Mech. Eng. Design of Synchrotron Radiat. Equip. and Instrum. MEDSI2020, Chicago, IL, USA JACoW Publishing
ISBN: 978-3-95450-229-5 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2020-THOA03

ALIGNMENT STRATEGIES AND FIRST RESULTS ON SIRIUS BEAMLINES

G. Rovigatti†, H. Geraissate, R. Leão, CNPEM, Campinas, Brazil

Abstract

The new Brazilian Synchrotron Light Source had its first friendly users late in 2019. During 2020, the first experimental stations were aligned and had the first beam successfully at the sample. The reference network of points used for the storage ring alignment was connected to an external network located in the experimental hall. Following this step, it was possible to extend these references to the hutches environment, where the beamlines components are installed. During the alignment of the first beamlines, a sequence of common tasks was performed, from the bluelining of the hutches footprints, to the components fine alignment. The position and orientation deviation of the main components will be presented for the Manacá, Cateretê, Ema, and Carnaúba beamlines. Two specific measurement strategies used for aligning special components will also be presented: (1) an indirect fiducialization procedure developed for most of the mirrors and their mechanisms using a mix of coordinate measuring machine and articulated measuring arm measurements, and (2) a multistation setup arranged for the alignment of a 30 meters long detector carriage, using a mix of laser tracker, physical artifacts, and a rotary laser alignment system used as a straightness reference.

INTRODUCTION

Sirius, the 4th generation Brazilian synchrotron light source is designed to accommodate 38 beamlines. The initial phase comprises 14 beamlines to be delivered until 2022 [1]. By the end of 2020, Manacá, Cateretê, Ema and Carnaúba concluded their installation and alignment phase and started their commissioning with friendly users.

All beamlines of Sirius have many critical requirements to work properly, such as stability and temperature. Alignment is one of these requirements, and its importance begins at the installation phase, guiding the positioning of big components (e.g. hutches and girders); continues at the commissioning, supporting the scientists in making the beam reach the sample position and remains essential over time, when installing new components, verifying deformations, etc.

This work describes how the beamlines alignment was managed and details particular cases where metrological methodologies were developed.

REFERENCE NETWORK

Alignment is a critical requirement to the well-being of a synchrotron accelerator. To reach the designed tolerances, not only a reliable equipment is necessary but also a metrological reference network needs to be created.

The main reference was created inside the radiation shielding (RS) of the storage ring (SR). Approximately 1220 SMR nests were distributed on the floor, walls and ceiling. Outside the tunnel, a secondary network was created for the Experimental Hall (EH). This one is referenced to the primary network and has approximately 730 points, at walls, floor, and columns. Also, tertiary networks were created for the hutches and long beamlines.

The strategy used to create the networks was a classical laser tracker (LT) survey, with several stations along the volume measuring the points of the network with redundancy. The stations followed a “zig zag” pattern and different heights were used for the instruments [2]. All LTs used were from the Leica AT400 family. Also, levelling campaigns were done inside the accelerators tunnel, at the EH and long beamlines. The equipment used was the optical level Leica NA2. Radius measurements were done from the central pillar of the Sirius building to inside the RS, to bring more robustness to the network [3].

A normal connection between networks would be done by a simple overlapping of common points between the environments. But, as the RS is fully enclosed, there is no way to do this between the Sirius primary and secondary networks. The only free lines of sight from inside to outside the RS are holes with Ø150 mm and 1 m length. So, the link was done using a reciprocal connection technique, using two LTs measuring each other and fitting spheres that constructs the rotation center of the instrument. With mathematical manipulations of the centers created, the located LT from inside the RS will reference the second instrument at the EH [3-5].

After each network is calculated, they are adjusted in space by means of least square transformations. The SR network is adjusted with respect to the last epoch and become the reference for the subsequent ones. The Hall network is then adjusted to the SR, preserving its level and using the common points for the other degrees of freedom; and the tertiary networks are adjusted to the Hall's following the same strategy, except for the hutches networks, which inherits the same level as their parent network.

Through the adjustment steps, the network uncertainty propagation is done with a Python based script, developed in-house, using Monte Carlo simulations of the possible transformation matrix between two networks, which considers the individual uncertainty value for each point on the networks [6]. It creates point-clouds for each network, calculates the different transformations possibilities and apply these transformations to the network being adjusted. As expected, the uncertainty results are influenced by which coordinate system is being used. A study was made to evaluate how it propagates from a source point within the

† gustavo.rovigatti@cnpem.br

Mech. Eng. Design of Synchrotron Radiat. Equip. and Instrum. MEDSI2020, Chicago, IL, USA JACoW Publishing
ISBN: 978-3-95450-229-5 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2020-THOA03

accelerator (an insertion device in this case) to the end of the longest beamline (Carnaúba), as shown in Fig. 1.

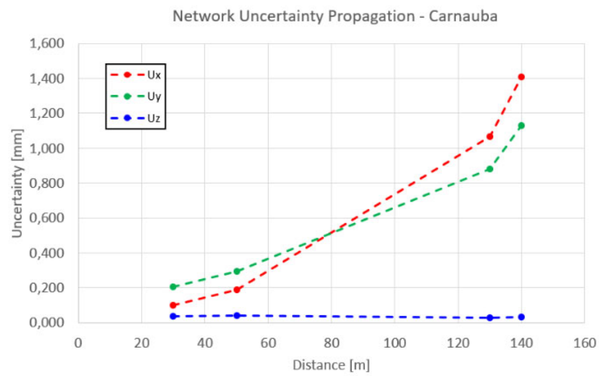

Figure 1: Uncertainty propagation for the Carnaúba beamline.

It is important to mention that these values are for the points in the network with respect to the beamline source, while the uncertainty for relative alignment of adjacent components are much smaller (in the order of a few dozen micrometers).

BEAMLINE INSTALLATION

From the point of view of metrology and alignment, all the beamlines follow a same sequence of tasks, beginning with data preparation and compatibilization of CAD designs with the geometric entities within the software SpatialAnalyzer™ (SA) from New River Kinematics.

The second step consists of blue lining the perimeter of the hutches and making as-built measurements of slabs and RS walls (interfaces of hutches and equipment with the building). This is necessary because all the parts of hutches are designed and manufactured to avoid gaps, according to as-built data. For the components, a study of shims is done for each pedestal of the beamline. Then, all drilling marks for bolts are done.

The next task is related to externalize references of the components, a procedure known as fiducialization. There are a lot of critical pieces in a component, and sometimes its main aspects are inaccessible for the LT because there is no position to put the station and have a good line of sight. Or, for example, that component cannot stay open during its positioning, because of vacuum and cleanliness demands. The solution to this problem is to relate accessible parts of the component to your functional characteristics, because when installing inside the hutches, almost any position of station will be able to see the external references and align the component.

It may be very simple for some components (collimators and shutters), but also challenging for others (mirrors, monochromators, slits etc.). Almost all of them needs to be fiducialized before their installation.

Following the fiducialization phase, the component must be installed and pre-positioned inside the hutch, which is done together with the installation team and beamline staff. Using a LT located at the reference network of that beamline, a pre-alignment of the component is done, achieving tolerances that will allow the vacuum assembly and commissioning, which may take days depending on the component. Finally, the components final alignment must be done also using a LT, achieving the designed tolerances.

CASE STUDIES

Mirrors Indirect Fiducialization

A novel technique of indirect fiducialization was developed for the Sirius mirrors. The method consists in matching geometries constructed from measured points in two acquisition setups. Firstly, the mirror substrate and optical axis/face are measured in a high precision CMM. Secondly, the mechanics that support the mirror is assembled inside its vacuum chamber and measured with an Articulated Measuring Arm. In this process, the assembly layouts that define the mirror position on its mechanism (Fig. 2) are measured and used to define the same geometries measured on the substrate. Four fiducial references outside the vacuum chamber are also measured. Finally, the coincident geometries measured on the substrate and on the mechanics are matched using least square transformations in SA, resulting in the mirror functional axis represented by the four external fiducial points.

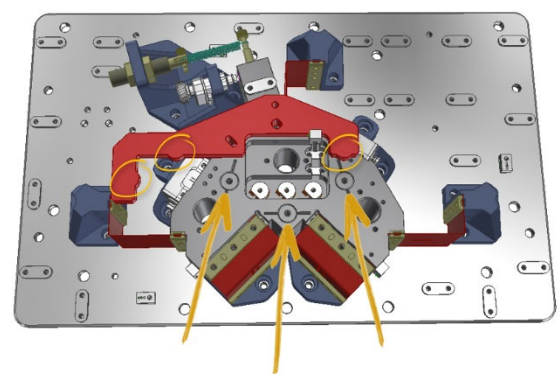

Figure 2: Mirror assembly layout. The yellow circles and arrows show the contact points between mirror and mechanism.

The Articulated measuring arm used (7 axis ROMER by Hexagon) have a basic volumetric accuracy of approximately $\pm 35\ \mu m$. But it is an equipment that also depends on other factors, such as operator experience and relative position between the Arm and the measured part. To quantify the task-specific uncertainty related to each different mirror system, the mechanism measurement process was repeated five times. The repeatability was then evaluated, and the average coordinates of the fiducial references are used during the mirror fine alignment in the beamline. The estimated uncertainty for the fiducialization of a mirror for the Cateretê beamline is shown as an example in Table 1.

ISBN: 978-3-95450-229-5 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2020-THOA03

Table 1: Cateretê M1 Fiducialization Repeatability in mm and mrad.

	Repeatability			
	Tx	**Ty**	**Tz**	**Mag**
StdDev	0.026	0.038	0.016	0.049
	Rx	**Ry**	**Rz**	
StdDev	0.1328	0.3189	0.2869	

Detectors Tunnel for the CDI Beamline

Cateretê beamline is one of the longest of Sirius. It is focused on using the coherent X-ray scattering and diffraction technique [7]. Its detector is installed over a carriage that moves longitudinally over a 30 meters long rail, inside a vacuum chamber.

This rail was installed and positioned by the AVS team (manufacturer) in partnership with the Sirius Metrology team. After completing the installation by the manufacturer, an acceptance test was done, aiming to validate the straightness and trajectory orientation of the carriage. The specification was to keep the vertical and horizontal straightness within a diameter of 1 mm along the whole longitudinal movement, requisite called Disc of Confusion (DoC).

Two setups (Fig. 3) involving LT were planned to be realized in this experiment, including a reference measurement using a laser alignment system (L-743 Ultra-Precision Triple Scan) from the manufacturer Hamar Laser Instruments, which has a good accuracy of 0.0013 mm/m with an operational range of 30.5 m in radius.

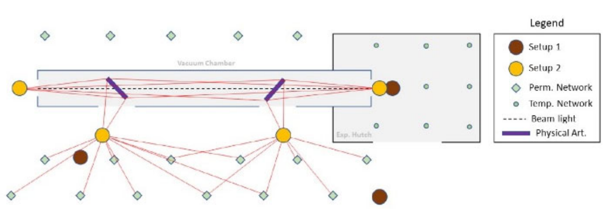

Figure 3: Setup schematics.

The first setup was a classical approach. It consisted in using two LT stations for measuring the permanent network and creating a temporary one. Then, a third station was located in the created temporary network inside the experimental hutch. This station measured the DoC, acquiring points every 1 m.

The second setup proposed a novel configuration. Two LT and two physical artifacts (PA) were used [8]. The LTs were positioned at the tunnel ends and doing a collaborative measurement of the points. The LTs location was made in two steps. First, two stations measured the permanent network and the PAs positioned inside the tunnel. Then, the second step was the location of the stations positioned at the tunnel ends, using the PAs previously located as a reference. Finally, the DoC was measured by both stations, acquiring points every 1 m.

The data analysis confirms that the combination of the measurements of LTs could decrease the measurement uncertainty and maintain it for the whole trajectory, which would normally increase with distance.

Also, using the PAs inside the measured volume increased the reliability and allowed a good location and orientation of the instruments. The comparison between the three DoCs (metric combining uncertainty, orientation, and trajectory) can be seen at Fig. 4.

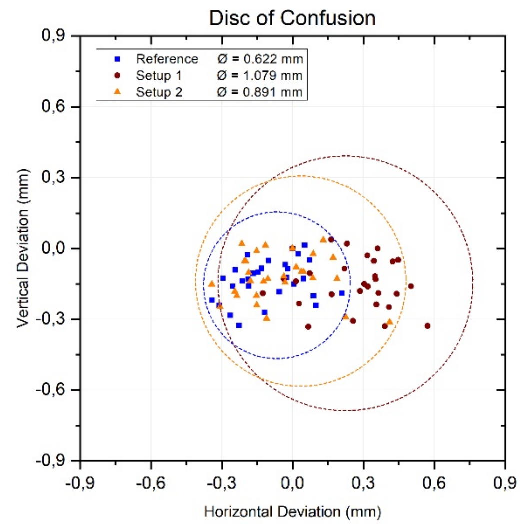

Figure 4: Disc of confusion of the acceptance test. It represents the minimum circumscribed circle for each data set and considers the setup estimated uncertainty.

ALIGNMENT RESULTS

Some of the Sirius beamlines entered commissioning phase at late 2019. The installation and alignment process were completed, and the first tests could be started.

Table 2 shows the compiled final alignment results for components of the 4 beamlines described in the introduction section. An average of the main coincident components results was done, since each one has its own tolerance.

Table 2: Alignment results of the 4 beamlines of the study in mm and mrad.

Comp.	X	Y	Z	Rx	Ry	Rz
Mirrors	-0.01	0.01	1.11	0.04	0.03	0.02
Collimators	0.04	-0.06	-0.19	0.23	-0.11	0.28
DVFs	0.03	-0.08	2.16	1.04	2.81	0.06
Shutters	0.05	-0.06	-0.13	0.05	0.09	0.13

CONCLUSIONS

Besides the alignment results, the feedback from the operators of the beamlines is good, showing that the alignment process done was successful. This shows that the strategies described along this paper were adequate and may continue to be used for the next beamlines.

ISBN: 978-3-95450-229-5 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2020-THOA03

REFERENCES

[1] R. Picoreti, H. Westfahl, "Sirius facility update", Synchrotron Radiation News, vol. 34, no. 1-3, pp. 12-13, 2021. doi:10.1080/08940886.2021.1902713

[2] R. J. Leao, C. R. Baldo, M. L. C. C. Reis, and J. L. A. Trabanco, "Engineering survey planning for the alignment of a particle accelerator: part ii. design of a reference network and measurement strategy", *Meas. Sci. Technol.*, vol. 29, no. 3, p. 034007, 2018. doi:10.1088/1361-6501/aa9dc3

[3] H. Geraissate, G. Rovigatti, and R. J. Leão, "Establishing a metrological reference network of points for the alignment of Sirius", presented at IPAC'21, Campinas, Brazil, May 2021, paper TUPAB310, to be published.

[4] Y. Gao *et al.*, "Laser tracker orientation in confined space using on-board targets", *Meas. Sci. Technol*, vol. 27, no 8, p. 085010, 2016. doi:10.1088/0957-0233/27/8/085010

[5] G. Rovigatti, "Validação de conexão recíproca entre Laser Trackers usando a técnica de calotas esféricas", Undergraduate thesis, Centro Universitário Salesiano de São Paulo, Campinas, Brazil, 2020.

[6] C. E. Papadopoulos, and H. Yeung, "Uncertainty estimation and Monte Carlo simulation method", *Flow Meas. Instrum.*, vol. 12, no. 4, pp. 291–298, 2001. doi:10.1016/S0955-5986(01)00015-2

[7] H. Westfahl *et al.*, "X-ray microscopy at Sirius, the new Brazilian synchrotron light source", *Microsc. Microanal.*, vol. 24, no S2, pp. 176–179, 2018. doi:10.1017/S1431927618013235

[8] D. L. Passuelo, H. Geraissate, G. Rovigatti, M. C. Oliveira, R. J. Leão, "Preliminary evaluation of physical artifacts to perform laser tracker relocations in confined environments", in *Proc. Metrologia 2019*, Florianópolis, Brazil, Nov. 2019, ISBN 978-65-990471-0-7.