energy injections are less than 5 μm. Electron beam orbit drifts detected by BPMs at the downstream of BM3 and Q2D during the beam time between full energy beam injections are 30 μm and 15 μm, respectively which are smaller than those of the beam time period between 2 GeV injections. The possible correlation coefficient between the movements of mechanical devices and beam orbit drift seem to be buried under the outstanding effect of other factors such as electrical instability.

Keywords: deformation, orbit stability, storage ring

1. Introduction

As the number of ID beamlines such as U7, EPU and U10 that require the micro-spot high resolution photon beams has been increased, the stabilization of the electron beam orbit drift becomes crucial to keep the beam intensity fluctuation to the most minimized level. To cope with this requirement, many efforts to improve the beam stability have been conducted in various related fields such as RF, diagnostics of electronic devices, control, etc. In addition to these attempts, it is also known that the motions of mechanical components mostly depending on the thermal variations have a great deal of influence on the electron beam orbit drift [1-3]. Our first measurement showed that the ramping process during the beam injection had a potent influence on the temperature variations of the machine components consequently resulting the deformations of those components, and acting as a possible source of the electron beam orbit perturbation [4]. To identify the exact characteristics of the effect of the temperature variations on the beam orbit, several measurements were carried out during both of the 2.5 GeV normal user service beam time with ramping process through 2 GeV beam injection and of the full energy injections at machine study. The vertical mechanical movements were recorded with the precision of micrometer. The data were analyzed together with the temperature changes and the BPM read-outs.

2. Experimental Set-up

The targets included in the measurements are vertical movements of a dipole magnet (BM3), a quadrupole magnet (Q2D), BPM chamber and a girder which has a similar shape of sector chamber 2 as shown in Figure 1. Figure 1 shows the sector chamber 2 of cell #4 at PLS storage ring. The locations of BPMs and the magnets are also shown.

Measurements on the vertical displacement changes were carried out at each 3-points on the top of BM3 and Q2D. The 3-points measurement ensures to check the tilting of the plane slope if it occurs. The movements of bottom parts of the magnets are excluded at this measurement because these data showed no significant relative changes with girder's matching plane locations. The Solartron Metrology digital probes having the resolution of 0.3 μm were used for this displacement change measurements.

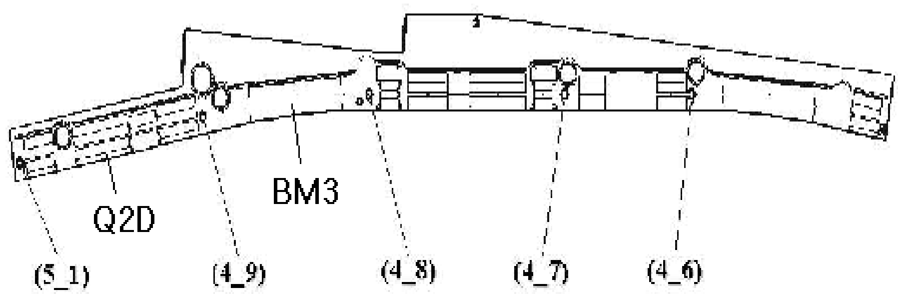

Fig. 1: Locations on the measurement objects. Sector chamber 2 of cell no. 4 is selected for the measurements.

The portion of thermal deformation of SUS stand holding the displacement measuring devices due to temperature changes were removed by the calibration [4].

3. Results and Discussion

3.1 Dipole Magnet (BM3)

The vertical motion of BM3 were measured for almost 5 days, of which about 2 days of user service beam time (2.5 GeV operation with 2 GeV beam injection and ramping up to 2.5 GeV) and the rest of about 3 days of the same energy operation with full energy injection at the period of machine study. By analyzing the data, it was found that there are distinct characteristics between the mechanical motions and the beam orbits with different operation modes as expected. The results of these measurements are plotted in Figures 2 and 3 with the BPM (4_9) values of y-direction that recorded at the same time for comparison. As shown in Figures 2 and 3, abrupt changes of electron beam orbit appeared from the BPM read-outs at every 2 GeV beam injection time, and similar phenomena in the deformation of BM3 in vertical direction with the temperature changes of the return cooling. These phenomena are seems to be well known for the ramping process due to magnet power supply [4]. At full energy beam injection, the

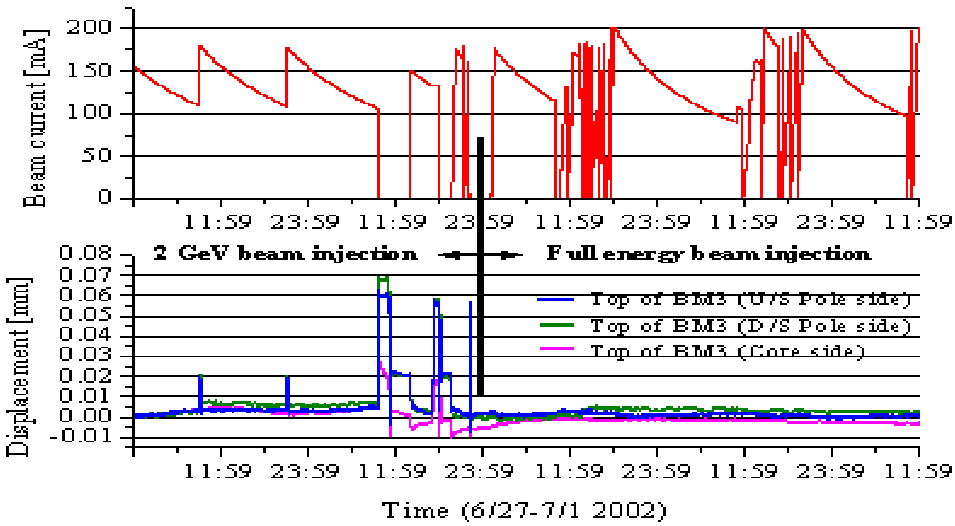

Fig. 2: Beam current and vertical movements of BM3 during user beam time with 2 GeV beam injections and the machine study period with full energy beam injections.

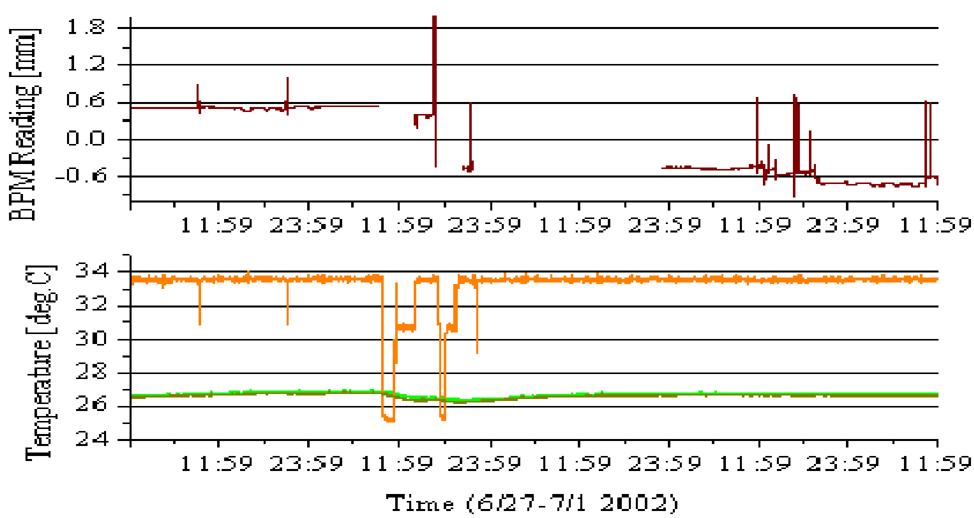

Fig. 3: Beam positions by BPM (4_9) and temperatures of returned cooling water and BM3 body during the same time span as Fig. 2.

temperatures of cooling water and BM3 body are well controlled within the variation of ±0.2°C, and no outstanding mechanical movement of BM3 are observed. The relative amount of vertical movement of the top of BM3 at both pole and core sides are less than 4 μm within the time spans of full energy beam injection except machine power off period. Therefore, from the bigger spikes in the electron beam position shown at the full energy injection regions in Figure 3, it is induced that the big perturbations have no relation to the mechanical motions of the magnets. The read-outs for the vertical beam position from the BPM (4_9) located downstream of the BM3 show very smooth beam orbit drift within the maximum value of about 30 μm during normal beam time period between full energy beam injections of about 12 hours. This value is much smaller than the case of the ramping between 2 GeV injections. The small bumpy shapes in the trace of electron beam position for this time span are due to machine study operations. From these results, any possible correlation between electron beam orbit drift and mechanical movements of BM3 might be negligible compared to the dominant effects coming from beam dynamics.

3.2 BPM Chamber

The vertical movements of BPM chamber were measured for the time span of full energy beam injection. The displacement changes of BPM chamber in vertical direction were found to be less than 4 μm, which is within the maximum resolution of BPM recording. From these results, it is noted again that the mechanical movements of BPM chamber do not contribute to the electron beam orbit drift as also mentioned in our previous measurement [4].

3.3 Quadrupole Magnet (Q2D)

Vertical motions and the temperatures of return cooling water and Q2D body itself were measured for the same time span during aforementioned measurement period. The measured vertical movements of Q2D are shown in Figure 4 together with the beam current at the same time span for comparison. In Figure 4, the vertical beam position data collected from the BPM(5_1) that locates downstream of Q2D and the temperature history of return cooling water, with the border line indication between 2 GeV and full energy beam injection cases, are presented. It is noted from Figure 4 that the transient vertical movement lasts for more than 12 hours to reach the steady state from the machine off. Final displacement reached during the full energy beam injection starting from the beginning of measurement are mostly originated from the movement of girder that will be shown in Figure 6. The big valley reaching the depth of about 40 μm in the middle of movement plot is mainly caused by machine power off. It might be deeper if the time of machine shutdown is longer.

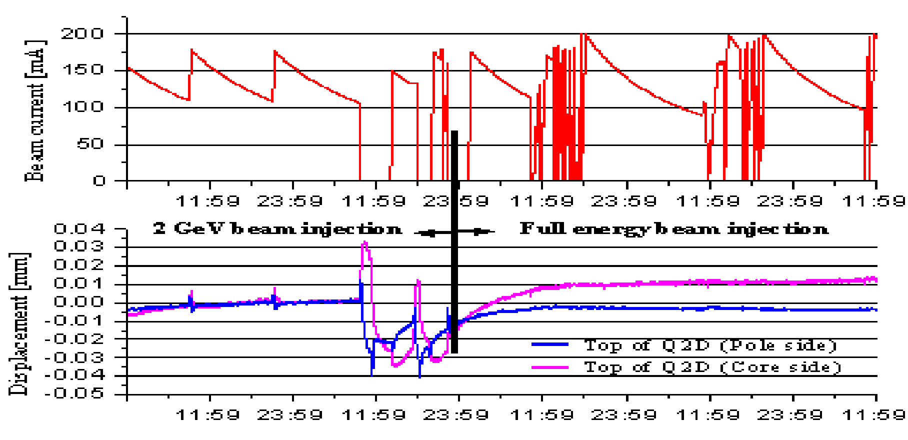

Fig. 4: Beam current and vertical movements of Q2D during user beam time with 2 GeV beam injections and the machine study period with full energy beam injections.

As would be expected, the spikes that are shown at every 2 GeV beam injection cases are not found in the movement of Q2D at the region of full energy beam injection. The displacements occurred during 48 hours in the full energy region after arriving at the steady state are less than 5 μm, and the beam drift recorded for about 12 hours between the full energy beam injections are 15 μm in maximum. This value is quite smaller compared to the value of about 50 μm that we got from the previous measurement during the normal user beam time between the 2 GeV beam injection with ramping process [4]. The beam orbit excursions at the full energy beam injection case have become smaller possibly due to disappearance of the mechanical movement, and consequently were having negligible effect arises from the mechanical motions of magnets as shown in Figures 4 and 5. The electron beam position just after the beam injection seems not to be returned to its original position by unknown reasons that are exclusive of the hysteresis of the mechanical devices. It is noted that the temperatures of the return cooling water and Q2D at the region of full energy injection are controlled within ±0.2°C as shown in Figure 5.

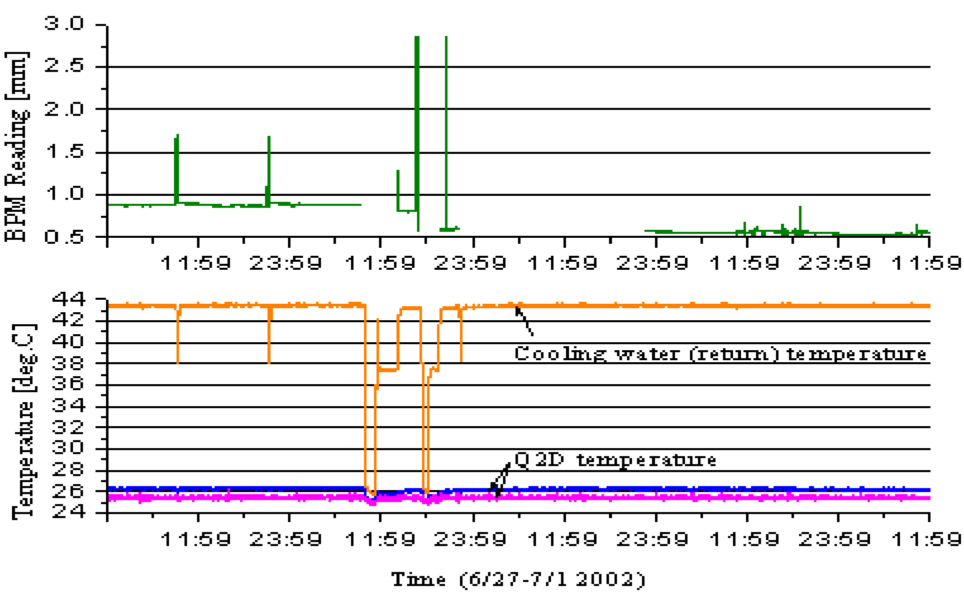

Fig. 5: Beam positions by BPM (5_1) and temperatures of returned cooling water and Q2D body during the same time span as Fig. 4.

3.4 Girder

Since all major mechanical components aforementioned were fixed together on the girder with proper supports, the movements of girder especially in vertical direction is important. The vertical movements of top surface of girder at the both pole and core sides of BM3 and Q2D were measured during the same measurement time span. The measurement results are presented in Figure 6. The girder positions at both pole and core sides of BM3 moved by the same patterns in the vertical direction, and those amounts were less than 5 μm within separate time spans of 2 GeV and full energy beam injection except machine power off stage. Referring to the plots, the movements of the girder seem to be induced by not only the temperature changes but the other factors, i.e. structural geometry. In Figure 6, the movements during both of the 2 GeV and full energy beam injection periods show the different trends at each period, although the major effects were caused by the temperature changes. With such a long time span measurement so far, it seems to be very difficult to extract any exact figures of correlation between movements and temperature. The accumulated amounts of vertical movements of girder at both sides of Q2D were less than 5 μm for almost 2 days in each injection mode as the case of BM3. Since this is about the same order of magnitude with the BPM resolution, no specific relation between girder movement and beam orbit drift could be deduced from this measurement [5].

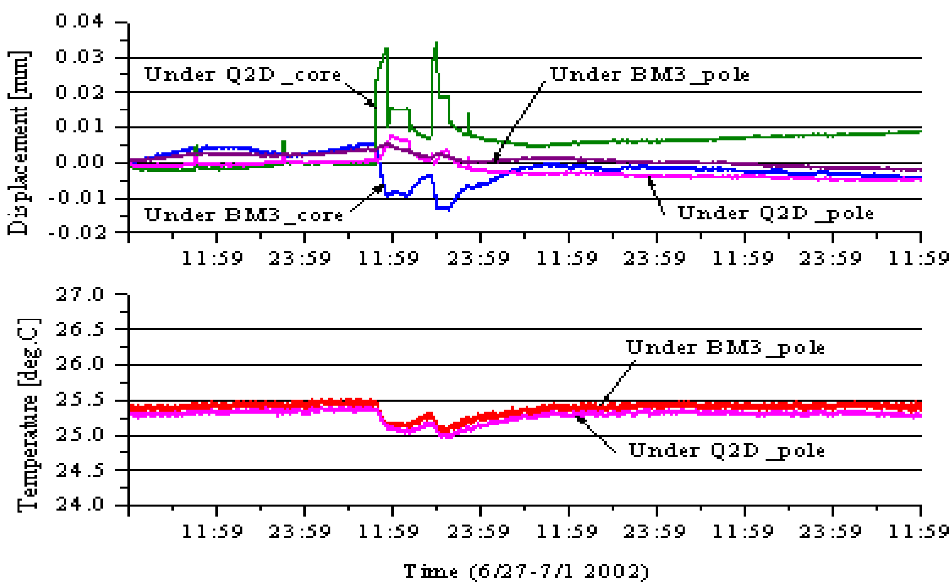

Fig. 6: Vertical movements and temperature changes at the specific points of girder during the same time span as Fig. 2.

4. Summary

Vertical motions of mechanical components of storage ring cell number 4 were measured for about four and half days during user service beam time with 2 GeV beam injections and machine study period with full energy beam injections. Data for electron beam position during the same time span were also collected and compared with motions of components to analyze the cause and effects of beam orbit drift. Large deformations recorded in the motions of BM3 and Q2D that occurred when 2 GeV beam injection case are not observed during full energy injection case. However, big spikes in the BPM reading values exist at every full energy beam injection times in spite of no significant deformations of the magnets. The electron beam orbit during the beam time between full energy beam injections seems not to be coupled by these spikes. The accumulated drift of electron beam orbit were 30 μm and 15 μm, respectively at the BPMs located downstream of BM3 and Q2D. It is induced that the beam orbit drift is not strongly co-related to the motions of mechanical devices from this measurement. Major changes of the motions of machine components seem to be resulted by the girder that shows the complex movement by the temperature change and other factors including its geometry. Any possible correlation between mechanical motions and beam orbit drift are not clearly revealed due to its negligible contribution compared to the other dominant effects coming from beam dynamics. Further investigation should be followed after achieving the beam stabilization of non-mechanical sources. More measurements are under planning at the other cells of storage ring and efforts to improve the identified issues such as operation mode, implementing feed back system and etc. will be continued.

5. References

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