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VALIDATION RESULTS FOR SIRIUS APU19 FRONT END PROTOTYPE *

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Abstract

A Front End (FE) prototype for a 19-mm period length Adjustable Phase Undulator (APU19) beamline of the new Brazilian 4th-generation synchrotron, Sirius, was assembled in the LNLS metrology building in January 2017 to validate main design concepts. Regarding stability, flow-induced vibration (FIV) investigations were carried out on the water-cooled components, and modal analyses were made on the X-Ray Beam Position Monitor (XBPM) support. As for the vacuum system, final pressure levels were investigated and a vacuum breach was intentionally provoked to verify the performance of the equipment protection system (EPS). In addition, cycling tests of the Photon and Gamma shutters were conducted to verify the FE reliability. Moreover, the three-layer protection system, developed to limit the maximum aperture for the high-power slits, was functionally evaluated. Finally, the results were used to improve the FE to its final design. This paper describes the tests setups and results obtained during the validations.

INTRODUCTION

The Front-End comprehends the group of components connecting the storage ring (SR) to the beamline. They are responsible for defining the final aperture, absorbing exceeding beam power and providing radiation protection, storage ring vacuum protection and photon-beam diagnostics [1]. Figure 1 shows an overview of the FE design, highlighting its main components position. An APU19 front-end was first prototyped to validate its mechanical design concepts.

RESULTS AND DISCUSSIONS

Flow-Induced Vibrations

The FE components must handle a high-power load from the APU19 white beam, therefore they must be water-cooled. The total error budget allowed for each component is 1% of the beam size (which is ~30 mm for the APU19 FE). This analysis aimed to quantify the vibration contribution of the cooling system.

A 3D accelerometer from Kistler (8726A) was used to measure the vibration level in each component with and without a water flow of 3 m/s. With the data, it was possible to investigate the RMS displacement on the beam transversal plane. The results for each component are compiled in Table 1.

Table 1: RMS Displacement of the Front-End Components

Component	Flow on [nm]		Flow off [nm]		Variation (%)	
	X	Y	X	Y	X	Y
Mask	22	48	20	40	10	20
Photon	607	44	80	23	658	91
Slit 1	203	28	53	19	283	47
Slit 2	173	31	54	23	220	35
XBPM	15	52	15	36	0	30

The large influence of the cooling system on the Photon Shutter can be justified by the fact that its driving mechanism doesn't have a high stiffness in the X direction. As the water inlet is in the same direction, the disturbances are intensified. Even so, all the contributions are below 1% of the beam size.

XBPM Support Modal Analysis

The XBPM is the most sensitive component in the FE, demanding very strict stability requirements for it to be reliable [2]. It is mounted on the top of a granite block, which is designed for higher stiffness, aiming at the first eigenfrequency value above 100 Hz when tightened to the ground. A modal analysis of the XBPM support was conducted to verify its performance and compare the results with the Finite Element Analysis (FEA) simulation previously carried out using Ansys Workbench [3]. Simulations were firstly done considering the support as a free-body and then as rigidly attached to the ground (grouted).

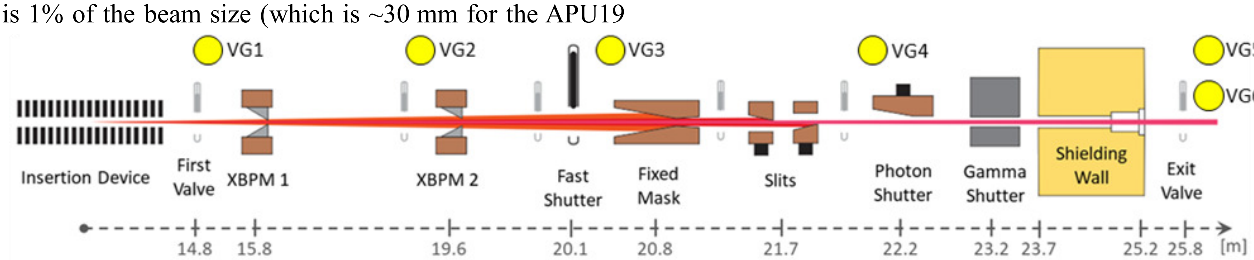

Figure 1: APU19 Front End general layout with each component's distance from the undulator. The vacuum gauges (VG) used to monitor the pressure level along the FE are represented by yellow circles. VG5 and VG6 are used in redundancy for the Fast Shutter (FS) actuation in case of an air inrush at the beamline.

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The first investigation made was a free-body analysis, aiming to evaluate the support internal vibration modes. The granite block was suspended by springs, decoupling the system around 1 Hz. Based on the simulation, some points of interest were mapped for the accelerometer positioning (Kistler 8786A5). For each point, the block was excited using an impact hammer instrumented with a force sensor (PCB Piezotronics 086C02). The results presented a good correlation with the simulation, with a maximum divergence of 1.2% on the eigenfrequency values.

The second investigation aimed to evaluate the performance of the support when tightened to the ground. The same measurement instrumentation was used, varying the interface between the granite block and the Metrology Building floor: tightened directly to the floor (no interface); or using metal shimmings (copper and aluminum) to improve the contact stiffness.

Table 2 shows the obtained results for the three first eigenfrequencies. The cooper-shimming interface presented slightly better results, but the performance is still below expected. A limitation was attributed to the stiffness of the Metrology Building floor. Further studies on this hypothesis are being carried out. However, a higher stiffness is expected for the Sirius especial foundation, and, for now, it was defined that the XBPM support for the six first beamlines will be grouted to the floor.

Table 2: Modal Analysis Results for XBPM Support

Mode	Simulation	Ground	Aluminum	Cooper
1 º	230 Hz	38 Hz	48 Hz	50 Hz
2 º	230 Hz	39 Hz	49 Hz	72 Hz
3 °	640 Hz	326 Hz	335 Hz	353 Hz

Vacuum Breach / EPS Validation

To investigate if the FE would effectively protect the SR in case of an air inrush at the beamline, a vacuum accident was provoked downstream the FE prototype. This study was carried out to validate three design aspects of the FE: the low conductance due to the reduced straight section diameter on the vacuum pipes; the pinhole effect due to the components small apertures; and the air velocity in case of an inrush accident.

The FE vacuum pipes were initially designed with a diameter of 63 mm, but since the photon-beam size generated by an APU19 undulator is about 31 mm x 16 mm, the vacuum pipe diameter as reduced to 38.8 mm, diminishing almost 40% of its size (and thus the overall conductance). This reduction should delay a shockwave impact in a few milliseconds.

The components small apertures, e.g. the gamma shutter (ø 10 mm), the slits (9 x 9 mm^2), and the fixed mask (ø 3.1 mm), also contribute for the FE protection effectiveness, through a "pinhole effect", which physically holds back an air shockwave (SW).

This experiment aimed to evaluate SW velocity achieved by considering different accident conditions. Similar studies were also conducted in other facilities to correlate the SW velocity to the leakage hole and pipe diameter [4, 5].

The test setup was prepared by adding a low-pressure chamber (LPC) with an ion pump and a vacuum gage (VG) in the FE upstream, which simulates the SR vacuum level (10^{-11} mbar). At the FE downstream, a 790 mm section of vacuum pipe and a small chamber were installed, with a pressure differential of eight orders of magnitude related to the atmosphere. This chamber includes the two redundant sensors for the FS activation and a window. To simulate the inrush accident, the window was broken by an instrumented impact hammer, and its signal was used to verify the exact moment of the breach. The acquisition system was an NI CRIO 9039, which acquired data of all the FE VGs at a rate of 90 kHz.

To determine the worst possible condition for the accident (largest aperture at window rupture with maximum SW velocity), the experiment was repeated four times, varying the window material: CuAg foils (100 µm and 50 µm) and Kapton foils (50 µm and 25 µm). Afterwards, it was repeated two more times considering the worst condition.

Figure 2 shows the obtained wave front average velocity through the FE. It varied from 121 m/s to 687 m/s on the breach moment depending on the window material: the thinnest Kapton foil presented the largest rupture aperture, thus the greatest initial velocity.

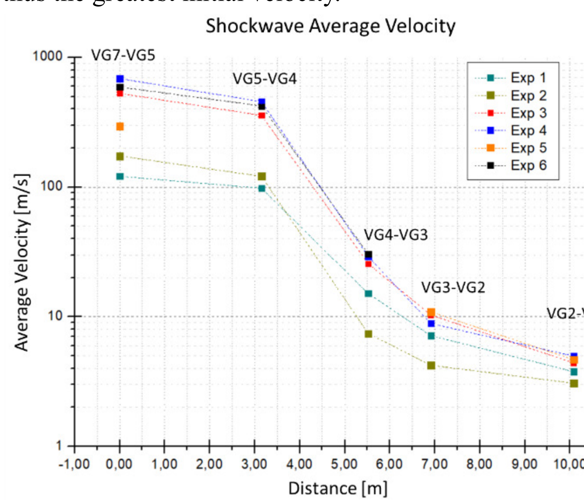

Figure 2: Average SW velocity in each FE section, calculated considering the instant on which the VG detected a pressure increase and the distance between two adjacent VGs.

Figure 2 also illustrates the "pinhole effect", verified by the great decrease on the SW velocity along the FE path, especially at the fixed mask region, which contributed for a reduction of 64% of its average values.

Figure 3 exhibits the time interval that the SW spent to reach each of the VGs. The red dashed line represents the FS closure time provided by its manufacturer (16 ms). As illustrated in the FE layout (Figure 1), the FS is located near the VG3, approximately 5.6 m from the inrush region. Considering the worst case, the SW reached VG3 in 61 ms, resulting in a safety margin of 3.8 compared to 16 ms from the FS closuring time.

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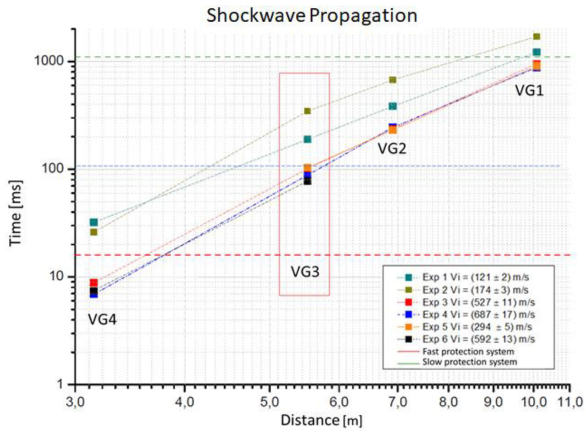

Figure 3: Comparison of the time interval for closing the fast shutter (16 ms - red dashed line) with the time that the SW reaches VG4 to VG1, and the reference time value for gate valve closure (1 s - green dashed line).

The final pressure data obtained with the EPS system online is shown in Figure 4. It demonstrates that, even with a pressure increase at the FE, the EPS system reacts to the event quick enough to preserve the vacuum level at 10^{-5} mbar in the FS region. The gauges upstream (VG2 and VG1) were not affected and the subtle pressure increase registered by PS0 (representing the SR) is due to the gate valve closure, recovering its initial state after 1.5 seconds.

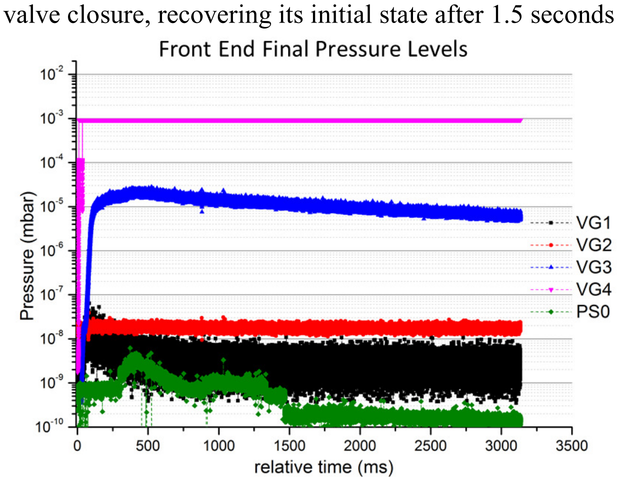

Figure 4: Pressure level after the inrush event. The FS blocked the SW and preserved the vacuum level upstream.

Cycling Stress

To verify the FE reliability, the system was submitted to a stress test, consisting of full cycles with the Gamma and Photon Shutters. During the cycling period (10 days), the components and limit switches fastening screws torque were verified daily, and the pressure level was monitored along the FE path. The system was not disturbed even after 10,000 cycles and the screws torque didn't show variations. By these results, the shutters systems were approved.

Slits Limit Switch System

The High-Power Slits motion system is based on Huber translation stages with micrometric accuracy. Even so, a three layers protection system was developed to ensure that the slits would never move beyond its maximum permissible aperture, avoiding damages to the beamline optics. The system is based on software control, limit switches (LS) and a Hard Stop. The use of inductive LS was proposed due to its low hysteresis and good repeatability. The DW-AV-601-M4-276 sensor by Contrinex was chosen. It was embedded in a housing, which is also used as the hard stop. Figure 5 shows the developed housing and LS system assembly.

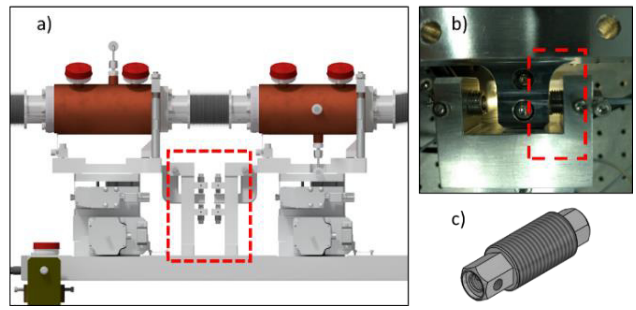

Figure 5: a) design for the LS system with 4 sensors per slit (2 vertical and 2 horizontal); b) LS system assembled for validation test; c) sensor housing.

To verify the sensor performance, a repeatability test was carried out. It consisted on evaluating the sensor activation position during several cycles, according to the Huber stage encoder reading. Each cycle consisted of: leaning the housing against the surface under test; moving this surface 50 µm on the opposite direction; mounting the sensor in the housing and pushing it to the surface until it activates; and finally, programming the stage to move away from the sensor and travel back to it until it activates and interrupts the motion. The encoder reading is then recorded. This routine was repeated 1200 times for each direction and the results are shown in Figure 6.

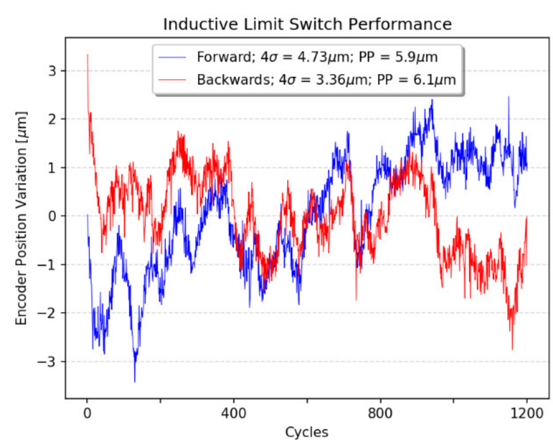

Figure 6: Inductive sensor performance on horizontal direction during 1200 cycles. The Y-axis is the deviation from the mean of the encoder reading when the sensor is activated.

With the proposed inductive LS, the system achieved a unidirectional repeatability of 4.73 µm and a peak-to-peak value of 6.10 µm.

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CONCLUSIONS

The FE prototype has fulfilled its purpose to validate the main aspects adopted on its design. It also elucidated minor details to be improved, such as the Photon Shutter mechanism stiffness, alignment mechanism, size of girders fastening holes, electronics panel positioning and bake-out tapes requirements. Based on the results, an improved designed was proposed, manufactured and the first three FEs are currently on installation phase at Sirius.

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