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ALIGNMENT VERIFICATION AND MONITORING STRATEGIES FOR THE SIRIUS LIGHT SOURCE*

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Abstract

The approach for the alignment of Sirius is the use of portable coordinate metrology instruments in a common reference, via a network of stable points previously surveyed. This type of network is composed of a dense distribution of points materialized in the form of embedded target holders on the special slab and radiation shielding. Phenomena such as ground movements, temperature gradients and vibrations could lead to misalignment of the components, possibly causing a degradation in machine performance. Therefore, the relative positions of the accelerator magnets need to be periodically verified along with the structures surrounding it to ensure a good reference to future alignment operations. This paper will present the status of Sirius monitoring systems, including data from the first months of operation of the hydrostatic levelling sensors. Also, possibilities with simplified network measurements for detecting structural deformations and assessing its stability will be presented, along with a proposal of a photogrammetric reconstruction of the alignment profile of the storage ring. Finally, it will be shown a compilation of analysis on the deformation of the Sirius facilities.

INTRODUCTION

Sirius, the new Brazilian 4th generation Synchrotron light source, has several stability and alignment requirements that were reached in design/construction phase [1] and in the fine alignment operation early this year [2], respectively. Although the high stability and achieved alignment results, long-term movements and deformations still may be a concern, especially because of the cut and fill characteristic of its site and temperature variations before the full temperature stabilization of the special slab and radiation shielding. Given that and the expected shrinking of the concrete during the curing of the Sirius structures, a series of monitoring systems and alignment verification strategies were implemented and integrated to analyse deformations. This work updates the status of these monitoring systems [3], in special the hydrostatic levelling system with some preliminary results on its commissioning. An overview on the alignment verification strategies for the Sirius' magnets and reference network will also be presented. Besides a proposal of an agile measurement scheme to reconstruct the Storage Ring (SR) alignment profile will be shown.

MONITORING SYSTEMS

The systems were designed to monitor the building, supporting structures and environmental variables. They are (1) a hydrostatic levelling system (HLS); (2) concrete instrumentation; (3) meteorological stations and (4) a seismic station. The following subsections presents details about the systems, including its status, assembly information and validation procedures.

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Hydrostatic Levelling System

Sirius' HLS is composed by a main network of 3” PVC pipe that cover the whole SR perimeter of approximately 518 m, and it was installed on the radiation shielding ceiling (see Fig. 1) due to access limitations inside the tunnel. The half-filled scheme was chosen due to its robustness to temperature gradients [4], shorter stabilization time [5] and because there were no limitations on levelling the whole pipe network. There are 20 sensors (provided by Fogale Nanotech) spread along the perimeter, and its layout was designed to allow the study of possible movements caused by the groundworks performed in Sirius site. In terms of software, data acquisition is made with an EPICS based application written in-house [6].

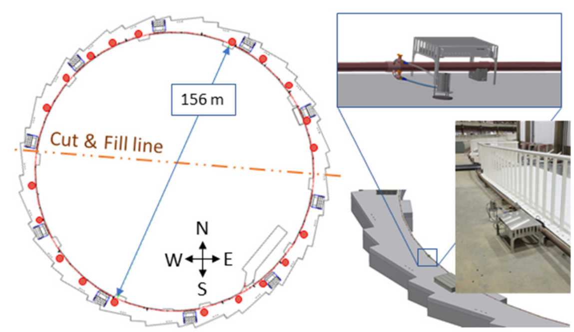

Figure 1: HLS's layout and assembly details. Red dots and lines represent the sensors and pipe network, respectively.

The system is currently under a commissioning stage, intended to validate its readings. To do so, a comparison was made between the vertical deformation sensed by the HLS in a 2.5-month time window and the deformation of the accelerator's special slab measured by a Leica NA2 Optical Level. The results are shown in Fig. 2.

Despite small differences potentially explained by measurement uncertainty, the large correlation between the measurements using completely different measurement principles and technology validates the use of the HLS for monitoring purposes, although future investigations will be performed to evaluate the measurement uncertainty of the system. Also, the comparison demonstrated that the ceiling follows the vertical movements of the slab, leading to the conclusion that it seems reasonable to monitor the vertical movements of the slab with the HLS on its current location.

Another metric used to check for the reliability of this type of system is the detection of small terrestrial tidal effects. In this sense, data from two sensors placed near the East-West direction in two quadrants of the ring was

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compared, and the time series and spectrum of the signal are shown in Fig. 3. Although there is a strong component with 24 hours period, the also expected 12 hours component is present but still unclear. Furthermore, workdays show higher amplitudes of movement in opposition to the weekends, and an apparent offset. Possible explanations include vibrations and uncompensated thermal effects in the system. Further studies will be conducted to investigate these phenomena.

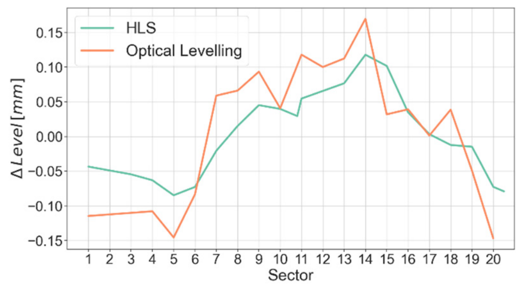

Figure 2: Comparison of the deformation indicated by the HLS and the one measured by Optical Levelling.

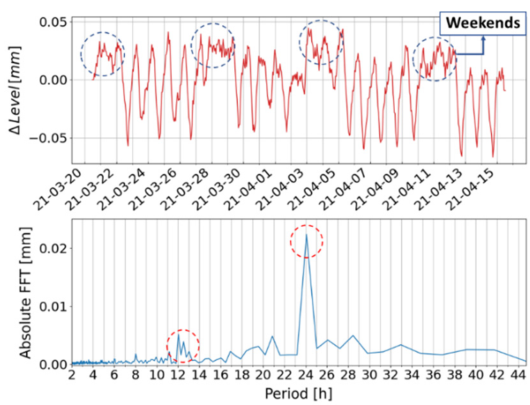

Figure 3: Comparison between the level readings of two diametrically opposed HLS sensors.

Concrete Instrumentation

To gather information on the behaviour of critical concrete structures of the Sirius facility, nearly a thousand temperature and deformation sensors (strain gauges) were embedded in the accelerator's special slab and radiation shielding during concrete pouring. That information was critical specially during the curing stage of the concrete back in 2017. Since then, we developed a new software solution (also integrated with EPICS), and currently the system is being used for deformation analysis.

Meteorological and Seismic Stations

Meteorological data is crucial to diagnose the source of certain types of long-term structural deformations, namely the ones related to local rain season, external environmental temperature changes, etc. Given that, a pair of meteorological stations were installed above external structures of the Sirius building, and data acquisition is expected to start soon. In the context of seismic activity, although it is not expected that Sirius will be affected by earthquakes in its lifetime, it is still interesting to monitor ground vibrations for diagnostic purposes on eventual instabilities on the machine. Sirius seismic station is already acquiring data from the accelerator's slab (outside the accelerators tunnel) and data analysis will begin shortly.

VERIFICATION STRATEGIES

In the alignment context, it is a common practice to periodically survey the position of accelerator's magnets and the reference network. In the case of the reference network, it is known that long-term deformations may impact its current mapped state [7], therefore it is important to monitor it for future alignment operations. Once the magnets are aligned, their position must also be checked from time to time to ensure they are still within its positional tolerances.

Radius Measurements

For periodic verifications of the SR radius, measurements of 5 control points inside the radiation shielding have been made with a laser tracker (LT) from a central pillar on the center of the building. This monitoring process started about 8 months after the concreting of the tunnel, and all the data is collected in the evening to prevent air-refraction changes affecting the measurements. The data is analysed using a Python script, through control points projection on an average plane and a circle fitting.

Network Simplification

The process of surveying the whole reference network of the accelerators is a highly demanding task, given its 1220 points that must be measured with high precision and redundancy. Therefore, a study was conducted to reduce the total amount of stations needed to reach results comparable to the complete survey previously made. Best result so far led to a reduction of 24% of the stations with 90% of the points with residuals from the complete network within 0.1 mm. Still, more simplified layouts should be evaluated before concluding this study.

Photogrammetry Survey Scheme

Sirius is now in operation, and in this scenario, every intervention inside the tunnel will have to be as fast as possible to minimize the downtime of the machine. Given that usual survey of the accelerator's magnets with LTs can take up to a few weeks to be concluded, we propose a mixed approach with high precise photogrammetry measurements and a complete survey potentially fitting in 8 hours in total. Long distance information will be given by LTs, whereas height differences between far away points will be provided by optical level campaigns. The measurement scheme will apply inter-changeable targets and a calibration procedure was already envisaged. Small scale tests were conducted to verify the precision and time requirements, and both were satisfied (repeatability of about 0.027 mm and 1 min per station – 220 stations planned). For the next step, it is planned to simulate a complete reconstruction of the SR magnet's profile with this method to test how the residuals pile up and affect the global shape of the reconstructed alignment profile of the SR.

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DEFORMATION ANALYSIS

Since its construction, Sirius' concrete structures have passed through a series of deformations both in vertical and horizontal/radial directions, which has been properly monitored along the past 3 years. In the following subsections the data and analysis upon these deformations will be shown.

Vertical Deformations

The SR was course aligned in 2018 [8] and in 2020, during an update on the reference network, the magnets were also measured. Figure 4 shows the absolute position of the magnets on both scenarios, where the accelerator's slab suffered vertical movements up to 1.75 mm peak-to-peak. This deformation is related to early foundation settlement – the structures were concreted at the end of 2017 – and was expected. In addition to that, when confronting the resultant profile with the cut and fill line of the site, the movement trend in both regions is remarkable.

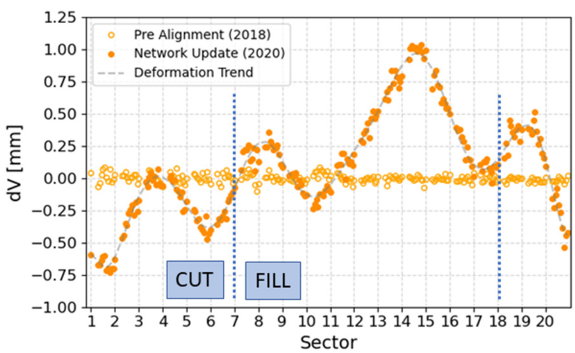

Figure 4: Vertical absolute position of SR magnets after the course alignment (2018) and during the network update (2020).

This deformation trend still can be found on recent observations but with at least one order of magnitude less, both by optical levelling campaigns (comparing Feb./2020 to Nov./2020) and more recently the HLS, as shown in Fig. 5, indicating a significant vertical stabilization. The oscillations in HLS readings indicates that there might be a seasonal behaviour on the movements, but a longer follow up is required to draw conclusions on that. Besides this effect might corroborate with the stabilization trend assumption.

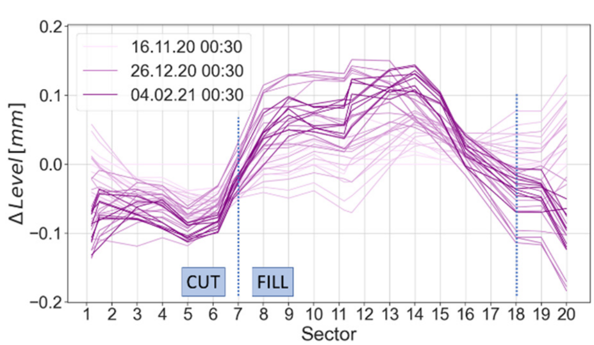

Figure 5: Vertical deformations acquired by the HLS from Nov./2020 to Apr./2021.

Horizontal Deformations

Figure 6 shows the horizontal displacement of the SR magnets in the same period of 2018 to 2020. It indicates an average retraction of the building in the radial direction of approximately 1 mm, possibly related to the curing of the radiation shielding and lack of thermal control inside the building at the time of pre-alignment. Direct measurements of the radius [2] and estimations of the machine's radio frequency on the same period also points to this retraction.

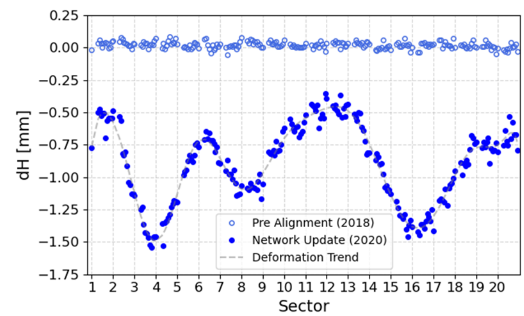

Figure 6: Horizontal absolute position of SR magnets after the pre alignment (2018) and during the network update (2020).

Lastly, in terms of temperature, Fig. 7 shows that after the initial curing, the concrete temperature seems to follow the external environment, and when the air conditioning entered operation the fluctuation stopped, indicating the beginning of thermal stabilization of the structures.

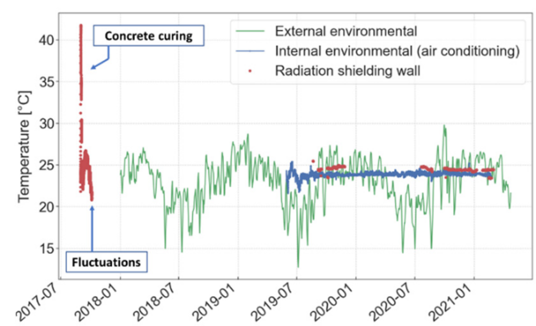

Figure 7: Timeseries of environmental and structural temperatures. Courtesy: Center for Meteorological and Climate Research Applied to Agriculture (CEPAGRI).

CONCLUSIONS AND NEXT STEPS

The status of multiple monitoring systems and verification strategies for the alignment of Sirius was presented, along with deformation data and analysis. For the next steps, it is planned an evaluation of the accuracy of the HLS readings, an investigation on the workdays drift and a longer follow up to seek for seasonal behaviour. Furthermore, HLS will be used to investigate the oscillations in the RF frequency of the SR and instability of the photon beam on CATERETE beamline [9]. Also, the conclusion of the installation of the meteorological stations and analysis of the seismic data will be carried out soon. Finally, it is planned the conclusion of studies for network simplification and final tests to validate the photogrammetric approach for reconstructing the SR alignment profile.

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