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VIBRATION ASSESSMENT AT THE CARNAUBA BEAMLINE AT THE SIRIUS/LNLS

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Abstract

CARNAÚBA (Coherent X-Ray Nanoprobe Beam-line) is the longest beamline at Sirius Light Source at the Brazilian Synchrotron Light Laboratory (LNLS), working in the energy range between 2.05 and 15 keV and hosting two stations: the sub-microprobe TARUMÃ and the nanoprobe SAPOTI, with coherent beam size varying from 500 to 30 nm. Due to the long distances from the insertion device to the stations (135 and 143 m) and the extremely small beam sizes, the mechanical stability of all opto-mechanical systems along the facility is of paramount importance. In this work we present a comprehensive set of measurements of both floor stability and modal analyses for the main components, including: two side-bounce mirror systems; the four-crystal monochromator; the Kirkpatrick-Baez (KB) focalizing optics; and the station bench and the sample stage at TARUMÃ. To complement the components analyses, we also present synchronized long-distance floor acceleration measurements that make it possible to evaluate the relative stability through different floor slabs: the accelerator slab; experimental hall slab; and the slabs in the satellite building, consisting of three inertial blocks lying over a common roller-compacted concrete foundation, the first with the monochromator and the remaining ones with one station each. In addition to assessing the stability across this beamline, this study benchmarks the in-house design of the recently installed mirrors, monochromators, and end-station.

INTRODUCTION

CARNAÚBA's (Coherent X-Ray Nanoprobe Beamline) [1] sub-micron station TARUMÃ and nanoprobe SAPOTI are the two experimental station at Sirius Light Source with the largest distances to the source, namely, at 135 meters and 143 meters from the insertion device, respectively. Then, due to the long optical lever-arms, beam sizes at the sample between 30 and 500 nm, and strict stability requirements for coherent imaging techniques, all opto-mechanical systems in CARNAÚBA must be carefully designed [2], assembled, installed, and validated.

As shown in the simplified diagram of Fig. 1, CARNAÚBA relies on an undulator source, which is located inside the storage ring tunnel, lies on the storage ring especial floor [3], and serves as the origin for the CARNAÚBA coordinate system. At 27.4m, already outside the tunnel, but still on the storage ring special floor, the first main opto-mechanical system is the side-bounce elliptical mirror (M1) [4], that focalizes the beam in the secondary source. Next, in the experimental hall, at about 54.3m from the source, the second main opto-mechanical system is composed of the secondary source mechanism and the planar mirror (M2), which finally directs the beam to the satellite building, where the monochromator (4CM) [5] and the experimental stations, TARUMÃ (TAR) [6] and SAPOTI (SAP), are found on special inertial blocks at 130m, 135m and 143m, respectively.

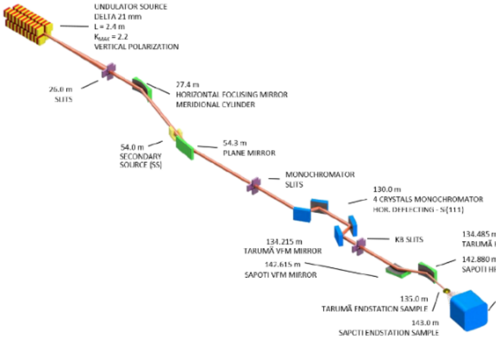

Figure 1: Simplified diagram of the CARNAUBA beamline.

METHODOLOGY

The different types of measurements relied on specific setups, hardware, and software. In the modal analyses, a triaxial modal accelerometer Kistler 8762A5, an instrumented impact hammer PCB Instruments 086C03, and a NI USB-4431 DAQ acquisition board with 24-bit resolution running with NI Signal Express at 10kHz, were used for the frequency response function characterizations. In a sequence of measurements for each component, by attaching the accelerometer to different points of the structure, while keeping the excitation with the impact hammer in a convenient point, animated mode shapes can be created using a software toolbox developed in-house. For each measurement point, a series of four impacts was repeated to maximize statistics for coherence and data quality. For each impact, the time signal was recorded for 2s, with a pre-trigger margin of 10% of this.

In the floor and component stability analyses two seismic accelerometers Wilcoxon 731 together with two power amplifiers P31 were used with the same acquisition board and rate mentioned above, but for a total of 60s. For the power spectrum density (PSD) calculations, it was used a window of 10s and 50% overlap. Then, for cumulative power spectrum (CPS) and cumulative amplitude spectrum (CAS) data, integration is made up to 450Hz, that is the maximum frequency for this seismic accelerometer.

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Finally, in the long-distance measurements two Lennartz Eletronic LE-3Dlite geophones were used in parallel with the two seismic accelerometers to extend the measurement range in the lower frequency. The measured locations included distances from 28m (insertion device to M1) to 143m (insertion device to experimental station), such that overcoming the challenges regarding hardware and synchronization required the measurement setup to be carefully studied and planned. Eventually, the *White Rabbit* protocol, developed by CERN, was implemented and used to synchronize the data with nanosecond precision [7]. In our scenario, just two nodes of the White Rabbit were mounted in a custom application that was developed in Labview for NI CompactRIO (which has also been selected as the standard controller for Sirius beamlines). The first one stood at the insertion device location, whereas the second node moved from location to location. The station with the insertion device was the master, sending synchronization pulses to the traveling station via an optical fiber. Then, carefully considering the noise level limits in the sensors, the time signals were subtracted, so that just the relative vibration between both points would be analysed, using the same parameters as for the benches stabilities.

RESULTS

Modal Measurements

The modal measurements were taken in all of the granite benches of the main opto-mechanical systems at CARNAÚBA, with the objectives of studying the mechanical resonances and mode shapes of the structure and investigating possible influences in the optical elements and the sample. Figure 2 shows an example of the animated mode shapes of the 4CM structure, in which each relevant subcomponent is displayed in a different color for clarity, and Table 1 summarizes the results.

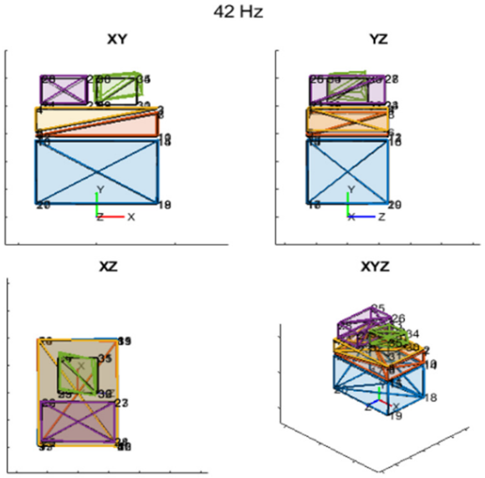

Figure 2: Representation of an animated mode shape for M1 modal Analysis. The components represented are bottom granite (purple), bottom granite wedge (red), top granite wedge (yellow), vacuum chamber (purple) and ionic pump (green).

Analysing the first modes, it can be seen that the fixation mechanisms of the ionic pumps are not fulfilling the designed stiffness requirements, such that their first decoupling occurs in low frequencies, around 40 to 60Hz. Nonetheless, as the pump weighs less than 10% of the bench and the vacuum vessel is stiffly coupled to the granite bench [8], the amplification effects caused by these modes are not expected to significantly impact the optical elements and internal mechanisms of the M1, the M2 and the monochromator, as they are designed for resonances above 100 Hz. The horizontal and rotation modes, that can impact the in-position stability of internal mechanisms in mirrors are in frequencies above 100Hz, being 148Hz for M1 and 130Hz for M2.

Table 1: The seven first natural frequencies, in Hz, for all CARNAÚBA opto-mechanical system installed. The acronyms BG and AG stand for *Before grouting* and *After grouting*, respectively.

M1	M2	4CM	TAR BG.	TAR AG.
42	42	39	40	180
56	46	44	52	215
64	51	55	62	317
78	64	60	70	402
91	70	74	94	498
148	104	109	107	529
170	130	137	213	631

For TARUMÃ, two scenarios can be considered, namely: before grouting the bottom granite part, in early commissioning phase for alignment validation; and after the grouting work. *Before grouting* there was a critical 40Hz natural resonance due to the limited stiffness between the bench and the slab floor, resulting from the three simple aluminium supporting shims. Excited by disturbances in the floor, the in-position stability of the sample stage was limited to 50nm RMS in the horizontal axis, in a frequency range from 1Hz up to 500Hz. *After grouting*, another modal analysis was run to evaluate the changes in the natural frequencies and mode shapes. With the additional stiffness, the first natural frequency jumped to 180Hz, as depicted in Fig. 3, and the sample in-position stability could be improved 10nm RMS from 1Hz to 500Hz. The SAPOTI station is under construction and could not be evaluated yet.

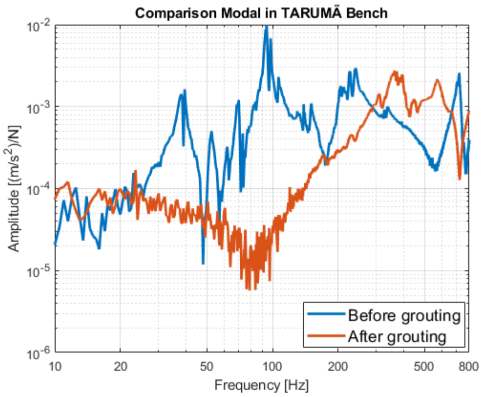

Figure 3: Comparison between the Frequency Response Function for the scenarios: *Before Grouting* and *After Grouting*.

Stability Measurements

To complement the modal measurements, stability measurements were made for the granite benches of all opto-mechanical systems and the surrounding floors. As explained before, many components lie on different slabs, such that these measurements help understanding the different characteristics throughout the beamline. Table 2 summarizes the RMS cumulative spectra from 2 to 450Hz for each component and the floor, whereas Fig. 4 shows a comparison between the horizontal PSD for the different benches, from where it is possible to notice the resonances described in the last section, influence the final stability. Evaluating the one third octave velocity bands and comparing results with the Vibration Criteria curves (VC curves) [9], all points analysed in CARNAÚBA beamline meet standard VC H and NIST-A1.

Table 2: Cumulative amplitude spectrum from 2 to 450Hz, in nm, for 6DoF floor stability around opto-components and 3DoF translations in the granite benches.

	M1	**M2**	**4CM**	**TAR**	**SAP**
X floor	8.17	7.77	10.71	9.04	12.42
Y floor	7.2	7.69	7.53	5.34	5.67
Z floor	7.32	6.64	13.87	16.37	9.58
Rx floor	1.97	2.46	6.51	10.31	9.31
Ry floor	1.30	1.78	11.60	3.95	5.35
Rz floor	1.47	1.79	1.31	1.49	3.49
X bench	9.39	9.17	11.71	10.59	-
Y bench	7.58	8.07	8.06	7.33	-
Z bench	7.63	6.98	15.07	17.38	-

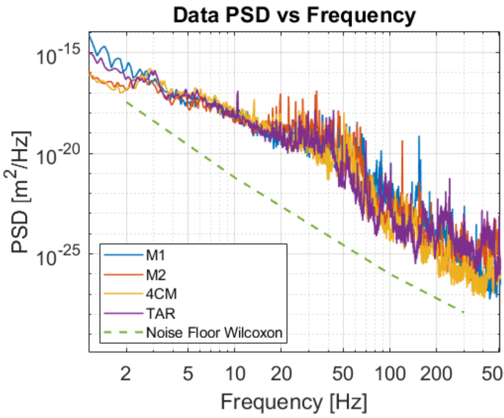

Figure 4: Horizontal Displacement Power Spectrum Density measurements for opto-mechanical system at CARNAÚBA and the seismometer noise floor to validate the measurements.

Long-Distance Stability Measurements

Finally, supplementing the local floor stability data, more information about correlation among the floor slabs was sought with measurements taken between the insertion device location and the opto-mechanical components locations: M1, M2, and both experimental stations. Table 3 summarizes the result for the 3 translational degrees of freedom that were measured, whereas Fig. 5 shows the three translational relative PSDs to the farthest measurement location, at the SAPOTI experimental station slab. The achievement of such high stability is extremely important since the beam stability in the experimental stations has a direct dependence on the relative stability of the source and secondary source.

Table 3: Cumulative amplitude spectrum from 0.5 to 450Hz, in nm, for the three translational axes, for the long-distance measurements. The line “DI” inform the distance, in meters between the accelerometer in each setup.

	Und-M1	**Und-M2**	**Und-Tar**	**Und-Sap**	**M1-M2**	**M1-TAR**
X	1.9	2.1	10.7	10.1	1.1	3.2
Y	1.8	2.0	6.5	5.8	2.0	2.4
Z	2.8	2.5	10.7	10.3	1.2	3.5
Di.	28	58	136	143	29	118

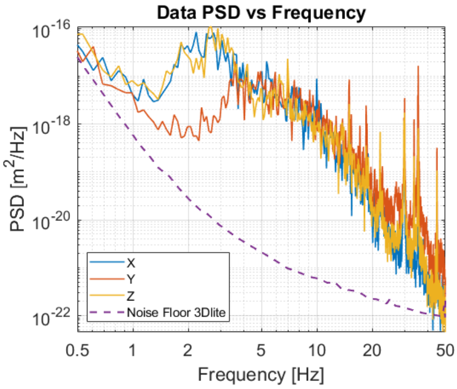

Figure 5: Relative displacement PSD for the long-distance measurement between the Undulator and the SAPOTI slab (143m) and the geophone noise floor.

It is possible to notice the good agreement between seismic accelerometer and geophone in both locations for the intermediary frequencies. For frequencies lower than 2Hz the data from the seismic accelerometer is dominated by noise, so that just de geophone can be considered. For frequencies higher than 50Hz the same occur with geophone data, such that just de seismic accelerometer can be used.

CONCLUSION

A full set of instruments and methods has been used for stability and dynamic analyses at CARNAÚBA, the longest beamline at Sirius that also hosts it’s the first nanoprobe TARUMÃ. The floor stability in all locations is remarkably well placed with respect to the common NIST-A and VC curves, with integrated displacement between 2 and 450 Hz below in the range from 5 to 15 nm RMS in XYZ. At the same time, the relative measurements over the long distances proved to be below 10 nm RMS, already partly limited by sensor noise. Finally, the granite benches of the opto-mechanical systems are validated, having achieved robust dynamic performances that do not amplify the cultural noise and providing suitable stands for the most sensitive beamline elements.

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