ORBIT STABILITY OF PLS STORAGE RING*

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Abstract

In order to improve the orbit stability of the PLS (Pohang Light Source), various efforts have been exercised. We are improving the temperature stability of machine-tunnel air and cooling waters better than +/- 0.1 ^{o}C. Temperatures and mechanical displacements of magnets, girders, and vacuum chambers have been monitored using precision instruments. It was found that, when the machine is started up or shut down, mechanical displacements of 100 μm are not uncommon. And at least 12 hours are required for the thermal stabilization of mechanical components in the tunnel. It was found that transients during beam injections that accompany de-ramping and ramping of the beam energy were closely related to orbit drifts. We measured vibration (~20 μm peak-to-peak) of electron beam position that was found to be caused by ripples of magnet power supplies. In this article, we also report recent results of the investigation of BPM instabilities.

1 INTRODUCTION

Modern light sources are required to meet stringent orbit stability specification, which is crucial for competitive user experiments. World-class machines are striving to achieve and maintain 1-μm level stability. For this, not only sub-systems and devices of the machine should be very stable and reliable, but also machine operation should be optimised to avoid various transients that adversely affect the orbit stability. Furthermore active orbit feedbacks are usually adopted.

Efforts to improve the orbit stability of the PLS (Pohang Light Source) started with upgrading our BPM's (Beam Position Monitors) to have micron-scale resolution and stability.[1] This is also essential for proper operation of orbit feedback systems. In 1999 we upgraded our BPM electronics adopting commercial BPM modules provided by the Bergoz Instrumentation. We have developed special ADC (Analogue-to-Digital Converter) electronics with built-in CPU's for the digital processing of BPM signals. These enabled us to achieve 4-μm resolution for all arc and ID (Insertion Device) BPM's. The resolution is limited by our 12-bit ADC's and we are developing 16-bit ones with stand-alone DSP processors for fast digital filtering of converted data. We aim to achieve the data update rate > 20 Hz for all BPM's.

The orbit stability of the PLS has been several tens of microns. As ones of the efforts to improve this down to micron scale, we have tried to elucidate causes of orbit drifts and eliminate them. We decided to install temperature and displacement sensors at 1 of 12 machine cells in order to monitor temperature variation and mechanical movement of magnets, girders, and vacuum chambers.

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2 DISPLACEMENTS OF MACHINE COMPONENTS

Fig.1 shows the mechanical displacements of selected bending and quadrupole magnets during normal operation.

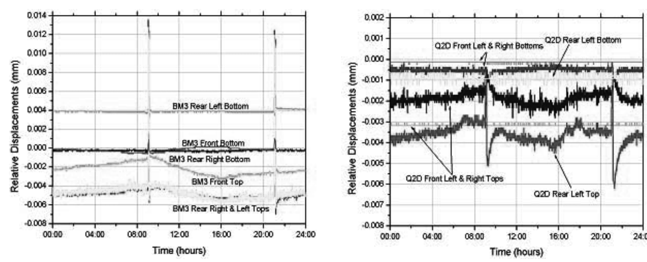

Figure 1: Relative (vertical) displacements of bending (left) and quadrupole (right) magnets at cell#4 during normal machine operation. Spikes around 9 AM and 9 PM are due to beam injection.

Magnet movements as large as 5 – 20 μm (mostly in upper parts of magnets) was measured during beam injections. This should be caused by transients of magnetic forces between pole-pieces arising through the de-ramp, fill-up, and ramp processes during beam injection. [2](The PLS storage ring operate at 2.5 GeV but beam injection is done at 2 GeV. This accompanies de-ramp and ramp of the beam energy and magnetic fields.) Also note slow drifts in magnet positions (several microns) after beam injections. Assuming gain factor of 10, this can be translated into the orbit drift of several tens of microns. Since our BPM's are installed on vacuum chambers, movements of these can cause apparent orbit drift. They were <10 μm that are not significant (gain factor = 1). Although needs further investigations, we suspect that various transients during our beam injections cause orbit drifts. This is backed up by measurements results of displacements and orbits when the machine is operated without de-ramp and ramp processes (machine was operated at 2 GeV only). There was no detectable movements of mechanical components and very small orbit drifts (comparable to BPM resolution).

The above is a strong motivation of changing our operation mode. That is orbit drift could be reduced if we could inject at 2.5 GeV and let the machine operate at the same energy. Major obstacle to this has been the pronounced leakage field in our injection septum and the following closed orbit distortion. But recently we have succeeded in injecting at 2.5 GeV and storing at the same energy with reasonable closed orbit distortion and lifetime after careful orbit corrections.

3 VIBRATION OF CLOSED ORBIT

In the U7 undulator beamline of the PLS, there have been fluctuations of photon beam intensity with frequencies between 10 to 20 Hz. In order to eliminate these, efforts have been done to reduce mirror vibrations caused by turbulences of cooling water and compressed air. Although substantial improvement has been achieved, the fluctuation has been still too large for competitive user experiments. We were led to suspect the existence of low-frequency oscillation (hereafter vibration) of the closed orbit. Time- and frequency-domain measurements of BPM analogue output revealed that the closed orbit vibrated with the peak-to-peak amplitude ~20 μm (see Fig. 2).

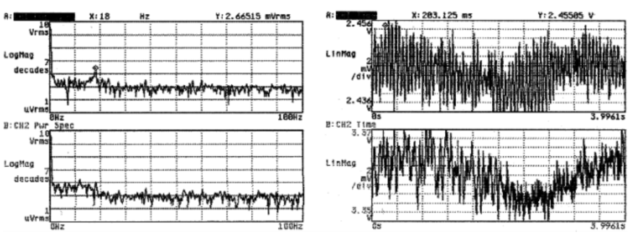

Figure 2: Closed orbit vibration measured by BPM and HP 35665A FFT analyzer. Left (right) traces are frequency (time) domain representations of BPM analogue output signals. Uppers and lowers traces are horizontal and vertical signals respectively.

Interestingly similar ripples were measured in the output currents of MPS's (Magnet Power Supplies). Further correlation study between the U7 intensity fluctuation and the MPS's led us to suspect the bending MPS.[3] Major ripple content of the bending MPS came from the LC filter at its output stage. Changing the ripple frequency of the bending MPS by changing L or C of the filter also caused the vibration frequency of the closed orbit. Modifying the LC filter and feedback circuits, we could improve the ripple of the bending MPS from +/-150 to <50 ppm. These work substantially reduced the intensity fluctuations in the U7 beamline. Specifically, the frequency peak (18 Hz) in the U7 intensity fluctuation that corresponds to that of the bending MPS ripple disappeared completely.

4 BPM INSTABILITY

BPM system is not only the most important diagnostic tool but also an integral part of orbit feedback system. In this regard, it should have high performance and be very reliable. PLS BPM electronics are modular, flexible, and reliable. Furthermore they have good resolution and stability. In spite of these, some BPM's have showed unstable behaviours with signal drifts or jumps as large as 500 μm. Interestingly these are all predominating in vertical orbit rather them horizontal one. These facts made us to investigate the existence of the TE (Transverse Electric) modes in the vacuum chamber with their electric fields are oriented vertically. Also, there have been strong intensity dependencies on the magnitude of the stored current. This means that the characteristics TE modes depend on the stored current and change as the current decays. One would imagine that some objects inside of the vacuum chamber that are sources of the TE mode, are heated by the wake of stored beam and change their shapes as the beam intensity decays.

Fig. 3 is the single-bunch spectrum of the button signals from a problematic BPM. (IDBPM81 that is installed at the U7 ID vacuum chamber. Note that for somehow reason, our IDBPM's are all installed on the ID vacuum chambers.)

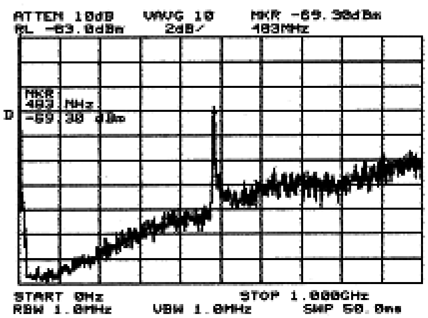

Figure 3: Single-bunch spectrum of IDBPM81 button signal. Note large peak at 483 MHz. Trace was smoothed and averaged.

Theoretically, the single-bunch spectrum when measured by a capacitive pick-up is the convolution of the single bunch spectrum, button response, and cable attenuation. It is generally starts from 0 Hz, smoothly increasing toward bell-shaped maximum, and decreases according to the cable attenuation. Fig. 3 is a part of the single-bunch spectrum with frequency span 0 – 1 GHz. Interestingly we can see there is large peak at 483 MHz that is not theoretically expected. (For reference, we measured the same spectrum of a normal BPM and measured expected smooth spectrum.) More interestingly, the upper and lower buttons of the IDBPM81 exhibited different spectra. That is, upper buttons showed peaks whereas lower ones did valleys at the same frequency. This phenomenon can be explained if we assume the existence of the TE mode with its electric field vector oriented vertically. Vertical electric field will be coupled to upper and lower buttons with 180^o phase difference. These out-of-phase TE signals are superposed to the normal TEM beam signals that are in-phase on all four buttons. As the result, the signal amplitudes at upper or lower buttons at the TE mode frequency will be larger or smaller than those at the other frequencies.

The consequence of the above is that if the TE mode frequency lies within the operation bandwidth of the BPM, it would cause the error (offset) in orbit reading. Furthermore if the magnitude or frequency of the TE mode changes with the time as the stored current decays, the orbit would look drift and have the intensity dependency. The 483-MHz peak in Fig. 3 has 8-dB amplitude that is translated into very large orbit offset. (An 1-dB signal difference between upper and lower buttons corresponds to ~1 mm orbit offset) Since the bandwidth of our BPM is narrow (1 MHz centred at 500 MHz), it would respond to the tail of the 483-MHz peak, and the orbit error would be considerably smaller.

In order to investigate on the drifting TE mode with the time, we have measured magnitudes of rotation harmonics around 500 MHz and logged their changes with time. Using the LabVIEW, we have computer controlled two SA's (Spectrum Analysers) through the GPIB. One SA was hooked to the IDBPM81 and the other to a normal BPM that was used as a reference. The reference BPM is required to normalize the dependency of the bunch spectrum on the filling pattern, bunch uniformity, current decay, and etc..[4] Fig. 4 is the typical multi-bunch spectrum around 500 MHz measured by the BPM button.

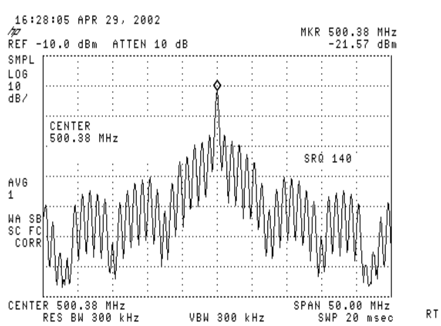

Figure 4: Typical multi-bunch spectrum around 500 MHz. Number of bunches is 400 with 68 ion-clearing gap.

Fig. 5 shows 24-hour variations of IDBPM81 vertical orbit signal, 483-MHz, and 517.2-MHz harmonics. The choice of the 517.2 MHz for comparison is rather arbitrary.

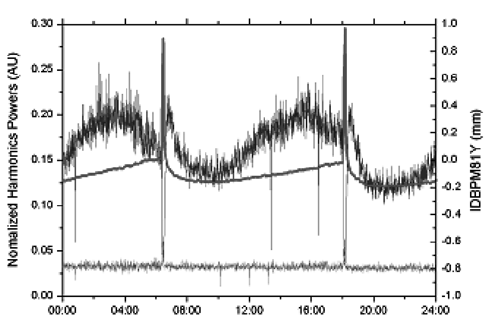

Figure 5: Comparison of time variations of 483 MHz (top trace), IDBPM81 vertical orbit signal (middle trace), and 517.2 MHz (bottom trace). Peaks in IDBPM81Y signal at 9 AM and 9 PM are due to beam injections.

In Fig. 5, it is clearly seen that there are strong correlation between the IDBPM81 signal and the 483 MHz but not with the 517.2 MHz. There were other harmonics that have strong correlations with the IDBPM81 (for example, 487.3 MHz) but not shown here for simplicity.
Similar things were done for rotation harmonics around 1 GHz. It was found that there was no drifting behaviours around this frequency. See Fig. 6.

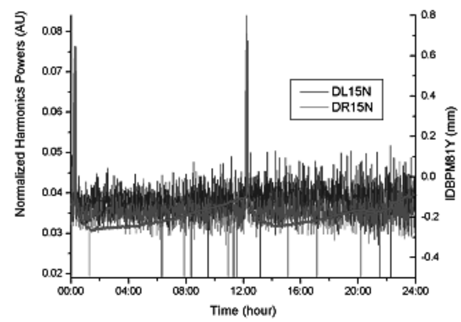

Figure 6: Comparison of time variations of two representative rotation harmonics at 983 MHz (top trace), 1017.2 MHz (middle trace), and IDBPM81 vertical orbit signal (bottom trace). Peaks in IDBPM81Y signal at 0 AM and 1 PM are due to beam injections.

From the result shown in Fig. 6, we can deduce one of the solutions to the BPM problems. If we heterodyne the 1 GHz down to 500 MHz and use it for orbit measurement, we could avoid the orbit drifts.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

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[4] Private communication with Dr. Jim Hinson at GMW Associates.