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OBSERVATION AND SUPPRESSION OF ORBIT DRIFT DUE TO PATH LENGTH CHANGES AND THERMAL EFFECT IN TPS

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Abstract

Tidal effect, ambient temperature fluctuation and other effects of the TPS site can cause the path length changes of the electron beam in the TPS storage ring. Off-energy orbit drifts from the path length change, if not varying the RF frequency, cannot be properly corrected by the horizontal correctors and this causes the fast orbit feedback system over its normal working range. RF frequency adjustment loop is therefore applied to compensate for the circumference change based on the accumulating corrector strengths of the fast orbit feedback system. Implementation and operational experiences will be discussed in the report.

INTRODUCTION

The TPS is a 3-GeV synchrotron light source which has opened for public users since September 2016 [1]. It currently offers 400 mA top-up mode operation. As a 3rd generation light source, it requires beam position stability of less than 10% of the beam size. Therefore, FOFB have been adopted to stabilize the electron orbit [2,3]. Later, closed orbit correction methods by RF frequency correction have been developed to compensate for orbit path length changes. While applying RF corrections, long-term observations of the RF frequency variations exhibit clear signs of periodic changes and show strong correlations with temperature changes and earth tides. Besides, orbit drift due to thermal effect is also observed at the beginning of beam accumulated.

RF FREQUENCY CORRECTION FOR PATH LENGTH COMPENSATION

RF frequency correction is used to minimize path length changes caused mainly by temperature drifts and earth tides after FOFB commissioning. The RF correction process polls all fast horizontal corrector currents, ΔI, at 1 Hz and converts them to corresponding orbit deviations with the response matrix R. Then, the dispersion function D is used to calculate the required RF frequency change Δf_{rf} to be applied to the RF cavities. The RF frequency correction is a slow process and restricted to less than 1 Hz change per step to prevent overshooting the frequency change given by

$$\Delta f_{rf}=D^{+}*RM*\Delta I,$$

where D^{+} is the pseudo-inverse of D. Figure 1 shows the block diagram for the controls. As a result, the orbit drift can be controlled and limited to less than 1 μm from day to day.

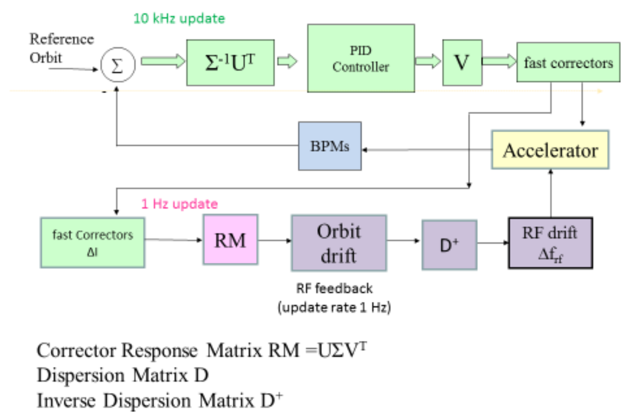

Figure 1: FOFB operation with RF correction (schematic).

In the TPS, it can be observed that there are dispersion-like orbit disturbance at 0.3~0.5 Hz contributing the major part of horizontal orbit variations except for disturbances from the 3 Hz booster power supply ramping. The dispersion-like variation could be concluded due to the vibration of the magnets, which is much amplified in low alpha mode. In addition, a long-term path-length drift due to temperature change and tides can be noticed. It shows that the orbit variation due to path length change around 0.4 Hz is too fast to be directly compensated by RF frequency correction while the FOFB has enough bandwidth to suppress it. We also note that sometimes these variations can be up to 20 μm in high dispersion areas and might cause temporary FOFB saturation.

OBSERVATION OF ORBIT STABILITY DURING PATH LENGTH COMPENSATION

Without FOFB and RF path length compensation, the horizontal orbit drift during one day can be up to one hundred micron as shown in the blue line of Fig. 2. When applying FOFB, it can correct some part of this orbit drift due to the circumference change, but there is still a residual error with respect to the golden orbit which cannot be fixed by FOFB and can be up to 20 μm in high dispersion areas. However, with RF path length compensation, the orbit stability can be controlled below the submicron level as shown in Fig. 2 (black line). The corresponding RF frequency correction per day is around 100 Hz, equal to path length about 100 um which is consistent with the observed horizontal drift without FOFB and RF frequency feedback.

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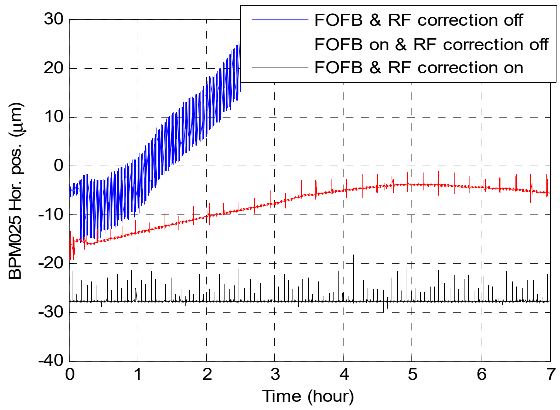

Figure 2: Orbit stability comparison with/without FOFB and RF path length compensation. The spikes are due to regular injection when FOFB and RF frequency correction is temporarily inactive.

OBSERVATION OF RF FREQUENCY VARIATION DUE TO PATH LENTH CHANGE

From archived data of RF frequency, it can be observed that the circumference of the electron orbit is affected by day to day temperature variations in addition to seasonal influences. There is also a small semi-diurnal RF frequency variation due to earth/ocean tidal effects as shown in Fig 3. Furthermore, it is also observed that the circumference continues to have contraction year to year although the data are recorded less than 2 years. This is because TPS is a new building and the concrete foundation of the storage ring is still getting dry and it makes the storage ring shrink.

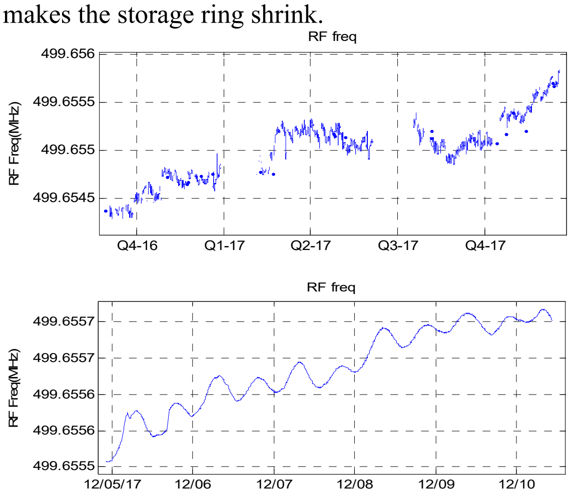

Figure 3: The upper plot is the RF frequency variation from September 2016 to December 2017 and the lower plot shows a more detailed observation for four days. RF variation per day is around 100 Hz, equal to path length about 100 μm.

For more details, Fig. 4 shows seasonal temperature variation versus RF frequency changes. The outside temperature of TPS site is decreasing while RF frequency is increasing where the 10 °C drop of the temperature would cause 400 Hz increase of RF frequency. In Fig. 5 the earth/ocean tides, the local temperature at the NSRRC site and the RF frequency are shown together in red/green, blue and black lines, respectively. It can be inferred that the circumference of the electron orbit is affected by the temperature and the ocean/earth tides as reflected by the simultaneous change of the RF frequency while correcting the orbit. The phase lag observed between the temperature, tides and RF variations will be further studied in the future.

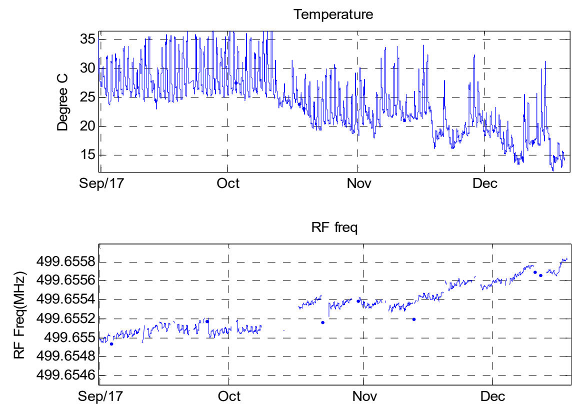

Figure 4: Seasonal temperature variation versus RF frequency changes. From October, the outside temperature of TPS site is decreasing while RF frequency is increasing. 10°C drop of the temperature would cause 400 Hz increase of RF frequency.

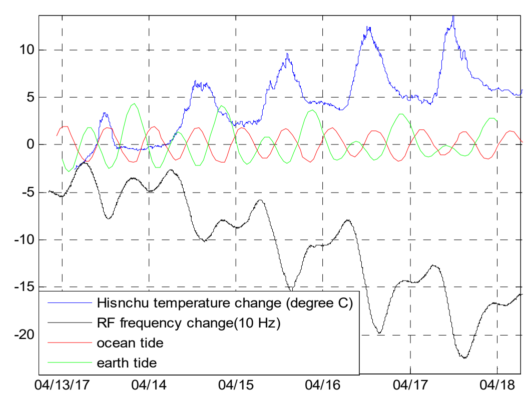

Figure 5: The black line is the RF frequency change while applying RF frequency corrections. The blue line is the ambient temperature on the NSRRC site. The red line is the ocean tide at the seashore about 15 km west of the TPS site provided by Central Weather Bureau of Taiwan [4] and the earth tides in green are calculated from the Program *solid* [5].

THERMAL EFFCT COMPARISON

From archived data of BPM position, it can be observed that the thermal effect affects orbit stability significantly. For the first 30 minutes of the beam stored, the orbit is not stable enough for user operations in spite of FOFB on. After 30 minutes, the orbit would be much stabilized but still have small drift especially for the vertical plane. The

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orbit drift around 2~3 μm for 5~6 hours in the vertical plane before it achieves an equilibrium. The phenomenon is worsen when TPS operated in 400 mA top-up mode from 300 mA.

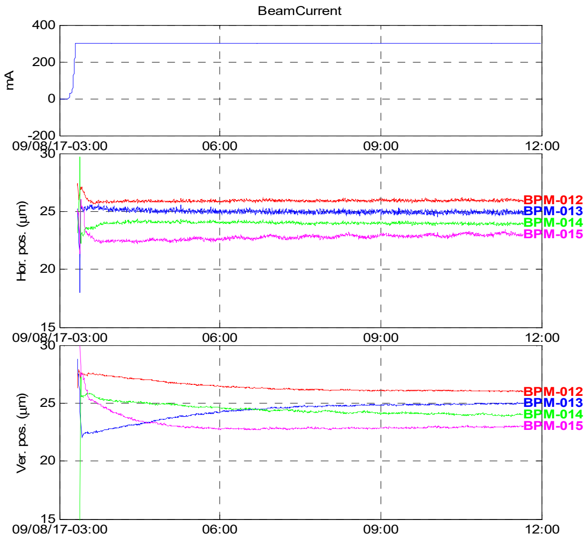

Figure 6: For the first 30 minutes of beam stored, orbit change could be up to 10 μm. Then the horizontal could be stabilized while the vertical orbit still have slow drift (2~3 μm) for the first 4~5 hours.

There were some efforts made to improve the thermal effect. Temperature control is in process and the mechanic supporting against displacement is being evaluated as well. In addition, FOFB could put the larger weightings on straight line BPM to further minimize the error. But it may deteriorate the short-term stability because the noise/spike of the local BPM with larger weightings would be amplified to interfere with the global orbit. Figure 7 is an example where BPM readings seems to have a small variation around 1 um with beam current changes. This variation became to worsen when 400 mA top-up mode than 300 mA as Fig. 8. This phenomenon is more obvious at the location of the injection section.

Figure 7: BPM position seems to have a small variation (less than 1 μm) with beam current at top-up mode, especially at the location of the injection section.

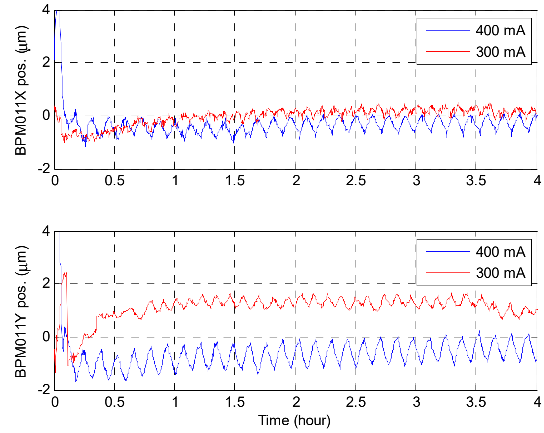

Figure 8: BPM position variation with beam current become to worsen when 400 mA top-up mode than 300 mA.

CONCLUSION

Closed orbit correction by the FOFB combined with RF frequency correction to compensate for path length variations is quite beneficial. However, it was observed that the thermal effect would cause the mid-term orbit disturbance at the first 30 minutes after the beginning of beam stored and long-term slowly drift for the following 4~5 hours before it achieves the equilibrium, especially in the vertical plane. This error would be amplified several times as observed at the end of beamline XBPM. It could be improved by put larger weightings on the straight-line BPM. But it may sacrifice the short-term stability when the target BPM readings are interrupted/corrupted. The trade-off is depended on what is the most users concerns.

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