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IMPROVEMENTS ON SIRIUS BEAM STABILITY

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Abstract

Sirius is a Synchrotron Light Source based on a 3 GeV electron storage ring with 518 meters circumference and 250 pm.rad emittance. The facility is built and operated by the Brazilian Synchrotron Light Laboratory (LNLS), located in the CNPEM campus, in Campinas. A beam stability task force was recently created to identify and mitigate the orbit disturbances at various time scales. This work presents studies regarding ground motion (land subsidence caused by groundwater extraction), improvements in the temperature control of the storage ring (SR) tunnel air conditioning (AC) system, vibration measurements in accelerator components and the efforts concerning the reduction of the power supplies' ripple. The fast orbit feedback implementation and other future perspectives will also be discussed.

INTRODUCTION

Since late 2020 the SR has operated for beamline commissioning and more recently for external users. The routine operation has started with 40 mA and 30 hours lifetime. Currently, 100 mA is provided with 16 hours lifetime, with two injections per day.

Beamlines are observing slow photon beam movements with periods of hours and others from 60 Hz mains frequency present in both planes of the beam orbit spectrum.

Future matters of concern are the horizontal orbit perturbation in the SR due to booster ramping at 2 Hz and its harmonics and the fast orbit transients caused by injection pulsed magnets. Both need to be addressed, as top-up operation is planned to start soon.

KNOWN INSTABILITIES

We separated the phenomena into 3 categories: short, medium, and long-term disturbances. Long-term ones show time scales greater than many minutes or hours, like temperature variations, and must be attenuated as much as possible, as they usually affect the readings of sensors used in feedback systems. Mid-term disturbances comprise the low-frequency phenomena up to the upper limit of the fast orbit feedback system (FOFB) system actuation range. Short-term instabilities are those on the scale of milliseconds or less. Most of the ground settlement has already occurred allowing two important girder alignment campaigns in 2021 and 2022 for SR and booster, respectively [1–4].

Long-term Disturbances

Sirius counts on a network of 20 hydrostatic leveling system (HLS) sensors installed on the roof of the tunnel that allowed us to detect 2-4 hours oscillations also noticed in the beamline experiments' data. The oscillation patterns were present in the SR radio frequency (RF) when the slow orbit feedback system (SOFB) is ON and in the BPMs and tunes with the SOFB OFF. The horizontal plane was more affected in the SR, while the vertical one was in the beamlines.

Slightly more intense oscillations were detected by HLS sensors on SR sector 11. Observing the surroundings of the building, a drilled water well with 180 meters in depth was found near the long beamlines, 20 meters apart from the building. Tests were performed by turning the water well pump off to check its influence on Sirius stability (Fig. 1). After turning off the source of the few-hour period oscillations, a 24-hour period disturbance is clearly seen, which indicated the existence of more sources of instability.

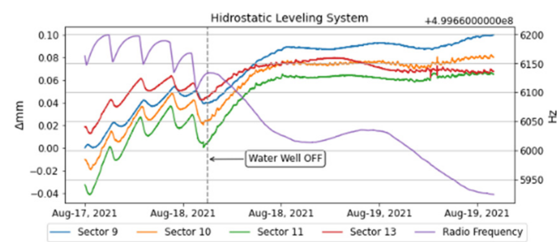

Figure1: RF readback and HLS sensors around sector 11. SOFB system ON.

A test where a second water well, with similar characteristics to the disturbing one, inside CNPEM (250 meters far from the Sirius building) was activated intermittently showed no measurable effect on the HLS sensors, orbit stability, or RF frequency. More distant wells, outside the institute should not affect the stability. Variations in the water level of the aquifer, influenced by rainfall will possibly cause much a smaller and slower effect.

As a temporary solution, a new operation mode was implemented in which the water is pumped every 10 minutes, with a constant duty cycle calculated to provide an average flow that meets the consumption demands.

Terrestrial tidal effects were expected to affect horizontal and vertical planes likewise, thus not being able to explain the large RF frequency variations when the well operated in modes other than the standard one (Fig. 2). Therefore, the possibility of some effects being related to temperature variations and possible deformations caused by thermal dilatation started being considered.

Sirius' concrete slabs have a network of temperature and strain gauge sensors installed in several layers around the building (Fig. 3, left). To check the correlation between the Sirius concrete temperature and the RF oscillation we developed a simple model of concrete ring expansion based

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on the measured temperature variations from NTC-type sensors and considering linear thermal expansion in the radial direction. In fact, a closer look at these sensors shows small 24-hour features in their data (Fig. 3).

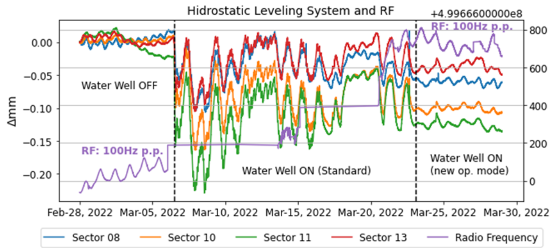

Figure 2: HLS sensors and the RF signal readback in three different situations: water well OFF, ON in the new mode and ON in the standard operation mode.

Initially, the average position of the temperature sensors in each sector of the building was estimated (Fig. 3, right), with the goal of estimating the movement of each region from the radial displacement of a respective point.

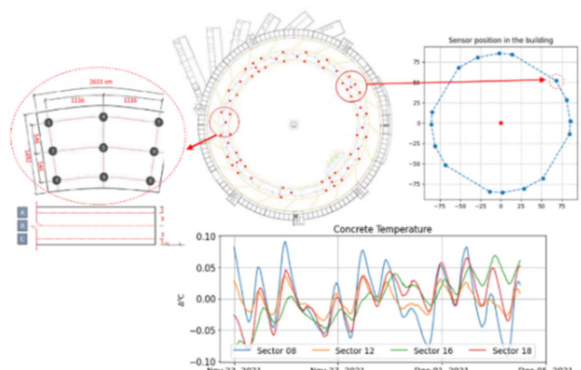

Figure 3: Layout of the Sirius building (center) indicating the location of temperature sensors around the accelerator at different levels. Details of the concrete boards with sensors location are also shown (left). Examples of NTC-type concrete temperature measurements (bottom).

Two characteristics of this system are not ideal: the total acquisition time of the sensor network is about 30 minutes and the sensors' readings are sequential. Furthermore, there are no sensors in all the positions A, B and C levels. Then, once collected, data are grouped in time frames of ±15 minutes regarding an arbitrary reference. After that, for each fixed time instant a new perimeter is calculated based on the linear thermal expansion of each point in the radial direction. Only the temperature variation and the concrete thermal expansion is considered. The resulting correlation graphs indicate that the perimeter changes could be explained by the temperature oscillations (Fig. 4). A 2-hour time lag between the curves improves the correlation. The observed high correlation (99.3%) evidences the potential influence of the temperature, and thus the AC control system, on the RF oscillation due to the perimeter expansion. As expected, recent temperature analyses (Fig. 5) show that the AC control system inside the SR tunnel is more stable than the experimental hall one.

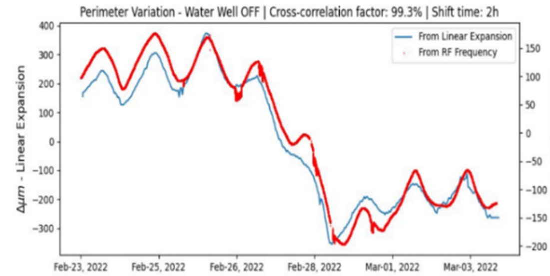

Figure 4: SR perimeter variation estimations based on linear expansion and RF frequency measurements.

Figure 5: Concrete slab temperature in different regions - inside the tunnel (curve 5), outside in the outer circumference (curves 4 and 6), and inner circumference (curves 6 and 9) for the tunnel Sector 15.

Since the SR tunnel slabs also have two regions of interface with the hall air, a preliminary simulation was performed to evaluate the deformation order of magnitude that a temperature gradient on the slab, generated by an offset between the tunnel and experimental hall temperatures, could cause. Results show that an offset of 1.5 °C imposes about 80 μm of radial expansion in one sector, which represents 50 μm on the circumference or about 50 Hz at RF (Fig. 6).

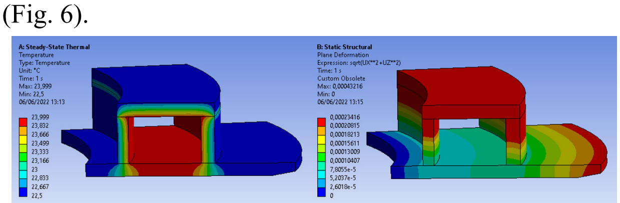

Figure 6: Temperature distribution assuming 1.5 °C difference between inside and outside the tunnel (left); correspondent planar thermal deformation (right).

Mid -term Disturbances

Among the disturbances with time scales ranging from seconds to milliseconds, the 2 Hz and 60 Hz interferences seen in both horizontal and vertical planes in all BPMs have the highest impact in the experimental stations.

Several tests were performed with stored beam showing evidence that the PSs themselves are not the source of the 2 Hz and 60 Hz noise we see in the beam. All steering magnets PSs were organized in groups and turned off, group by group, with a stored beam with no evidence that they could be the cause of the 60 Hz contamination. The same was done for the trim coils of quadrupoles PSs, with no sizeable influence observed. Besides that, for the high-power PSs the ripple was checked with an external DCCT and no important 2 or 60 Hz component was found. These frequency

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lines were always largely below the specifications, as well as the total integrated noise, below 20 ppm.

To ensure that these small ripple magnitudes were not enough to disturb the beam due to some unknown effect, another test was performed with all high-power SR PSs to systematically impose a 2 Hz sine component of controlled amplitude to the output current to determine the amplitude needed to affect the beam in the same amount as the 60 Hz disturbances [1]. Results showed that components with amplitude of roughly 200 and 800 ppm are required on dipoles and quads, respectively, to disturb the beam similarly to the 60 Hz component regularly observed (Fig. 7).

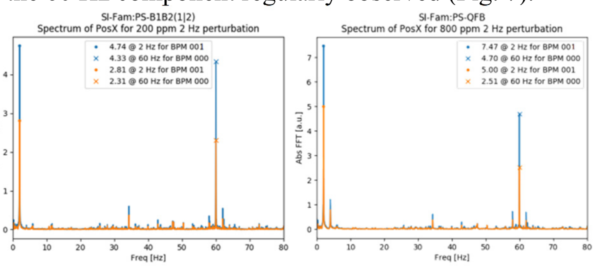

Figure 7: Spectra of the horizontal position for a 200 and 800 ppm at 2 Hz controlled disturbance injected by the bends and part of the focusing quads' PSs into the beam.

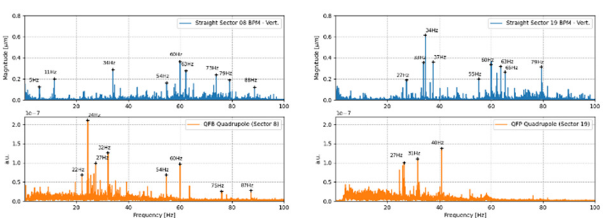

Figure 8: Vibration and beam position spectra at SR sectors 8 and 19.

Preliminary vibration measurements were performed on some SR QFP and QFB quadrupoles to compare the main frequencies with those found in the beam spectra (Fig. 8). The source of the low-frequency vibration disturbances, mainly below 50 Hz, will be investigated.

Short -term Disturbances

The energy oscillations induced by RF noise are also a matter of concern and cannot be eliminated by means of the SOFB or FOFB systems. At Sirius, noise present in the low-level RF control system shows up in multiples of 64 Hz. BPMs in dispersive regions present a horizontal perturbation around 1.5 kHz modulated with 64 Hz harmonics. The measured values are comparable to the requirement of 10% of beam size. Improvements in the Sirius LLRF system are ongoing [5].

Septum pulsed magnets and the non-linear kicker (NLK) cause significant disturbances in the stored beam (Fig. 9). Leak fields from the septum and mechanical errors in the spatial positioning of the eight NLK wires through which the pulsed current flows are the causes of the beam disturbances that are in the time scales of milliseconds.

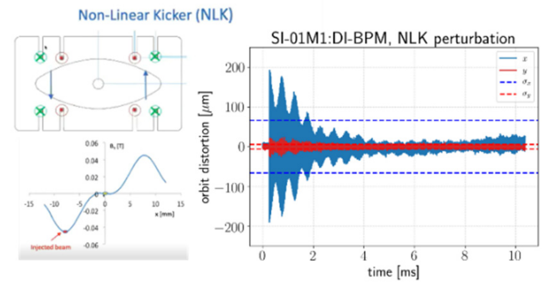

Figure 9: Simplified schematics of the NLK vacuum chamber and its expected filed profile (left) and orbit distortion at both plans measured by the upstream sector BPM (right).

Tolerances for NLK ceramic chamber assembly are critical and represent a challenge for manufacturing. Aiming to reduce the pulsed disturbances, mechanically and remotely adjustable inductors are foreseen to be installed in parallel to the installed wires, allowing a fine tuning of the current pulse through each wire. Additionally, operation with local horizontal and vertical bumps is being studied to reduce the NLK bumps in the beam orbit.

The immediate next step toward reducing the septa leakage fields is installing additional shielding foils in vacuum chamber flanges close to the stored beam. Upgrading the fast pulsers to control the amplitude of the negative part of the current pulse to reduce the long tail that lasts several milliseconds after the fast pulse is also foreseen.

FINAL REMARKS

The complete deactivation of the water well is foreseen for the end of 2022. To improve the beam stability, it is possible to operate with either the well OFF, then supplying the institute with water trucks or operating the water well in the new mode, fast cycling its pump.

Simulations, air and concrete temperature data analysis indicate the building AC system is the main cause of the perimeter variation occurring with 24-hour period. Improvements in the system are foreseen for this year.

Tests indicate that the PSs' stability is not the root cause of the 60 Hz disturbances seen in the beam orbit. Surveys of AC magnetic fields around the SR are ongoing. Currently, only the SOFB is implemented and operates with a 25 Hz actuation rate and about 1 Hz bandwidth. The Sirius FOFB is in its final phase of installation and all the magnets, network, and electronics are in place. Operation in closed loop is expected in the third quarter of 2022.

Besides improving the septa shielding and NLK field at the center position, we aim to use the timing system to generate blanking signals (about 20 ms-long) to the beamlines every injection (twice per second) to cope with the remaining fast disturbances.

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