IMPACT OF THE VPU UNDULATOR ON THE SIRIUS STORAGE RING BEAM DYNAMICS

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Abstract

This work evaluates the effects of the two vertical polarization undulators (VPUs) installed at the SIRIUS storage ring electron beam dynamics. These insertion devices (IDs) are light sources for the CARNAÚBA and CATERETÊ beamlines at the SIRIUS. The analysis combines numerical simulations and beam-based measurements to quantify static and dynamic orbit distortions, optics perturbations (tune shifts), effects on injection efficiency, and changes in equilibrium beam parameters, and also on beam lifetime. The effectiveness of ID feedforward compensation in mitigating orbit distortion is assessed.

INTRODUCTION

The CARNAÚBA (CNB) [1] and CATERETÊ (CAT) [2] beamlines were modernized with the installation of the first vertically polarized undulators (VPUs) at SIRIUS. Previously, CNB and CAT had Adjustable Phase Undulator (APU) type insertion devices (IDs); the VPUs increased brightness compared to the APU for user experiments. Figure 1 shows a comparison between the brilliance of both sources.

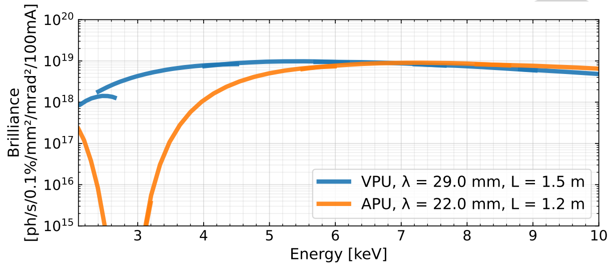

Figure 1: Brilliance comparison of the old APUs and the new VPUs.

A key factor was the matching between the undulator polarization and the vertical plane of incidence in the four-crystal monochromator. The VPUs were installed in low-beta straight section. The section parameters are presented in Table 1 and the VPU parameters in Table 2.

When these devices are installed, they can generate orbit distortions, tune deviations, and alterations in the nonlinear response of the ring. In the case of SIRIUS, this point is particularly relevant because the injection is done off-axis [6], which makes it important not to impact the dynamic aperture. Therefore, the experimental characterization of VPUs is not limited to evaluating photon emission, but also includes the effect on beam behavior in the ring.

Table 1: SIRIUS Storage Ring Parameters

Storage ring parameters		**Symbols [units]**
Nominal energy	3.0	E_0[GeV]
Natural emittance	250	ϵ_0[pm rad]
Coupling (emittance ratio)	1	κ[%]
Energy spread	0.084	σ_E[%]
Hor. beta function @ ID SS center	1.49	β_x[m]
Ver. beta function @ ID SS center	1.43	β_y[m]

Table 2: VPUs Parameters

ID parameters	**CAT**	**CNB**	**Symbol [units]**
No. periods	51	51	N
Period length	29	29	λ_u[mm]
ID length	1.5	1.5	L_u[m]
Max. gap	80	80	g_{max}[mm]
Min. gap	9.7	9.7	g_{min}[mm]
Peak field @ min. gap	0.83	0.85	B_{max}[T]
Deflec. par. @ min. gap	2.24	2.31	K_{max}
Spectrum range	0.8 – 24	0.8 – 20	[keV]

This work focuses on the effects observed during commissioning with the new VPUs and the strategies used to minimize these impacts. This report is organized to connect the different aspects of the machine: first the orbit, the optics, followed by injection efficiency, and finally, the impact on beam lifetime.

EFFECTS ON ORBIT

The presence of residual field integrals in insertion devices typically leads to closed-orbit distortions (CODs) [3]. In the case of VPUs, this effect was evaluated as a function of the gap in order to measure the dynamic response of the distortion during gap movement.

Figure 2 should present the measured CODs as a function of the VPU gap with the slow orbit feedback (SOFB) and fast orbit feedback (FOFB) correction systems turned off.

To mitigate this effect, an orbit feedforward (FF) system was implemented using dedicated correctors installed close to the devices. The correction tables were constructed from measurements at different gaps and adjusted to reproduce the local contribution of the VPU, separating it from more global variations in the ring [4]. The central idea of this approach is to anticipate the necessary correction before the

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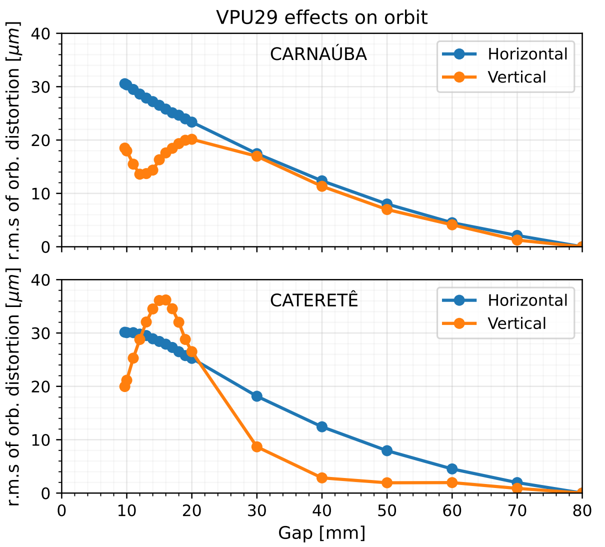

Figure 2: Orbit distortion generated by the VPU as a function of the gap.

orbit deviates, preventing the FOFB system from operating near its limit.

Figure 3 shows an orbit distortion measurement at a rate of 6024 Hz at the beam monitor position (BPM) after both VPUs. The solid line is a filtered signal using the Savitzky-Golay cubic filter [5]. In both cases, the measurements were performed by moving the VPU gap at a speed of 1.5 mm/s with the FFwd on and off. It should be noted that with the activated FFwd, there was a 9-fold reduction in horizontal distortion for the CNB, while for the CAT it was 7.5 times.

EFFECTS ON LINEAR OPTICS

The influence of VPUs on linear optics was investigated using tune measurements. Since the devices were installed in low-beta regions, the initial expectation was for limited effects. However, even a small perturbation can be relevant if added to other ongoing corrections or requires frequent adjustments during operation.

Figure 4 shows measurements of vertical and horizontal tune deviation as a function of the VPU gap. The tune deviations indicate a small vertical and horizontal shift as the gap is closed, in the third decimal place. This response is consistent with the expected focusing effect for the device. This perturbation remains within an acceptable range. Therefore, a dedicated optical FF is not necessary. Furthermore, due to the low magnetic field gradient at the maximum gap (80 mm), it was not necessary to apply global tune correction to reduce the tune shift that the VPU could cause when inserted into the storage ring.

INJECTION EFFICIENCY

Injection efficiency was used as an indirect indicator of the effect of VPUs on the machine's dynamic acceptance. Since SIRIUS operates with off-axis injection [6], any significant

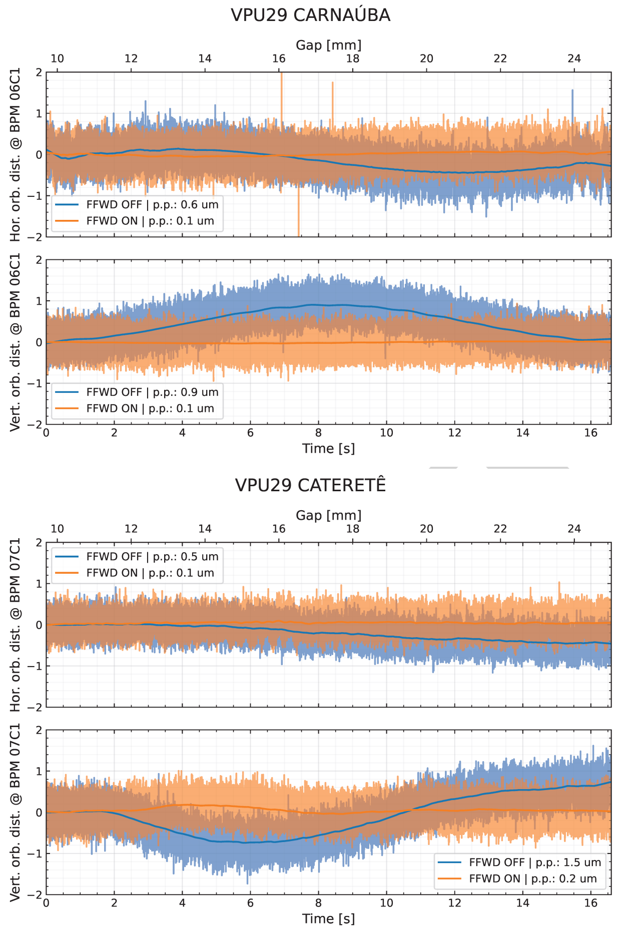

Figure 3: Orbit distortion generated by the VPU as a function of the gap and feedforward compensation.

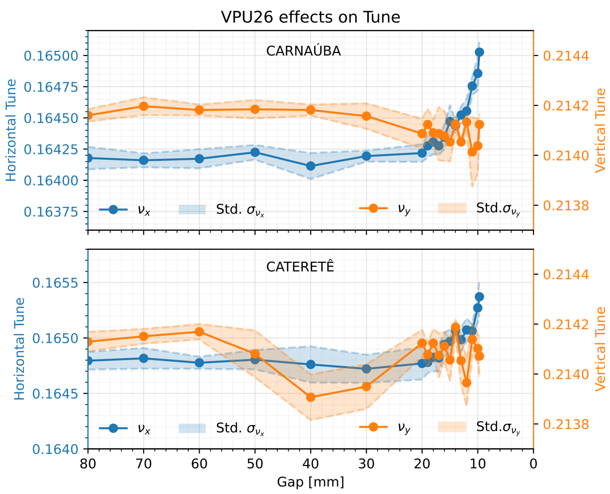

Figure 4: Tune deviation as a function of the VPU gap.

degradation in dynamic acceptance can reflect in reduced efficiency, especially when the gap is closed.

Measurements were performed at different gaps, with repeated injection pulses to allow for a statistical evaluation of the results. Figure 5 shows the results of these measurements.

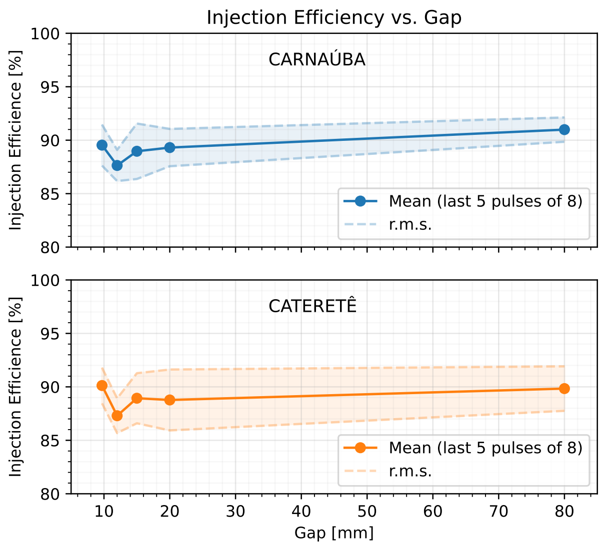

Figure 5: Injection efficiency as a function of the VPU gap.

This point closes the connection between the linear response and non-linear effects. If the orbit is corrected, the tunes is kept under control, and the injection efficiency remains stable, then the impact on the overall beam dynamics tends to be small. This consistency between the different diagnostics implies that the installed devices do not impact the machine during user operation.

LIFETIME IMPACT

The beam lifetime behavior is also part of the evaluation because it synthesizes possible changes in the overall ring dynamics into a single observable. A significant reduction in lifetime could indicate increased coupling, reduced acceptance, or greater sensitivity to nonlinear perturbations.

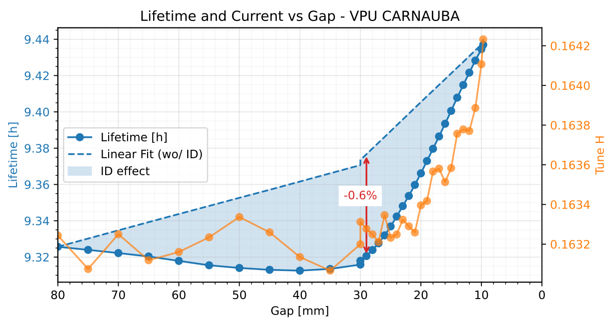

Figure 6: Lifetime as a function of the CNB VPU gap.

For VPUs, the analysis should be interpreted in conjunction with the orbit and injection results. If efficiency is maintained and orbit and tune corrections remain effective, then no significant degradation in lifetime is expected associated solely with closing the gap. The Figure 6 shows the variation in lifetime as a function of the VPU gap and current. The maximum reduction in lifetime was around 0.5%. Further studies will conduct a more robust investigation into this effect, both to examine the issue of repeatability and the dependence of this lifetime degradation as a function of the current.

CONCLUSION

The results show that the new VPUs can be operated in a manner compatible with the SIRIUS routine. The orbital distortion caused by the VPUs during gap movement was corrected using feedforward. Without this compensation, the machine's correction system may operate near its limit.

In linear optics, the observed effects are modest. Vertical and horizontal tunes shows little variation. Therefore, local tunes correction was not necessary for these devices. Injection efficiency remains stable, suggesting that the dynamic acceptance of the ring was not significantly degraded.

Taken together, these results show that the VPUs meet the beamline requirements while preserving the necessary conditions for ring operation. The central point is not only that the device functions as a radiation source, but that its impact on the machine remains within the range that SIRIUS can correct and sustain during operation.

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