LONG-TERM STABILITY OF THE BEAM POSITION MONITORS AT SPRING-8

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Abstract

Stability of the BPM system is critical for synchrotron light source rings to keep the quality of photon beams and to stabilize the photon beam axes. The BPM system of SPring-8 has suffered from fluctuating gain imbalances among 4 electrode channels, which results in variations of offsets for beam position measurement. We recently surveyed the logged data of the BPM and the operating environment, and revealed several features of variations of the offset errors of the BPM. To cure step variations of the offsets, inspections of switch modules of the readout circuit are necessary. For variations correlated with the dew point of the environment, we consider that a possible cause is change of reflection coefficients in the BPM cables damaged by radiation. Further investigations are necessary to find the causes of other variations of the BPM offset errors.

INTRODUCTION

For synchrotron light source rings, accuracy of the BPM system is crucial for the quality of the source electron beam. Elaborate efforts are paid for calibration of BPM offsets including pre-installation bench calibration, survey at installation and beam-based alignment after commencement of operations. Stability of the BPM system is even more important as it is critical to keep the quality of photon beams and to stabilize the photon beam axes as well.

The BPM system of the SPring-8 storage ring has suffered from fluctuating gain imbalances among four 4 electrode channels. A major origin of the imbalances is voltage standing waves in the cables of the BPM caused by reflections at locations with impedance mismatching. While the imbalances are routinely corrected in accordance with a beam-based measurement [1] for several time per year, they fluctuate during the operation periods and result in variations of offsets for beam position measurements. Fluctuating BPM offset errors could degrade stability of the beam orbit and the photon beam axes.

Stability of the BPM system would be affected also by mechanical and electrical stability of the components comprising the BPM system, vacuum chamber and supporting girder of BPM, signal cables and readout electronic circuits. In order to find and cure the causes of variations of offset errors of the SPring-8 BPM system, we recently surveyed extensively the logged data of the BPM and the operating environment, such as the temperature and the dew point (DP).

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SPRING-8 BPM SYSTEM

The SPring-8 storage ring consists of 48 cells and six BPMs are regularly placed in each cell. The totals of 288 BPMs are processed at 24 stations of BPM readout circuit. The electrode of the BPM is button-type and four buttons are placed in skew positions. Signal from each button electrode is transferred from the accelerator tunnel to the BPM circuit outside the tunnel through 3 coaxial cables connected; 2.5-m long flexible “a-cable”, ~25-m long low loss “b-cable” and 5-m long flexible “c-cable”. A block diagram of the BPM circuit is shown in Fig. 1 [2]. The circuit employs multiplexing method. Three BPMs are processed by one common channel comprised of an RF amplifier, a mixer, an IF amplifier and an ADC. A reference signal supplied for the frequency down-converter is delivered from a master oscillator through a phase-stabilized optical fiber cable, which is commonly used for 12 BPMs from two cells.

Beam positions at each BPM are continuously calculated with a repetition of 1 kHz and sent to a ring-buffer on a DSP board. The position data sampled by 1 kHz can be used for analyses of the orbit fluctuations and of error source position at sudden beam loss. Slow position data averaged for 600 ms are sent to a control workstation for routine global orbit correction with 1 Hz repetition [3]. Typical resolution of the averaged position data is 0.1 μm (rms).

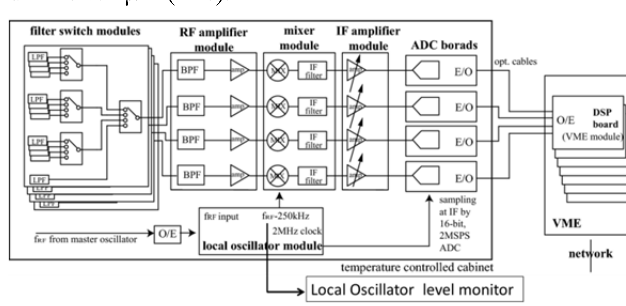

Figure 1: Block diagram of the SPring-8 BPM circuits.

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BALANCE ERROR OF BPM

In order to distinguish instrumental fluctuations of the BPM system from real orbit fluctuations, we introduce an index, "balance error" of BPM.

For a BPM comprising four electrodes at skew positions, beam positions x and y are generally calculated by using four channel voltages, as $x = k_x\,\Delta_x/\Sigma_x$ and $y = k_y\,\Delta_y/\Sigma_y$. Beam positions are also available by using three voltages out of the four. There are four combinations to choose the three electrode channels yielding four pairs of x and y positions as,

$$x_1 = F_1(V_2,V_3,V_4), y_1 = G_1(V_2,V_3,V_4), \quad (1)$$

$$x_2 = F_2(V_1,V_3,V_4), y_2 = G_2(V_1,V_3,V_4), \quad (2)$$

$$x_3 = F_3(V_1,V_2,V_4), y_3 = G_3(V_1,V_2,V_4), \quad (3)$$

$$x_4 = F_4(V_1,V_2,V_3), y_4 = G_4(V_1,V_2,V_3), \quad (4)$$

where V_1, V_2, V_3, V_4 are voltages of each channel. The functions F_1, F_2, F_3, F_4, G_1, G_2, G_3, G_4 are the mapping functions of BPM determined by the geometry of the BPM chamber. If the whole BPM system is ideal without any errors, the four position pairs must be identical. The discrepancies reflect relative errors among the four BPM channels. We define an index of "balance error" of BPM as,

$$\varDelta_x = \max(x_1,x_2,x_3,x_4) - \min(x_1,x_2,x_3,x_4), \quad (5)$$

$$\varDelta_y = \max(y_1,y_2,y_3,y_4) - \min(y_1,y_2,y_3,y_4). \quad (6)$$

The balance error is related to the offset error of the BPM. For the geometry of the BPM chamber of SPring-8, the vertical balance error $\varDelta_y$ is about 1.5 times larger than horizontal $\varDelta_x$. Hereafter, the vertical BPM balance error $\varDelta_y$ is used as an index to evaluate the stability of BPM.

FEATURES OF BALANCE ERROR OF SPRING-8 BPM

An example of trend of the balance error of the SPring-8 BPM for one operation cycle of SPring-8 (2nd run of 2015FY, May/07-June/06) is shown in Fig. 2. The upper panel shows balance error defined in the previous section with the environment data, the temperature and the DP. The temperature is measured in the accelerator tunnel near the BPM. The DP is calculated from the temperature and humidity measured by the air-conditioning system for the tunnel. The lower panel of Fig. 2 shows voltages for each electrode channel normalized by the mean of the four, subtracted by the initial values in the plot. The BPM shown in Fig. 2 is stable and the balance error is less than 5 μm. Slight fluctuations in each voltage reflect actual orbit fluctuations.

Through the extensive survey of the logged data of the BPM and the operating environment, we have revealed several features of variations of balance error of the BPM. Figure 3 shows an example of BPM with balance error correlated with the DP. Drift of balance error is 48 μm. Voltages of some channels are also correlated with the DP.

Figure 4 shows an example of BPM of which balance error varies like step functions. Some of discontinuous jumps of balance error are identified to occur at occasions after beam abort and changeover of beam filling-pattern. Jump of balance error is 10 μm. Voltages of some channels jumped simultaneously with the balance error. Sources of the jumps could be failed behaviors of RF switches in the BPM circuits which select one of 4 BPM electrodes. Inspections of the switch modules and exchanges of the faulty ones are planned.

Figure 5 shows an example of BPM balance error variating with a period of approximate one day. Voltages of some channels also varied with the same period. Variation of balance error is 25 μm. The period of approximate one day suspected the environment temperature as suspected cause of variations. However, no significant correlation has been found so far. Further investigations are necessary to find the cause.

Figure 6 shows an example of BPM with fast variations of balance error. Voltages of some channels also varied. Variation of balance error is about 7 μm. No significant correlation has been found so far with other parameters. The behavior of variations seems to change at the changeover of beam filling patterns, suggesting that the source of the variations could be the beam, for example higher-order modes of electro-magnetic waves excited in the vacuum chamber.

The features of variations of the balance errors of the SPring-8 BPM are summarized in Fig. 7. The BPMs with variation smaller than 5 μm are counted as stable BPMs. When the balance error of a BPM has both the correlation with the DP and the step behavior, both "DP" and "step" are counted up. The variations correlated with the DP and the step variations are the majority, accounting for 20% and 18%, respectively. For BPMs with step variations, of balance error, inspections of the switch modules of the readout circuit and exchanges of the faulty ones are planned. We will discuss possible causes of variations correlated with the DP in the next section.

DISCUSSION

Among the BPMs showing variations of balance errors correlated with the DP, we have found that the BPMs with cables damaged by radiation have large variations (C05-6, C17-6 and C42-2 in Fig. 7). Figure 8 shows TDR waveforms of the cables of the BPM C05-6. Reflections in portions of the cables irradiated by radiation scattered by a photon absorber is evident (Fig. 9). To investigate the cause of the imbalance variation, we replaced the damaged cables with new ones and covered them with Pb tube with 3 mm thickness for shielding radiation. The cables removed from the BPM C05-6 were installed in the BPM C07-1 which did not show variations correlated with the DP.

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We also removed the cables from the BPM C29-6 which showed variations with the DP. TDR waveform of the cables also indicated unusual reflection similar to that of the BPM C05-6 caused by the radiation from the photon absorber. We measured TDR waveforms of the removed cables in a humidity controlled chamber to investigate the effect of the DP to reflections. Fig. 10 shows TDR waveforms measured by changing humidity at a fixed temperature (28℃). Significant changes of voltage reflection coefficient were revealed near the end of the damaged cables on the button side. A new cable was measured for comparison, which had small reflection coefficient independent of the DP.

We have found that the reflection coefficient of a radiation damaged cable is affected by the DP. Therefore, we consider that a possible cause of the BPM balance error correlated with the DP is the variations of standing waves in the BPM cables damaged by radiation which is dependent on the DP. To confirm this idea, we will carefully observe the imbalance variations for the BPMs C05-6 and C07-1 after the machine operation is restarted in September.

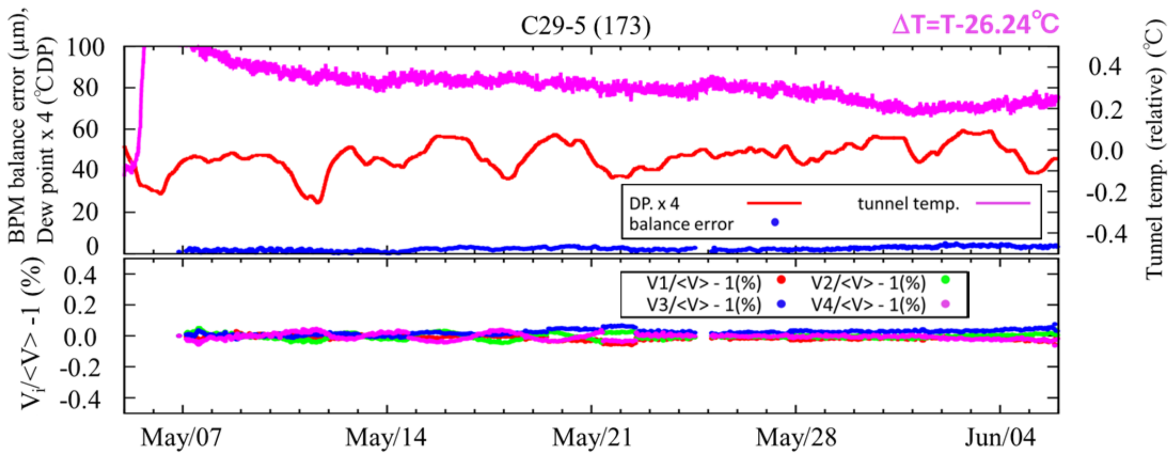

Figure 2: An example of stable BPM. Peak-peak variation of balance error was ~5 μm. Slight variations in voltages are due to beam orbit variation. Legends are common for Figs. 3-6.

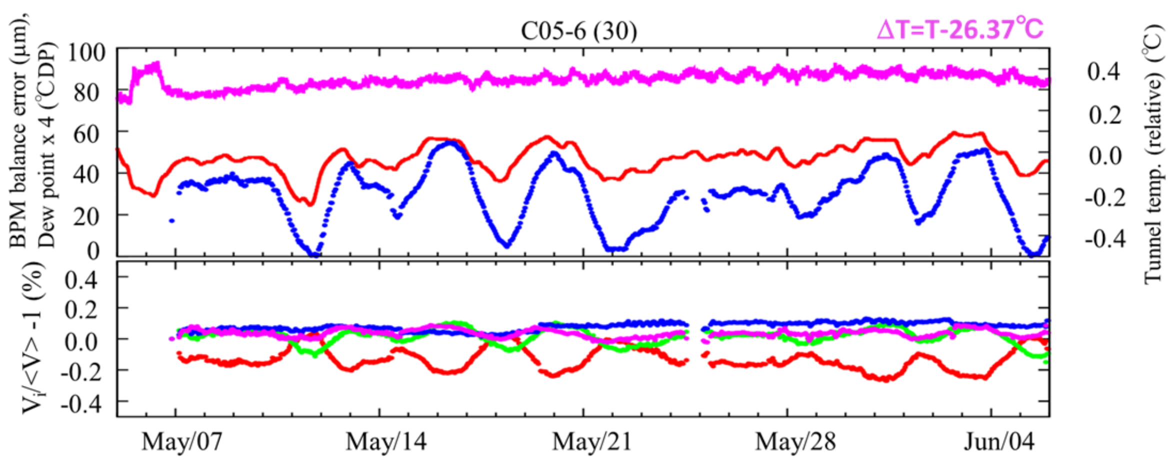

Figure 3: An example of BPM with balance error correlated with the DP. See Fig. 2 for legends.

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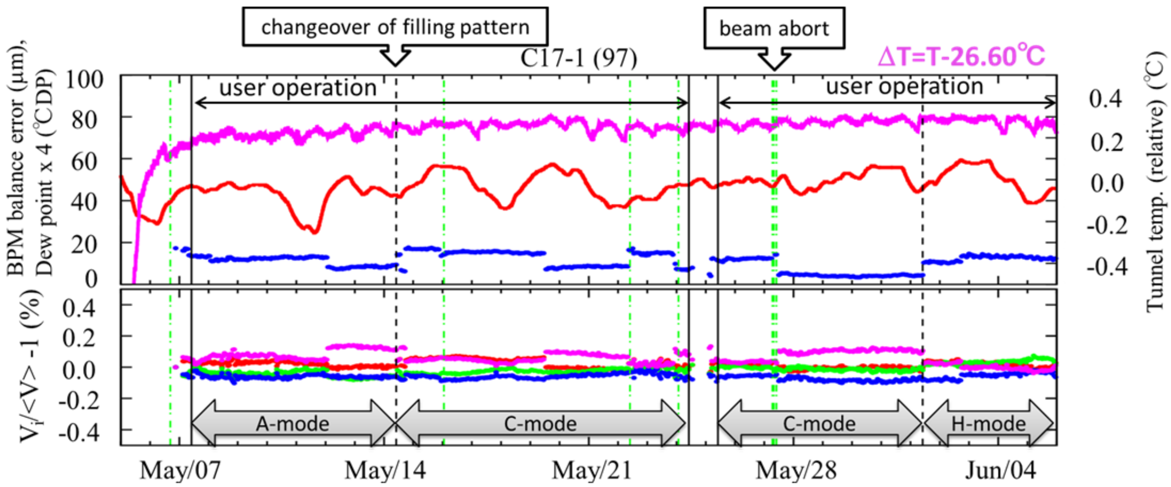

Figure 4: An example of BPM with step function like variations of balance error. See Fig. 2 for legends. In operation modes given in the figure, bunches are stored as follows [4]; A-mode : 203 bunches with each bunch current of 0.5 mA are equally spaced, C-mode : 29 bunch trains are equally spaced. Each train consists of 11 bunches with the bunch current of 0.3 mA, H-mode : one bunch train which consists of 924 bunches with the bunch current of 0.1 mA and one isolated bunch with the bunch current of 5mA. In every operation-modes, the total beam current stored in the ring is 100 mA.

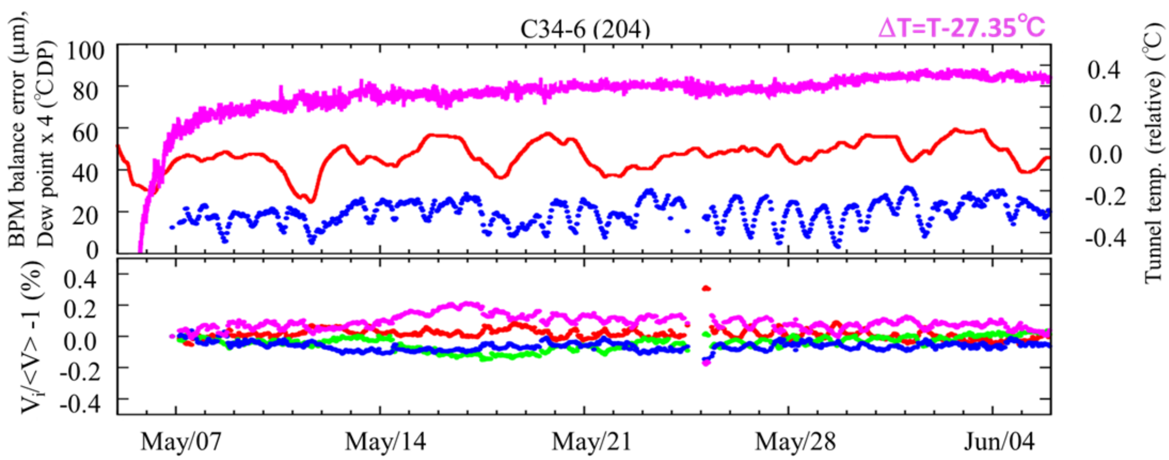

Figure 5: An example of BPM with balance error varying with a period of approximate one day. See Fig. 2 for legends.

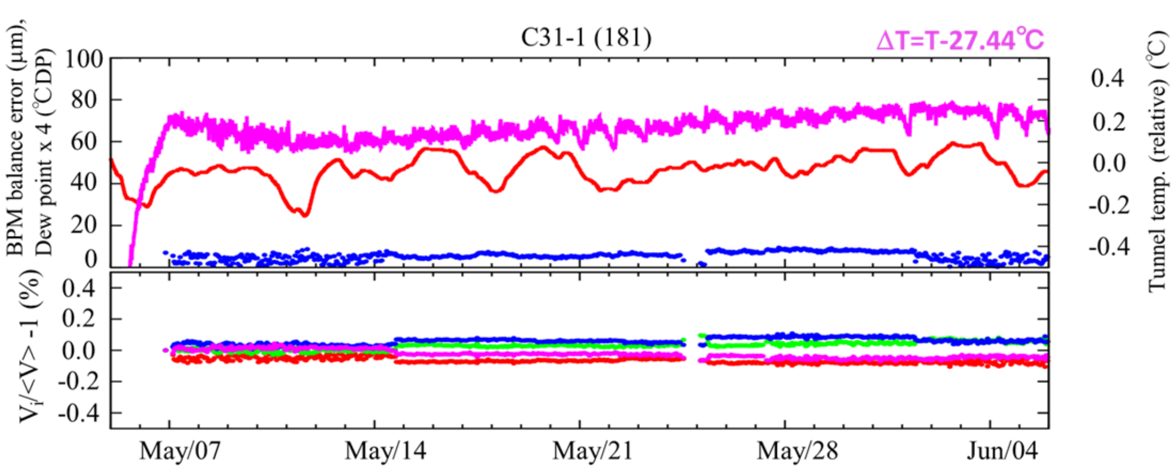

Figure 6: An example of BPM with fast variation of the BPM with balance error. See Fig. 2 for legends.

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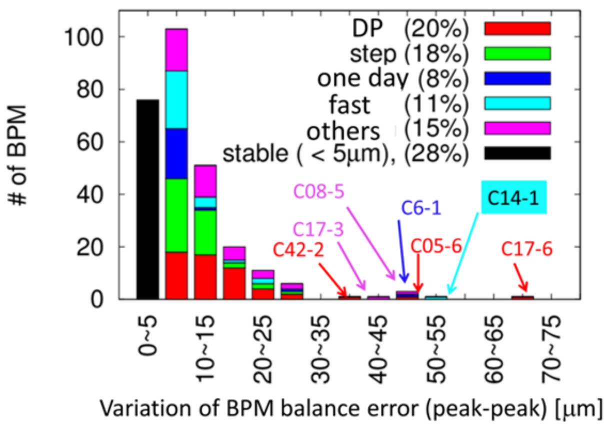

Figure 7: Histogram of the peak-peak variations of the BPM balance error. BPMs with variations smaller than 5 µm are counted as stable.

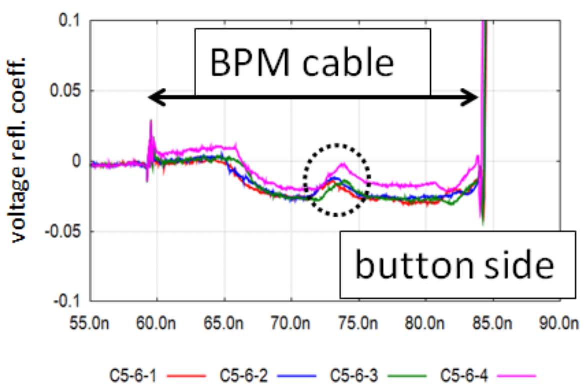

Figure 8: TDR waveforms for the cables of BPM C05-6. Humps around 73 ns correspond to shade of a steering magnet girder placed between the cables and a photon absorber (Fig.9).

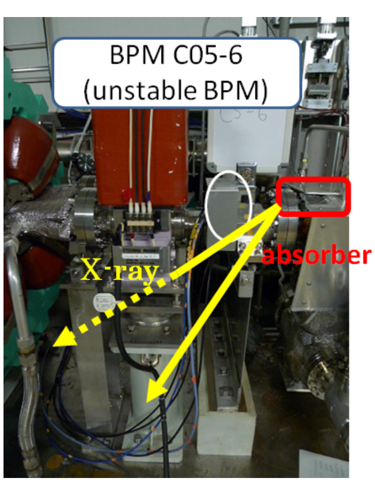

Figure 9: Layout of the BPM C05-6 and the photon absorber

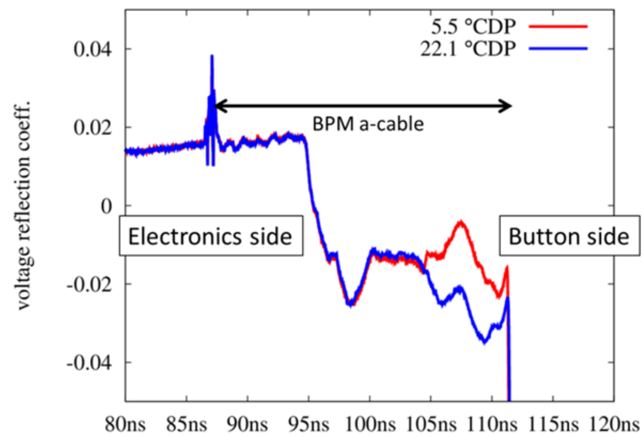

Figure 10: TDR waveforms of the damaged BPM cable (C29-6-2) measured by changing the DP at a fixed temperature (28℃) .

SUMMARY

In order to find and cure the causes of variations of offset errors of the SPring-8 BPM system, we recently surveyed extensively the logged data of the BPM and the operating environment, such as the temperature and the DP. We have revealed several features of variations of the offset errors. To cure the step variations, inspections of the switch modules of the readout circuits and exchanges of the faulty ones are planned. For variations correlated with the DP, we consider that a possible cause is the variations of standing waves in the signal cables damaged by radiation which is dependent on the DP. Further investigations are necessary to find the causes of other variations of BPM offset errors.

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