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BEAM CENTROID STUDIES AT THE CANADIAN LIGHT SOURCE *

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Abstract

The Canadian Light Source (CLS) storage ring RF frequency varies on timescales of seconds to days. Over approximately 20 years it has drifted from its design value. We outline and discuss our efforts to identify, disentangle and mitigate the potential sources of variations in the RF frequency on various timescales. These sources include the building temperature regulation, the orbit correction algorithm and the dipole power supply. Further, orbit correction generates an undesirable amount of beam noise through the dispersion correction. We have ongoing efforts to understand and improve orbit correction and remove the noise it propagates into the RF frequency.

OVERVIEW

The Canadian Light Source (CLS) is a third generation light source located in Saskatoon, Canada. The storage ring (SR) design length is 170.88 m and normally operates in top up with a beam energy of 2.9 GeV and beam current of 220 mA . The SR consists of twelve double bend cells; there are twelve insertion devices (IDs) in eight of the twelve straight sections. The RF frequency at commissioning was 500.018 MHz [1]. It is easy to assume that the longer drifts in the RF frequency are due to temperature fluctuations and that shorter time scale variations are due to IDs. However, understanding when these assumptions are correct and the underlying mechanisms for the RF frequency variations will allow us to build a better understanding of beam and RF frequency fluctuations that are not temperature or ID dependent. We will discuss how the following systems affect the beam and RF frequency:

- Thermal drifts of hours to days occur in the SR tunnel and are suspected to cause drifts in the RF frequency.
- Oscillations in beam monitoring systems with periods of minutes correlate with water changes.
- Every three seconds, the orbit correction (OC) algorithm adjusts the RF frequency.

TEMPERATURE REGULATION

In the last two years, the RF frequency has varied between 500.049 51 MHz and 500.043 56 MHz. Both extreme values are linked to problems with the building temperature regulation. The low frequency event occurred when the building cooling system malfunctioned because the outside temperature was too high. The high frequency event occurred after an extended maintenance period when the average air temperature in the (SR) was at least 1 °C below its expected setpoint. There are also less extreme fluctuations in the RF frequency that seem to be temperature driven. On

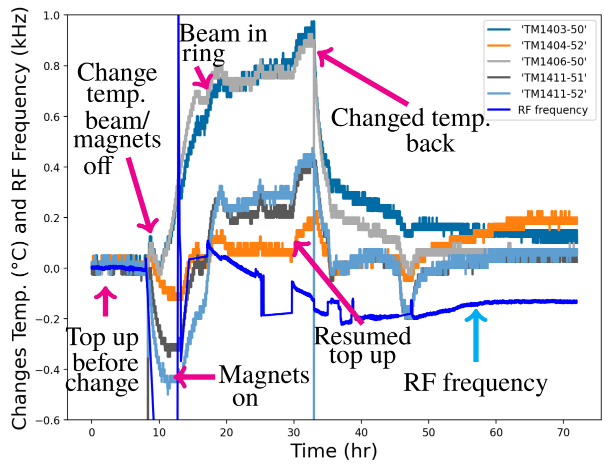

Figure 1: Changes in SR air temperature and RF frequency for Dec. 11, - Dec. 13, 2023. Deep blue RF frequency change [kHz]; the remaining lines are the air temperature changes for some SR monitors [°C]. System changes are indicated with magenta arrows.

Dec. 11, 2023 we increased the storage ring (SR) tunnel air temperature setpoint by 0.75 °C[1]. The experiment goal was to increase the physical length of the SR and decease the SR RF frequency so that it would be 2.5 kHz to 4 kHz lower. The target temperature change of 0.75 °C was determined from the linear expansion of stainless steel (beam pipe). The setpoints changes were reverted on Dec. 12 at 8:58 due to a problem with injection. The injection problem was not related to the temperature change but it negated our ability to conduct follow up measurements. Figure 1 has the temperature changes for some of the 26 SR air temperature monitors before, during and after the experiment. The experiment did not result in either a uniform change in the air temperature or the expected change in the average air temperature. The setpoint was changed shortly after the machine was turned off for routine maintenance; at approximately the same time, some of the magnet power supplies (PS) underwent maintenance and the dipoles magnets were off for several hours. We observed a drop in the air temperature when the beam and the magnets were off. Theoretically, we would expect the air into the SR should have adjusted as the heat sources turned off and then back on while keeping the air temperature roughly the same. Instead, the air temperature increased when the magnets were turned back on, and again when low

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[1] The SR air temperature setpoints are 26.0±0.1 °C and are calculated from the average of two values per cell.

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current beam was in the ring. There was another increase when we went into top-up.

If the machine has been in top up for more than two hours, the SR air temperature is relatively stable. However, it has slow drifts over many hours or days. Due to the system temperature regulation, the drifts depends on water and air temperature in the rest of the building and the external air temperature. These slow changes in air temperature are also correlated with changes in the RF frequency and together are compatible with thermal expansion.

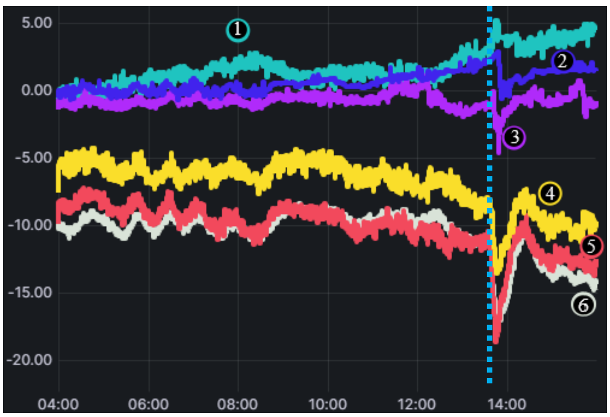

Figure 2: April 9, 2024 beam and water system correlations. Curves numbered from top to bottom, (1) RF frequency change scaled, (2) change in water temperature [°C] out of dipole PS, (3) BPM [μm], (4) XSR beam centre y, (5) water pressure to SR magnets scaled and (6) XSR beam centre x.

The building heating and cooling system consists of both glycol and water loops and air temperature regulation is coupled to the water system. The glycol loop has fluid coolers that are external to the building, and goes through a heat exchanger with the primary water loop which then goes through separate heat exchanges for each of the secondary loops[2]. One of the fluid coolers drives an oscillation that propagates into the primary water cooling/heating loop. The PS for the SR magnets are on the primary loop. The shortest observed oscillation has a five minute period and the primary water temperature changes by 1-2 °C over the oscillation period.

Figure 2 has a longer period beam and water temperature oscillation followed by a global increase in the system water temperature and the regulation response (sharp fast drop in temperature at dashed line). Data is shown for one beam position monitor (BPM) but similar oscillations are observed in all non OC BPMs[3]. XSR is our diagnostic beamline. Both XSR and the BPM have the same periodic oscillation between 4:00 and 8:00. However, for the system change, the BPM and RF frequency correlate with the water temperature changes at the dipole PS but the XSR changes correlates with the SR water pressure.

[2] There are secondary loops for the SR magnets, some of the beamlines components and the RF systems.
[3] This BPM, BPM1411-01:X, has the clearest signal

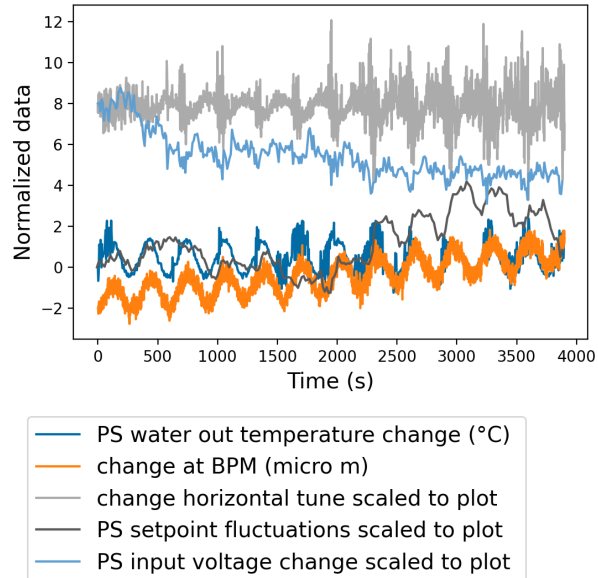

Figure 3: Five minute oscillation on Feb 13, 5:55-7:00, 2024 with tune feedback system off and decay mode.

The SR dipole PS does not meet it technical specifications. It is likely that cooling water changes at the PS could induce temperature dependence into the output from the PS to the dipole magnets. Data in Fig. 3 has curve offsets and scaling applied to illustrate the correlation between the horizontal tune, PS water temperature change, the beam and dipole PS setpoint fluctuations. The drop in the main voltage correlates with a change in the size of the dipole PS fluctuations at 6:35 which results in tune noise. The 5 minute periodic behaviour in the main voltage is most likely due to the load from the fluid cooler fans. The BPM drift is due to thermal drift in decay mode.

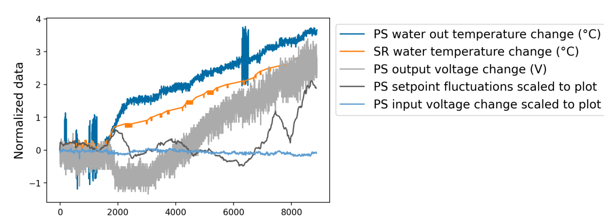

Figure 4: April 21, 12:40-15:08, 2024 decay mode and temperature regulation malfunction.

We have recently re-installed monitoring on the dipole PS output voltage. The voltage monitor shows correlations with changes in the main voltage. Generally, the grid voltage is higher at night and lower during the day. The output voltage from the PS inversely correlates with the main voltage and during the higher night voltage we see less fluctuations in the PS and less noise in the tunes. We have not observed the short five minute water temperature oscillation since the new monitor was installed in the spring, so we do not have definitive evidence for dipole PS voltage correlation with

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this oscillation. However, we have observed correlations with the output voltage and water oscillations like those in Fig. 2. Figure 4 has an extreme example of water temperature variation due to temperature regulation malfunction. The malfunction caused the water temperature to increase throughout the building, including the water to the SR magnets and strongly correlates with the rise in the output voltage from the dipole PS.

ORBIT CORRECTION

The current orbit correction (OC) algorithm was designed to remove the dispersive component of the orbit from the correctors so that the correctors are not correcting dispersion; the algorithm adjusts the RF frequency to compensate for the dispersion. The algorithm is based on the 2005 UPAS notes of J. Corbett and A. Terebilo [2]. The measured reference dispersion is used to calculated the dispersive orbit at the BPMs and the dispersive component in the correctors. Part of the corrector setpoint change is scaled by two factors; a straight scaling and a limit on the maximum change in the corrector setpoints. The calculation of the dispersion correction is sensitive to very small changes in the BPMs; these inaccuracies mean that large scale factors lead to inaccurate correction and an increase in beam noise.

If a horizontal corrector and corresponding BPM are removed from OC, the mathematical changes to the algorithm parameters changes the dispersion calculations. When this happens, the correction generally adjusts the RF frequency by around 0.5 kHz. The orbit has not changed and the new corrected orbit still passes through the remaining BPMs at zero. The correction can add ‘kinks’ to the orbit and this brings up the the question, do we have kinks in our orbit from long term operation of this algorithm?

The dispersion correction is needed due to long drifts in the air temperature and subsequent SR expansion, but the current implementation is problematic because it adjusts the RF frequency every three seconds. Ideally, the best solution would to be a new algorithm but the best implementation is not clear, so we are testing various edits to the existing algorithm to mitigate the existing flaws and reduce how often the RF frequency is adjusted.

USING OC TO DETECT WATER LEAKS

In the last six months, we have had five instances of water leaks on SR quadrupole magnet coils. The correctors nearest to the water leak may have setpoint changes of 4-10 times larger than normal. The changes in corrector setpoints predict water leaks more than 24 hours earlier than our other indicators. In order to positively identify a potential water leak, we first have to make sure we eliminate all other possible sources of water pressure and corrector setpoint changes. The water pressure into the SR elements has the same oscillations and large changes that are observed in the primary water loop temperatures. There are also routine manual adjustments. Once we account for these normal water pressure dependencies, we can correlate slow corrector drifts with a collective drop in the water pressure. Figure 5 shows corrector setpoint drifts for a water leak on January 25, 2024.

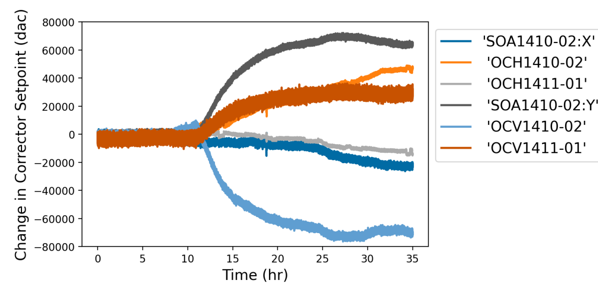

Figure 5: Jan 25, 2024 changes in corrector setpoints (dac) near water leak. Normal drift would be ~10 000 dac.

CONCLUSION

Untangling how water and air temperature regulation impacts the beam and RF frequency has allowed us to gain further insights into beam stability. Further study is needed to determine if the air temperature and ring length have an absolute correlation. Many of the observed relative changes in SR RF frequency can be explained through changes in the SR air temperature. However, there are also times where the SR air temperature is stable or increasing and the RF frequency is also increasing. We have yet to determine if our unexpectedly short ring is due to temperature, orbit correction, cold magnets, dipole PS instabilities or all of the above. We will be able to test our hypotheses regarding the instability of the dipole PS and its effect on the system when we replace it in 2025. We are in the process of updating our orbit correction algorithm in order to improve our dispersion correction.

ACKNOWLEDGEMENTS

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